ANIL KUMAR GANGULY

(1918 - 1988)

AND

THE EVOLUTION OF HEALTH PHYSICS SCIENCE IN INDIA

COMPENDIUM OF MEMOIRS

Collated and edited by M.R. Iyer

Reviewed by L V Krishnan,

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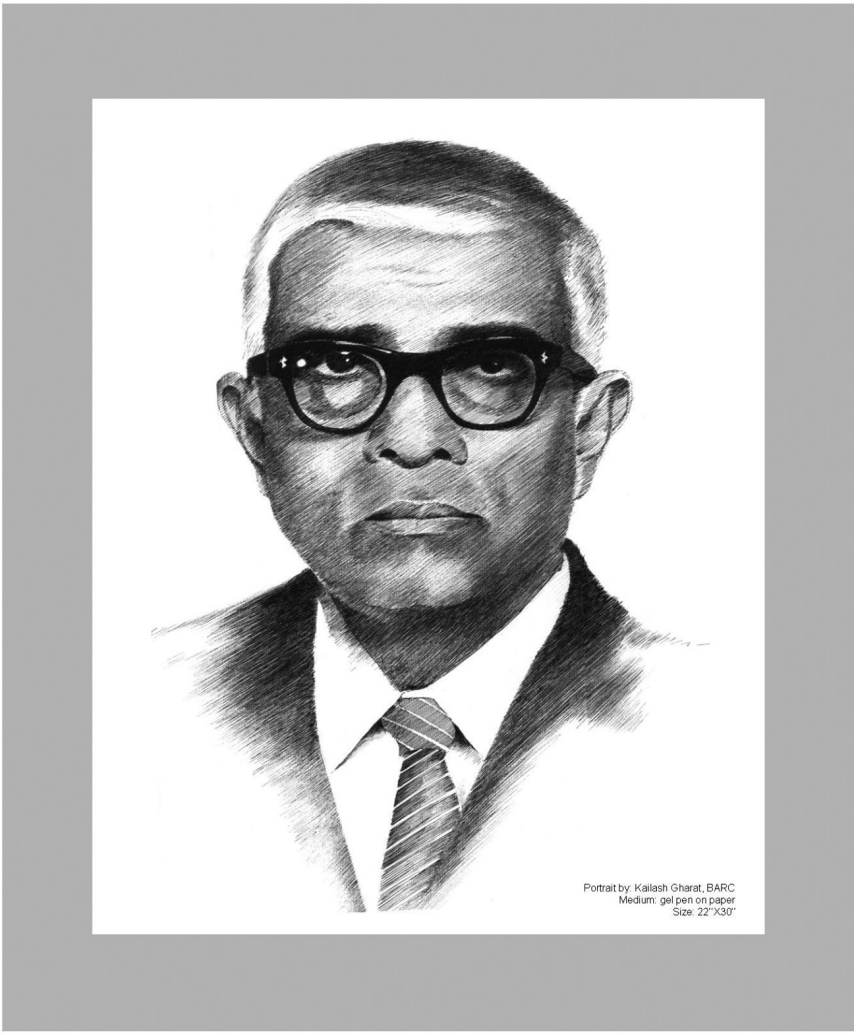
Birth Centenary Volume



ANIL KUMAR GANGULY (1918 - 1988)

FOREWORD

Dr. A. K. Ganguly was a rare wise person who shaped health and safety related activities as well as safety regulation in Indian Atomic Energy program with great insights as well as foresight. Thanks to the legacy of Dr. Ganguly, we can boast of our impeccable safety record today.

I was one of the active participants in the IAEA program on 'Nuclear Safety Standards' in its early stages of development, from the Indian side. I still remember some specific elements of Indian safety philosophy that emerged at that time, largely guided by Dr. Ganguly. Notion of treating all humans as equals, effective independence through independence of mind, nurturing research as an integral part of safety program and such other notions were brought home to me as a part of the discussions that took place at that time. Calibrated evolution of our safety regulation framework that took place hand in hand with the development of the atomic energy program to reach the present day robust stage, without blindly copying the systems that existed in more advanced countries, is to a large measure, a result of Dr. Ganguly legacy. Dr. Ganguly was the safety Guru to many within the country as well as abroad. Ganguly school was distinctly visible to many of us even though we were working in other domains.

During early stages of development of Dhruva reactor there was a raging debate on the reactor concept that should be adopted. On one side there were those who wanted to pursue the concept of full moderator tank with fixed heavy water level and control done by rods like in NRU reactor of Canada. On the other side were some of us who felt that we should develop the concept based on moderator level control. Shri Seshadri was responsible for development of the reactor control system and I had the responsibility for the reactor block. One day Seshadri took me to Dr. Ganguly to apprise him of the debate and the merits of adopting level control. After hearing a some what long presentation, Dr. Ganguly said 'OK, leave all this aside'. He asked Seshadri, 'how confident are you in taking this development through'. '100%' said Seshadri. Dr. Ganguly then turned to me and asked me the same question. I also repeated '100%'. 'In that case, I am with you' he pronounced. While the comparison of merits and demerits was important, level of confidence in carrying out a new development was perhaps even more important. That was the message of the wise man.

I am also witness to another debate between Dr. Ganguly and civil engineers in the Dhruva implementation committee. The pressure at which the containment building should be leak tested was the subject of debate. Analysis had revealed

that there would be hardly any pressure build up even in a worst case accident scenario in the reactor. The civil engineers thus proposed a very low pressure for the design and hence for leak testing. Dr. Ganguly insisted that the leak test be conducted above a minimum pressure which would permit reliable leak rate measurement. That would mean that the design pressure would be set from consideration of reliable leak test rather than the maximum pressure the containment building would see any time in its life. Doctor as he was affectionately known carried the conviction.

That was Dr. Ganguly. A wise man, a friend philosopher and guide. Logical, flexible yet very firm when needed. A guru to younger people in his group. A foresighted visionary who could shape the safety program and safety regulation in the country with an independent mind.

In the birth centenary year of Dr. Ganguly, it is only appropriate that a compendium of memoirs from students and coworkers of Dr. Ganguly has been prepared and would be brought out by Indian Association for Radiation Protection in its forthcoming annual meeting. That is a fit way of expressing gratitude and paying our respects to the memory of Dr. Ganguly. Further the compendium would be of significant value in terms of documenting the history of development of Atomic Energy in this important area.

Anil Kakodkar
November 4, 2017
Mumbai

PREFACE

In the evolution of the Atomic Energy program in India spearheaded by the great visionary Dr Homi Jehangir Bhabha, only a few took indelible firm strides on his close heels, as Dr. Anil Kumar Ganguly did. Dr. Ganguly, whose birth Centenary is being celebrated in 2018, is undoubtedly one of the forefront leaders of that era. Dr. Ganguly placed a firm foundation for Health Physics and Environmental sciences in India from the scratch, even as Dr. Bhabha started sprawling his grandiose plans for the Indian atomic energy program. The term "Health Physics" originated as an innocuous label for the science of radiation protection coined by Compton during the days of Fermi demonstrating the chain reaction for the first time at the Chicago Pile CP1 reactor at the University of Chicago. The role of Health Physics (HP) in India was aptly redefined by Dr. Ganguly to include the safety of the facilities, the personnel, the public and *the environment*, instead of limiting it to radiation hazards control for occupational workers as was followed in USA. Apart from being a profession related to monitoring of radiation levels, he gave it a firm and committed direction, showing how the profession transcends into many other branches of science. Hardly a few would have contributed so much for the evolution of the HP science, as Dr. Ganguly did in just two decades of his service, from 1956 when he joined AEET till he retired in 1978. He was an environmentalist at heart par excellence. The role model he carved out for environmental protection in our atomic energy programme had its influence in other industries in India in maintaining the sanctity of the environment. His definition of Health Physics in the atomic energy program had international repercussions, as Dr. Ganguly was considered by many as the 'guru of Health Physics', including Beninson, who headed ICRP for several years.

Dr. Ganguly put into practice the mandate set forth by Dr. Bhabha: *"Radioactive material and sources of radiation should be handled in Atomic Energy Establishment Trombay AEET in a manner, which not only ensures that no harm can come to workers or anyone else, but in an exemplary manner so as to set a standard which other organizations in the country may be asked to emulate."* Going by that, Dr Ganguly generated a whole gamut of expertise and experts and set a whole norm for environmental sanctity for the Nation at large. This led to an increased national awareness of the environment and led to the formation of a separate Department of Environment.

I was a fortunate close bystander to these extraordinary evolutions and the procession of stalwarts produced by the program and have been naturally

eager to record this for the benefit of the newer generation. I first started undertaking this exercise sometime in 2008, but did not pursue it due to lack of a clear objective. But the desire persisted in my mind. More than a year back, sometime in 2016, in view of the impending birth centenary year of Dr. Ganguly in 2018, when I proposed to collect the memoirs of all the coworkers and students of Ganguly, there was an overwhelming response. About 35 of them enthusiastically shared their reminiscences. At the same time, I did not want to lose the opportunity of recording also the 'history of evolution of Health Physics sciences in India' by including how the mission set forth by Dr. Ganguly was taken forward by his colleagues and students. When I proposed this, Dr. D V Gopinath, one of the close collaborators of Dr. Ganguly, had initially some reservations about going beyond the narration of Doctor's achievements. But later he saw the merit of the suggestion and I went ahead and covered this in the appeal and there was a great response. He himself wrote an absorbing account of his "Golden days with the Master" which is included as an annexure to this Compendium. My intention was to fully illustrate the impact of the visionary initiatives of Dr. Ganguly *beyond his times*. Due to the momentum of the great initiative of Dr. Ganguly, his mission was further carried on by his students and today we have a versatile and dynamic health physics program that finds its utility in all facets of our atomic energy program which many may not realize. One of the examples was Dr. Ganguly's pioneering efforts to initiate the institution of Environmental Survey Laboratories (ESL) attached to every nuclear facility in the country, so much different from the nuclear programs around the world. Dr Bhabha saw the merit in this innovation and whole heartedly supported and even noted in the file that *"if there are no funds for ESLs, let there be no nuclear power"* sensing reservations from some. The ESL system stood the test of time and serves the nuclear power plant operators in producing factual proof to the public on the impact of their operation and enabled them to provide tangible evidence that their operation does not have any health impact on the public. Though, there are many facets brought out in the memoirs, this one example is sufficient to bring out the visionary role of Dr. Ganguly. Without Dr. Ganguly around, our safety program could have looked so much different, as pointed out by many in the memoirs.

Part I of the Compendium deals with the life sketch of Dr Ganguly and his contributions. I have drawn liberally from the memoirs of various contributors and in most part can be considered the summary of those in Part II and should not be construed as a repetition. Part II contains the memoirs by a number of colleagues and students of Dr. Ganguly, who had the privilege and benefit of working with Dr. Ganguly. Each narration is a self-contained one, on one or

more specific area of specialization initiated and nurtured by Dr Ganguly. In that sense this compendium is co-authored by almost 35 of his students and coworkers at the grassroot level. I believe that this Compendium is first of its kind in narrating the historical evolution in any stream in DAE.

During my initial attempts to generate interest in celebrating the birth centenary of Dr. Ganguly, his vast coterie of students and co-workers, mostly advanced in age, were excited about it but had physical limitations. Thus in many cases I had to record the interviews, transcribe and edit it with their help to narrate their memoirs. In the pursuit of gathering information, often I have been led to a dead end and had to take recourse of various publications to narrate the story and fill in the gaps as in the case of contributions of T Subbaratnam. S Somasundaram, who is settled in USA, took the trouble of patiently writing his memoir running to about 80 pages in his own handwriting from his memory, due to his physical inability and advanced age to work on a computer. This is an example of the sincere help provided by many in compiling this volume.

I thank all the contributors who have put in their heart in narrating their experiences in spite of some of them having been at a disadvantage physically due to old age. One of the satisfaction I had was to record a part of the history of BARC, perhaps the last attempt that could be made in view of the fast disappearing clan of people who had the good fortune to work and get befitted from Dr Ganguly. During the course of the preparation of this compendium, this stark fact was becoming clear to me, as much as five of the contributors had disappeared behind the curtain of time. And in a few years only this compendium would bear testimony to that great evolution!

L V Krishnan, N Ramamoorthy, D D Rao and Pushparaja have been kind enough to review the critical parts of this compendium and moderated my introductions and remarks. If this compendium serves to excite the nostalgia of the older generation, and the curiosity of the present generation and encourages them to follow in the footprints left by the Master, it would have eminently served the purpose.

M. R. Iyer

ACKNOWLEDGEMENTS

The Editor of this Compendium of memoirs wishes to acknowledge the spontaneous support and whole hearted efforts from 35 students and coworkers of Dr Ganguly to provide contributions on their reminiscences of Dr Ganguly. The compendium, as a matter of fact is authored by them, only I tried to put it together to the best of my ability. When I started the venture I never foresaw the enormous efforts it involved. But my friends and colleagues put me at ease and helped at all stages of its preparations through this 18 months of work. It has been an exciting period interacting with old friends, renewing comradice and of riding a "time machine" in visiting the past nostalgically and was quite self satisfying for me. The period has not been without some pangs when a few of them departed in the midst of these interactions. I appreciate the patience and understanding of my wife and family members at this retired man jabbing the computer keyboard all the time, whole day and night in the midst of some unavoidable indispositions.

I acknowledge the spontaneous help provided in editing and moderating the draft of this compendium by L V Krishnan, N Ramamoorthy and Pushparaja. I thank the IARP office bearers, acceding to my request to sponsor the publication of this compendium, in particular Dr Pradeepkumar, President of IARP and Assocaite Director of HS&E Group BARC and Dr D D Rao who went through the draft of the compendium and arranging for its publication.

The volume is dedicated to the memory of my *guru* and mentor Dr A K Ganguly and the close association I had for full 3 decades and the numerous close interactions I had with him.

List of contributors to whom the editor is indebted:

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CONTENTS

PART I

Dr. A. K. Ganguly and his Contributions

M R Iyer

1.1 INTRODUCTION

In the evolution and of the Atomic Energy program in India, only a few took indelible firm strides, on the close heels of Dr. Bhabha, as Dr. Ganguly did. The more I did research on the life and works of Dr. Ganguly, whose birth Centenary is being celebrated in 2018, this became more and more apparent to me. We the students of Dr. Ganguly were intensely motivated in the respective paths he had chosen for each one of us. As we were vigorously pursuing those paths, we had little time to have an overall view of the personality of "Doctor", as Dr. Ganguly was endearingly addressed by most of us. In my association with him from 1958 and all the way till his premature demise in 1988, nearly 3-decades long (which at this point of time looks rather short), I don't remember to have addressed him as 'Sir'. This is because, he considered 'Sir' as a vestige of British imperialism and he discouraged his students from addressing higher ups by the term Sir! And he himself followed that directive in personal interactions and used that only where it was absolutely required by protocol.

But what a journey it was! It was like a life in the proverbial '*gurukulam*' of Indian education system set in a modern scientific establishment. There was personal bonding between the teacher and students, far away from the normal run of stereotyped boss-subordinate relationship. Now looking back, the overall view of Dr. Ganguly that we had was like the proverbial story of six blind men trying to describe an elephant and ending up in confounding description! Each one of his students had a concept of him, mostly confined to his field of work, while this opportunity of compiling his biography gave me an optical instrument to gather and record a multitude of views and glimpses into his personality, leading to an overall portrayal of his personality. This was possible by talking to and interviewing his students and co-workers and from the reminiscences received from them. L. V. Krishnan, who has been helping me in reviewing the various memoirs contained in Part II of this compendium, shared my sentiments and wrote that these "have given him a sneak peek of the contributions from the various colleagues, and that reading through them evokes magnificent memories and further heightens

admiration and respect for Dr. Ganguly". People in general seem to have an aversion for history. It is necessary to have a realistic stock taking of history. Historical analysis should look into the overall achievements of individuals to build a ladder for future generation to climb further. In scientific pursuits history is often forgotten, though every student of science is supposed to start his research thesis with a critical review of the work done by earlier workers to define the objective to be accomplished in the thesis. This format was insisted by Dr. Ganguly on everybody approaching him to do research under his guidance, and we all followed that pattern. As someone wrote in an article in another context recently *"… if you don't know where you have come from, you will never appreciate where you are going"*.

During my interactions with people in the preparation of this volume, very rarely, a few tried to point out the human failings of Dr. Ganguly. I have patiently listened to them and impartially analyzed those views and found this could largely be attributed possibly to personal predilections and bias, due to his being a stickler of principles, and in that process someone invariably gets temporarily offended, but that is not history! We are all human beings and all of us on close analysis will have failings. We can indeed find those even in the case of great visionaries. But recording of history should be for keeping the ladder upright for younger generation to climb up. Acrimony in personal relationships which one can notice at times in the history of evolution of our Centre in the last 6 decades should be seen as an inherent *background radiation,* which cannot be avoided, but when the signal of their contributions spikes and is gigantic, the background interference vanishes.

There was something rare in the personality of Dr. Ganguly, which enthused people around him to start thinking and every conversation, be it official, personal or social, was interspersed with this spirit. He never went behind position or money. He accepted whatever came in his way and never did any canvassing, as his younger brother, a retired nuclear engineer in USA revealed to me. In his tryst with radiation chemistry at University of Notre Dame and his earlier research work at Calcutta University on ion exchange of soils, he could have found avenues easily to work his way up in United States as a successful academician, or an entrepreneur with potential for earning "not thousands of dollars per month, but per hour" as recounted by his brother; but his nationalist temperament made him anxious to get back to India to serve, where his base existed. That was the main reason he enthusiastically accepted the offer made by Dr. Bhabha to join the Department of Atomic Energy (DAE).

He was not a ritualistic religious man. Nevertheless, he followed the essential principles of religion to be unselfish in the pursuit of truth. He was influenced by the teachings of Ramakrishna Paramahamsa and Swami Vivekananda. He was intrinsically a teacher, teaching was in his nature. This made him develop his ethics in science.

D V Gopinath, one of the more successful students of Dr. Ganguly, writes "There was never a dull moment with Dr. Ganguly around; whatever may be the activity with which he was associated, his involvement was complete and whatever be the topic for discussion, his participation was total. But the spirited discussions with Dr. Ganguly never left any rancor in him and that was the experience of almost all of his students. Whenever I think or talk about Dr. Ganguly a certain amount of soul-searching becomes inevitable, and in the final analysis, the question stands out, what made Dr. Ganguly what he was?" Gopinath further notes that "it appears that Dr. Ganguly was living on two different planes; outwardly he was in complete resonance with his surroundings, sharing its excitement, its joy and its anxiety. Deep inside there was this person with total objectivity and scientific detachment." Here was one person in the middle of self-confident scientific community who can be easily told "Doctor you are wrong", as many of his students would agree. Invariably such acceptance results in more balanced analysis of the topic of discussion by his students and leads to the final revelation, after all Doctor was not so "wrong"! I have personally come across numerous instances of his instilling confidence and encouraging new ideas; he often remarked, when people point out the problems in implementing his ideas *"Give me one reason why you can do it and not 99 reasons why you cannot do it"* and this made many a student of his to pursue the difficult path and succeed. Many such incidents and anecdotes are narrated in the collection of memoirs in Part II of this compendium. The idea is to enlighten the younger generation about those challenging times of early evolution of atomic energy in our country and sow the seed for further productive work in future.

The establishment of Environmental Survey Laboratories (ESL) at each one of our nuclear installations is a unique feature in the Indian nuclear power program; ESLs are standing monuments to Dr. Ganguly who was the pioneer in this field. These were established before the nuclear facilities went into operation, to collect baseline data and subsequently to monitor the changes if any due to the operation of the facility. Dr. Ganguly meticulously selected the location for the ESLs several kilometers away from the reactors and in the Power Plant townships, so that these can continue to serve for analysis of low activity samples, even in case of some mishaps that may increase the

radiation background in the exclusion zone. Another important aspect was that he insisted that these should be operated by Health Physics Division, BARC, which is independent of the nuclear power station management. This has been a unique feature to win the confidence of the public.

During my initial attempts, more than a year back to generate interest in celebrating the birth centenary of Dr. Ganguly, his vast coterie of students and co-workers, mostly advanced in age, were excited about it. But to make the event meaningful, it was necessary to simulate interest in the active members of the radiation protection fraternity and the stakeholders in the national atomic energy program of the post-Ganguly era. Sensing interest from some quarters I was prompted to write a note giving an overview of "Who was Ganguly and what did he do?" to rekindle awareness. This was essential, since history often has a short memory, especially when people are pre-occupied, often intensely with present day problems.

1.2 WHO WAS GANGULY?

Dr. Ganguly was the person whom Dr. Bhabha selected from his successful high academic perch in Radiation Chemistry at the University of Notre Dame in USA, where he was a research associate and colleague of Prof. Magee. He was known for his achievements in Radiation Chemistry and was the originator of Ganguly-Magee theory. Dr. Jagdish Shankar, one of the architects of the atomic energy program, was sent by Dr. Bhabha on a mission to identify bright young Indians in U.S. Universities for leading the Indian Atomic Energy Program and he found in Dr. Ganguly a brilliant chemist who had done excellent work on soil chemistry in India earlier and then followed it up by significant work in Radiation Chemistry in USA. Dr. Shankar realized that he would be of high potential for the waste management and health physics program of Atomic Energy Establishment Trombay (AEET) as the present Bhabha Atomic Research Centre (BARC) was known, which was taking shape in 1956.

Dr. Bhabha gave Dr. Ganguly many important assignments and Dr. Ganguly lived up to his expectations and went about developing a broad-based Health Physics interdisciplinary program for the budding Research Centre at Trombay. One of the activities he started right away was the environmental studies of the Trombay harbor bay in 1957. Thereby he made his mark in the atomic energy program following Dr. Bhabha's directive that whatever is undertaken in DAE must become a path-breaking initiative in the nation. The pioneering work by Dr. Ganguly in the environmental safety program in atomic energy

led to awareness on the need for such studies in other industrial activities in the country.

When we talk of evolution of Health Physics discipline in India, it is invariably tied up with the professional career of Dr. Ganguly. From being a profession generally related to merely monitoring of radiation levels, he gave it a firm and committed direction, showing how the profession transcends into many other branches of science and turned it into a meaningful and effective radiation protection program that requires expertise in so many fields. Dr. Ganguly generated a whole gamut of expertise and experts. The following provides an abundant illustration:

- He studied the marine environment of Trombay creek, which was to be the recipient of possible discharges from the upcoming nuclear research center AEET. He then went about setting up limits of discharge of radioactivity based on the "recipient capacity" of the environment. His group produced international experts and expertise on estimation of Plutonium in low levels in the environment which was accepted by IAEA.
- He initiated and executed the first comprehensive IAEA project MARINA in 1960 on studying the impact of nuclear installations on the marine environment.
- He initiated the waste management activities at Trombay, as this was one of the mandates of the Health Physics Division in the initial days. He investigated the temperature distribution in radioactive spheres foreseeing the possibility of immobilization of waste way back in 1959.
- He introduced the concept of Environmental Survey Laboratories, operationally independent from the management of power plants and other nuclear facilities. The concept has stood the test of time and continues to be of high utility to the nuclear power operators in assessing the impact of operation of nuclear power stations on the society. His initiative attracted the attention of WHO and IAEA in the very early days and the Agency advised other Member States the need for a minimum environmental program in nuclear reactor sites.
- With his concept of a fixed Exclusion Zone supplemented by a zone free of unrestricted growth of population around a reactor, he laid the foundation norms for the selection of nuclear power plant (NPP) sites, starting from Tarapur and Rajasthan sites.
- He laid the foundation for the regulatory activities in India starting from the preparation of report on Safety Analysis and Waste Management for Canada India Reactor (CIR) (later named as CIRUS, acronym for Canada India Reactor & Utility Systems) in 1960. He was one of the four

members of the Safety Committee for Reactors at Trombay set up in 1962 with A. S. Rao as Chairman, the other two being V. Surya Rao and V. N. Meckoni. He was nominated Chairman of the Safety Committee set up for the Plutonium Plant in 1966. He was the Chairman of DAE Safety Review Committee (DAE-SRC), the forerunner of AERB, that was set up by an Office Order of Secretary, DAE in 1975 to oversee the regulatory aspects in all DAE units. He induced and inducted many Reactor Engineers and Fuel Reprocessing Engineers to participate in the regulatory activity.

- TL dosimetry work was initiated by him in 1964 and BARC became one of the global pioneers in the field.
- He was selected by Dr. Sarabhai, acknowledging his pioneering environmental research, to organize the country's first ever National Symposium on the topic of "Pollution and Human Environment", on the directive of the Committee on S&T (COST) of the Union Cabinet in 1970. This was in preparation for the country's participation in the U.N. Conference at Stockholm on the theme of 'Man and Environment'. Subsequently, it led to the formation of a separate Ministry of Environment in 1972 by the Government of India.
- A number of activities that he initiated in diverse areas like oceanography, radiation ecology, thermal pollution, radiation transport, dosimetry, criticality clearance computations, fission and fission product physics, etc., attracted wide attention in those days. These activities have been instrumental in establishing a comprehensive and self-reliant radiation safety program for the multi-faceted activities involving radioactive substances in DAE and elsewhere in the nation.
- In commissioning of computer codes in Trombay, his students were among the first. Experts on radiation transport in his group did pioneering work on developing radiation transport codes for shielding and these were included in a handbook on shielding published by the American Nuclear Society. Some members of his core R&D Group of initial days rose to be effective contributors to the Indian nuclear strategic program later
- His contribution to the setting up of the Indian Society for Radiation Physics is noteworthy and led to the formation of the International version of it, **International Radiation Physics Society** (IRPS)
- He foresaw the need for addressing possible impact of Tsunami at Kalpakkam coast, as early as 1975 when the FBTR was being set up.
- Without such a visionary at the helm, especially in the formative years of our program, the Health Physics discipline could have been shorn of many of its R&D components (Ed)

- Dr. Beninson, who was Chairman of International Commission on Radiological Protection (ICRP), and its member for 27 years, held him in high respect and considered him as his *Guru*. Dr Abel Gonzales of Argentina who was a member of ICRP and UNSCEAR also consider Dr Ganguly as his Guu.
- Environmental radioactivity monitoring carried out by various groups under Dr. Ganguly led to basic research on how heavy elements interact with the organic matter in sea bed and helped understand their mobility.
- Dr. Ganguly's concern for environment made him a much larger figure as an environmentalist transcending the boundaries of a Health and Safety program in AEET/BARC.
- He was non-compromising, and frankly expressed his firm convictions, if he found any lapse in safety matters.
- He was forthright and firm in his convictions and was known to have passed strictures against even governmental agencies, when it comes to a question of environmental protection.
- He also had the unique knack of making his views expressed without hurting anybody and in a pleasant manner, and there are many anecdotes on this.
- There are many instances when the work initiated by him in the past, served the Centre very well in practically managing contingency situations.
- He initiated basic work on the principles of laser isotopic enrichment by starting a group known as Multi-Disciplinary Research Section in 1972.

1.3 EARLY DAYS IN CALCUTTA

Dr. Anil Kumar Ganguly was born on November 1, 1918 in a village called Faridpur, now part of Bangladesh, and later lived in a joint family of about 17 members in North Calcutta. He was the second among 8 brothers and a sister. His father Harshnath Ganguly worked for the Railways and his mother was Hironmoyee Ganguly. His uncle had a small business. Life was absolutely simple in those days. Even for his higher studies he had to use candle-light at night since there was an electrical problem in the rented house where the family stayed. His elder brother studied medicine and was the ideal for Dr. Ganguly in the initial days. A younger brother became a nuclear engineer with the Westinghouse and after a successful corporate career, he is now retired and settled in USA. His only sister married one of his students in BARC, P. P. Chakraborty.

Dr. Ganguly's sister passed away on December 10th while I was correcting the final proof of the compendium. During her funeral which I attended, I came across for the first time, Prof. Prabuddha Ganguli, a nephew of Dr.Ganguly, whose scientific career was moulded by Dr.Ganguly step by step which saw

him blossom as a scientist in IIT, TIFR, as a von Humboldt fellow in Germany, in BARC and finally in the Indian industry. I am tempted to add this piece and also his reminiscences as Annexure 4 to this compendium, which brings out yet another dimension of the personality of the great Guru.

Dr. Ganguly had to work and earn from his college days to support his education. He did this by giving tuitions and his intrinsic qualities of an excellent teacher started flowering even in those days. He secured a B.Sc. Hons degree with flying colors in 1938 and subsequently did M.Sc. in 1940 from Calcutta University. Dr. Ganguly then joined the Scottish Church College and worked there from 1941 to 1949. During this period, while working as a faculty member of the Scottish Church College, he started doing his doctorate under the guidance of Prof. Sushil Kumar Mukherjee. He carried out research on studies of systematics of fixation of elements in soil. His studies on speciation in soil chemistry enabled him later to do pioneering work in environmental safety studies and studies on the uptake of radioactivity in marine environment. In 1949, his teacher considered his dissertation was of a high enough standard to warrant presenting it for the degree of D.Sc., rather than PhD. His work on colloidal chemistry has been referred to in several textbooks.

After obtaining his D.Sc., Dr. Ganguly became a Lecturer at the Science College, University of Calcutta. He guided a few students for their Ph.D. degree at Calcutta University. During this stint in Calcutta University, he had very useful interactions with stalwarts like Prof. S. N. Bose and Prof. Prafulla Chandra Ray, who were his idols during his student days. One of his contemporaries Prof. Purakayastha, was a pioneering radiochemist in India and it was he who prepared the target for fission cross section measurements by Prof. Saha as early as in 1944. His scientific outlook was shaped by these scientists. Continuing in the Chemistry faculty of Scottish Church College, he guided a few students for their doctoral dissertations. It was during his stint as a lecturer there, that 25 year old Dr. Ganguly married Binapani. They had three sons and a daughter. Dr. Ganguly then had a stint working as a Physical Chemist at the Bengal Chemicals Immunity Research Centre during 1951-52. Even in those early days he proved his scientific acumen and his work led to the manufacture of an antiseptic formulation. Somehow, his discovery could not earn a patent from Bengal Chemicals and his interest in the work faded gradually. He was looking for suitable openings and finally, he decided to proceed to USA for carrying out research and secured a post-doctoral research associate position at the University of Notre Dame in 1953.

Dr. Jagdish Shankar in his INSA Memoirs on Dr. Ganguly had this to say of his early days:

When his parents took him for admission to the school, the head master was so impressed by his ability to spell English words, that he was admitted directly to class 3. After his return from a pilgrimage to Puri with his parents, the headmaster is said to have asked Dr. Ganguly how much water there was in Puri. He replied that there was plenty of water and as for the depth, it was always more than the depth of his legs! Dr. Shankar notes that during his M.Sc. course he came in contact with stalwarts like Prof. Meghnad Saha and Sushil Mukherjee, who left their indelible mark on him. He particularly recalled the phenomenal memory of Meghnad Saha who remembered the name of every one of his students and could remember their telephone numbers too without referring to the telephone directory. Dr. Shankar remarks that Anil Kumar Ganguly himself had developed an excellent memory for facts and figures. Shortly before his death, Dr. Ganguly mentioned to Dr. Shankar that he is yet to meet as perfect a gentleman as his teacher and friend Sushil Mukherjee.

1.4 RADIATION CHEMIST IN NOTRE DAME

At the University of Notre Dame in USA, he worked with Prof. Magee on Radiation Chemistry and undertook some important basic work on formation of radicals under the action of radiation in aqueous systems. The Ganguly-Magee theory published in 1956 was an important contribution to the field of radiation chemistry and has been referred to by many workers. The "beads on a string model" proposed by Ganguly and Magee (Ganguly and Magee, J. Chem. Phys.25, 129, 1956) was generalized to allow Monte Carlo techniques to be used in calculating the influence of track structure on the yield of free radicals at early times following energy deposition by ionizing radiation in aqueous solutions. The work was of seminal importance and formed the basis for many subsequent investigations in radiation chemistry, even as late as 1982 (Miller & Wilson). His brother Sushil Ganguly, who worked as a nuclear engineer for four decades with Westinghouse in USA, observes that four research scholars who were being guided by Ganguly took off from where he left and got their doctorate creditably. Much later, one of the bright training school alumnus in BARC, J. P. Mittal, pursued his post-doctoral work in chemistry under Prof. Magee and carried out creditable work. Mittal rose to become Director of Chemical Group in late 1990s, the position which was decorated by Dr. Ganguly earlier in 1970s. The text book on Theoretical Chemistry by Gladstone was so familiar to Dr. Ganguly, that he could verbatim quote to me from the book and highlight the principles to apply the Order Disorder phenomenon in alloys to nuclear systems and finally we proposed an Order Disorder model of binary fission successfully.

Those days Dr. Homi Bhabha was spreading his net wide across the world for inducting promising candidates for the atomic energy program in India. Dr. Jagdish Shankar notes that he first got in touch with Dr. Ganguly when he was asked by Dr. Bhabha to scout around for potential candidates to lead various aspects of the Indian atomic energy program. During these explorations Dr. Shankar came across the name of Dr. Ganguly in the University of Notre Dame and expressed his desire to meet him. When he went over to Notre Dame, he was led to the basement of the University building, where he found Dr. Ganguly bent over some books and papers (because of his poor eye-sight). When Dr. Shankar was informed by Dr. Ganguly about his earlier work on ion exchange properties of clay minerals and that he was currently doing radiation chemistry, it struck Dr. Shankar that he might be a suitable person for organizing health physics and waste management in AEET. But, this meeting was very brief. Dr. Shankar invited him to come to Chicago which was about an hour's journey away by train, for detailed discussion. They had dinner together and Dr. Ganguly returned to his University later in the night. Dr. Shankar found the discussion during the journey and dinner to be extremely fruitful. Ganguly at once impressed him with his deep knowledge of the subjects and by his simplicity and integrity and on the spot Dr. Shankar offered him a position in AEET. Dr. Shankar says "thus started a new career, and collaboration and friendship which continued in later years." Much later, Dr. Ganguly was elevated to the post of Director of Chemical Group in BARC in 1972. Due to very short service left Dr. Shankar remained as Head, Chemistry Division and was to report to him. Dr. Ganguly was visibly embarrassed and expressed this to many including me. As a matter of fact, the first thing Dr. Ganguly did on receiving the order was to rush to Dr. Shankar's office on the II floor of Mod Lab to offer his respects, brushing aside everyone else.

His brother Mr. Sushil Kumar Ganguly was already in USA as a nuclear engineer with Westinghouse, when Anil Kumar Ganguly was at Notre Dame. During the preparation of this compendium, I had an occasion to meet S. K. Ganguly in November, 2016 in Mumbai and share his reminiscence of his illustrious brother. He confided to me that when Ganguly was selected for AEET, he had another offer for an academic position in Calcutta University. At first, he seemed to have been a bit unhappy to be away from academic pursuits and nervous to foray into uncharted waters, but later when he attracted students around him soon after joining AEET, he was in his elements and created virtually a "Ganguly school" in AEET, which very few could achieve. S. K. Ganguly remarked that "In his tryst with radiation chemistry at University of Notre Dame and his earlier research work at Calcutta university on ion

exchange of soils, he could have found avenues easily to work his way up in United States as a successful academician or an entrepreneur with potential for earning "not thousands of dollars per month but per hour", but his nationalist temperament made him anxious to get back to India to serve, where his base existed." While he did not make that kind of money, his ideas sown into the minds of his students did so in many cases and that talks volumes for the vision of Dr. A. K. Ganguly. The indelible mark of lofty principles of scientific stalwarts like Prof. Meghnad Saha, Prof. S. N. Bose and Prof. Mukherjee during his days in Calcutta University, taken along with the spiritual teachings of Swami Vivekananda and Ramakrishna Paramahamsa, had already molded his nationalist feelings. The academic outlook and unquenchable thirst for venturing into varied scientific forays that Dr. Ganguly had could be noticed in all the scientific programs he initiated in AEET, as has been revealed in the memoirs of his students and co-workers in Part II of this compendium.

1.5 GANGULY ERA IN HEALTH PHYSICS PROFESSION IN ATOMIC ENERGY

Identified as one who could organize 'Health Physics' and 'Waste Disposal Groups' in the Atomic Energy program, Dr. Ganguly was appointed Head of a newly created Radiation Hazards Control Section when he joined the Atomic Energy Establishment Trombay, as BARC was then known. The RHC Section was part of the Health Physics Division under A. S. Rao, who was one of the five veterans selected by Dr. Bhabha to give shape to his plans for structuring AEET. A. S. Rao had specialized in electronics and as operational Health Physics depended on radiation monitoring instrumentation, he was in overall charge of Electronics Division as well as Health Physics Division. He was a humble person and a perfect gentleman. He recognized the talent and capability of Dr. Ganguly and gave him a free hand to put his imprint on the health physics program of the AEET. On his part Dr. Ganguly had great respect for A. S. Rao and the mutual trust both had for each other was one of the significant factors which enabled Dr. Ganguly to bring up a broad based health physics program in India. Dr. Bhabha used to give assignments to Dr. Ganguly concerning health safety and environmental issues. Dr. Bhabha rang up Dr. Ganguly from Canada calling for a CIR hazard evaluation report to be urgently prepared before the start-up of the CIR reactor. This is mentioned elsewhere in this compendium. An example that showed Dr. Ganguly's respect for authority was that in all policy matters which he evolved, he had associated A. S. Rao. Thus in the paper "Health and Safety Criteria for Siting Power Reactors in India" presented at the 1963 IAEA Conference that incorporated the Department's policy on selecting sites for reactors, Dr. Ganguly was a

co-author of A. S. Rao. Dr. Ganguly was given full charge of health physics in 1963 and Mr. A. S. Rao had started concentrating more on electronics organization and finally he left for setting up the Electronics Corporation of India Limited (ECIL) in Hyderabad in 1967.

When we talk of evolution of Health Physics discipline in India, it is invariably tied up with the professional career of Dr. Ganguly. From being a profession generally related to only monitoring of radiation levels, he gave it a firm and committed direction, making it transcend into many other branches of science, transforming it into a meaningful and effective radiation protection program encompassing expertise in so many fields. At the time when Dr. Ganguly joined the Department of Atomic Energy, Dr. Bhabha was busy sketching a roadmap for the atomic energy program in India and all his ideas were being given shape to develop the Trombay campus as a nuclear centre enveloping all activities of the complete nuclear fuel cycle. Thorium Plant of The Indian Rare Earths had already begun operation at Trombay. The research reactor Apsara, the first one in Asia, was just commissioned (in August 1956). For many on the scene, health physics and radiation hazards control meant only radiation monitoring, radiation monitors, decontamination of work areas (some even called us scientific sweepers!) and use of copied terminologies of REP, RAD and REM used as units of radiation dose. Duties of many of the early health physicists included decontamination of the floors, but someone down the line changed it to stipulate that the "Health physics surveyors" would do only monitoring to confirm that the contamination levels are brought to acceptable limits and nothing more. Influenced by the Canadian system, reactor operators tended to introduce the nomenclature "radiation surveyors" for health physicists at the CIR reactor. But someone fortunately resisted and it was changed. V. K. Gupta in his memoirs remembers that "the engineers who had gone to Canada for training in operation, on their return were keen to adopt the Ontario Hydro radiation protection system of surveillance and services. This was not acceptable to Dr. Ganguly and he held to his ground and structured the Health Physics Division according to his grand vision. The very same people, who wanted to mimic the Canadian system, later became his admirers and were even inducted into the regulatory activities under DAE-SRC by Dr. Ganguly. Thus, many in the Health Physics Division, who started their career as health physicists, grew under Dr. Ganguly, to become leaders in various branches. I thought of narrating these reminiscences just to stress how different the Health Physics profession would have looked without Dr. Ganguly being around in those early years.

In the initial days, some even thought that the health physics profession does not call for "wasting" some of the best scientific manpower being harnessed

into the program then. This was also reflected as bias against recruitment of top rankers from the AEET Training School (started by Dr. Bhabha in 1957) for the health physics program. As a matter of fact, the input from the AEET Training School for Health Physics gradually reduced to a trickle after two or three batches. However, the teacher in Dr. Ganguly helped transform the scientific manpower available to him into 'first class scientists' in spite of this. Many of his successful students, who made their way to the top, had started their career at the lowest rung as scientific assistants. The "Ganguly School" churning out such excellent manpower was unique to AEET. Coincidentally, it appears that in the early years, Dr. Bhabha also had similar ideas about manpower development, when he decided that the minimum qualification for entry into AEET Training School as B.Sc. level for physics and chemistry streams. And he was proved right when many first rankers turned out to be B.Sc. degree holders, since the curriculum in the AEET Training school was based on starting completely on a new slate. It is only much beyond Dr. Bhabha's days, and after several batches (from 21st Batch starting in 1977), it was changed, when entry qualification for science stream was made M.Sc. degree.

It goes to Dr. Ganguly's credit that he provided a strong scientific content to the health and safety program. Besides laying a firm foundation for an exemplary health and safety practice in all our nuclear installations, he recognized, nurtured and established a multi-faceted R&D program in health, safety, and environmental disciplines, which essentially shaped the "Ganguly school" that produced so much of excellence all around. Classical physicists considered that "Health physics is no physics at all!" And some even mocked it as a "multidisciplinary indiscipline", but even they developed respect as Dr. Ganguly spread out his plans. It was all due to his universal scientific outlook that transformed health physics into a dynamic, multi-disciplinary, multi-faceted science, and furthermore, evolved the related field of radiation physics. He would initiate investigations if it arouses his scientific curiosity, even if it were considered as exceeding the limits of his domain of responsibility and stepping into gray areas. And he will invariably arrive at an end result, which apart from producing primary scientific knowledge and experts, found an application in his assigned field of activity! Finally none could stop him and he had his own way and carried conviction. There was a time when anybody looking for some result or information for application in the atomic energy program, could turn to Dr. Ganguly to provide the results or the experts in that connection. Many of the memoirs in Part II of this compendium bear testimony for this in terms of several examples described therein.

Radiation Physics, Radiation Transport, Radiation Ecology, Environmental Chemistry, Chemical Engineering, Radiation Biology, Marine Biology,

Oceanography, Atmospheric Sciences, Radiation Dosimetry, Fission Physics, Radiation Instrumentation, Nuclear Safeguards, Non-destructive Testing techniques, are some of the subjects he had initiated work on. He showed that some aspects of all these have a bearing on perfecting a self-reliant radiation safety program for a multi-faceted research centre like AEET/BARC.

Mr. S. D. Soman was the first health physicist in AEET, much before the arrival of Dr. Ganguly on the scene. When the need for health physics surveillance for the numerous sources handled in TIFR arose, the choice fell on him in 1953. He had started his scientific career in TIFR in 1952 carrying out research on beta spectroscopy under Prof. Thosar. One of the earliest challenges Soman met in his new assignment were the accidental widespread contamination of a few rooms in TIFR with Po-210 from a standard source used for testing alpha detectors. He directed the decontamination by suggesting chipping of the surface of the wooden furniture. Another was in Tata Memorial Hospital where a radium plant was in operation for filling needles with radon gas for cancer treatment. Personnel operating the plant were found to be contaminated often and Soman suggested steps to remedying the situation. Later on the plant was decommissioned in 1959 and J L Kapoor provided the health physics coverage for this. When AEET was formed by Dr. Bhabha, Mr. A. S. Rao, who was one of the confederates of Dr. Bhabha and who laid the foundation for electronics support in AEET, was asked to also organize health physics operations. The electronics control instrumentation for the reactor was carried out by A. W. Pereira in the Reactor Control Division under A. S. Rao. Development of instrumentation essential for the health physics program was also started by Dr. Bhabha in a unit known as Health Physics Instrumentation under Mr. G. H. Vaze. This was also under the overall direction of Mr. A. S. Rao. Thus, A. S. Rao became Head of the Health Physics Division and Mr. Soman started his health physics work in AEET under Mr. A. S. Rao. Dr. Ganguly on joining AEET in 1956, headed the RHC Section in the Health Physics Division, and thus started the close association of Dr. Ganguly and Mr. Soman. Dr. Ganguly nurtured Soman step by step to take up further responsibilities in operational Health Physics.

Mr. S. D. Soman became the most trusted lieutenant of Dr. Ganguly in organizing operational health physics starting with CIR reactor. He had spent a year at the NRX reactor at Chalk River, Canada preparing himself to take up this responsibility. SDS followed on the footsteps of Dr. Ganguly and first became Head, RHCS in 1963, then Head, Health Physics Division in 1987 and finally rose to guide the destiny of the Health Physics organization as Director of Health and Safety Group after the departure of Dr. Ganguly from the scene. He had a balanced and down-to-earth practical approach in addressing

and solving health physics related matters and problems. And he was finally called upon to be the Chairman of AERB (1990-93) after the term of Prof. A K De, the first Chairman of AERB. Prof. De was earlier the Director of IIT, Bombay. Soman was the first Chairman of AERB with first-hand wide experience in directing health physics operations in nuclear fuel cycle activities. Soman's reminiscences of Dr Ganguly are contained in Annexure 2.

Soman had the knack of getting along with the management in providing health physics surveillance. One of the factors of his success was his humble nature and he was never carried away by over enthusiasm, nor was he eager to project himself and his colleagues. His advice to me in facing departmental interviews was that "you don't have to tell everything you know, but just enough to meet the objective", a very practical advice, to curb the tendency to project oneself before seniors, that even led to disastrous ego problems! Unlike Dr. Ganguly, he was cautious not to overstep his boundaries of domain responsibility. He was identified to be the most suitable person and hand-picked to organize direct health physics coverage for the 1974 PNE operations.

Soman's contributions to operational health physics are numerous. Realizing the need for expertise in Tritium measurements to back up the extensive PHWR program of DAE, he initiated Tritium monitoring program and developed various methodologies. T S Iyengar worked in close collaboration with Soman in setting up a Tritium laboratory. He started a program to design and fabricate specialized protective equipment and apparels, which were extensively required in the fuel reprocessing operations. In the post-Ganguly era, he molded my area of work and asked me to find avenues of work that would be of immediate relevance to health physics based on the earlier accomplishments. This led to many successful ventures. Some of them involved use of microprocessor technology for online micro-met data analysis for assessing impact of reactor operation on the environment and developing and producing a large number of microprocessor based 4 K multi-channel analyzers, a basic tool for an effective health physics program. At that time, the availability of these were at a premium in the Division putting limitations on the work. This finally led to our developing an Aerial Gamma Spectrometry system, which was useful for a quick assessment of the impact of the operation of nuclear reactors on the environment and in case of accidents. It was also widely used to locate disused/orphan sources, both in India, and abroad, the latter through IAEA. This also led to deploying very useful unobtrusive compact road and rail vehicle mounted systems for this purpose. All these were possible due to the exhortation of Soman, while the genesis of these programs should be attributed to Dr. Ganguly.

Dr. Ganguly and Soman offer a study in contrast, one with an insatiable thirst for scientific conquest, the other making his presence felt with his modest aspirations but down-to-earth attitude for development. Both were complementary in bringing up health physics operations in AEET/BARC. This aspect of Soman's personality can be seen by an anecdote: Once someone approached him for promotion and had the temerity to utter that if he is not promoted, he may have to look for alternate avenues. Soman at once passed on a sheet of paper to him and asked him to sit down and write out a resignation letter. And added "one less means less headache, and if more go away, then no headache".

The saga of development of health physics under Dr. Ganguly in AEET will not be complete without a mention of a few of the early players in the profession. Mr. Somasundaram, who also nurtured the health physics operations, was another dimension to modesty. Thanks to him, much before the centralized documentation activities in AEET came into being, HPD had a system of formal documentation following the example of US National Laboratories. Several reports of the activities of the Division were brought out under various series, such as AEET/HP/Th, AEET/SM, AEET/HP/Survey since 1957. He brought to bear his editing capabilities invariably in the preparation of all the early reports (see Annexure 1). Not only that, when Dr. Ganguly was encouraging new entrants to spend time in library to discover health physics, Mr. Somasundaram organized a functioning Divisional library with the scientific staff overseeing the activity. This was much before the Library and information activities in AEET started and was a forerunner of divisional libraries in AEET. The library was self-supporting and he organized a system of procuring reports and publications from abroad by making available ready-made reprint request cards. D V Gopinath reminiscences that in the initial stages of formation of Indian Association for Radiation Protection (IARP), when it experienced some birth pangs, "it was Somasundaram who worked silently and steadfastly for a few years and put IARP on a sound footing organizationally as well as financially". (see Annexure 1). One of the hallmark of Somasundaram's contributions is that in many instances he was content in working in the background with minimum "noise". Even in the preparation of this Compendium when the editor sent the edited condensed version of his 80 page handwritten manuscript he removed many portions in which I tried to bring out his qualities!

Somasundaram undertook further development of (whole) body counting techniques that were initiated by Mr. A. S. Chhabra for assessing intake of radioactivity by radiation workers for estimation of internal dose preparatory

to commissioning of CIR reactor. He developed compact shadow shield body counters for application in screening radiation workers at various nuclear plants. The shadow shield counters developed by him were also used in radiation medicine applications. His developmental work on estimation of plutonium by lung counting is noteworthy. The steel room he set up in Trombay was one of the best facilities of its kind in the world. He was also the first to recognize the need for developing Indian Standard Man data for establishing the limits for intake of radionuclides in Indian conditions and carried out pioneering work on this.

Subbaratnam was a chemical engineer recruited to initiate the waste management activities in the Health Physics Division, which was one of the mandates given to Dr. Ganguly when he joined AEET. Eventually when those responsibilities were transferred to Chemical Engineering Division, Mr. Subbaratnam preferred to continue in HPD and concentrate on operational health physics. With his engineering background, he could contribute very well in organizing operational health physics in power reactors and headed the Power Project Safety Section of HPD. He meticulously studied radiation protection philosophy of ICRP and became one of the few experts in DAE, who clearly understood ICRP with all its associated biological, legal and social intricacies. In the aftermath of the Chernobyl accident in 1986, he analyzed the accident meticulously collecting details. With his background as an engineer combined with his expertise on interpretations of various complex ICRP recommendations, he delivered many lectures in various forums on the analysis the accident. Perhaps he was the only one who for the first time understood the accident so well, and it was hence truly educative to listen to his lectures on the topic. He was given an assignment by Trombay Council of BARC to carry out an exercise to estimate the "cost" of a 'man-rem', but the results became controversial.

One of the earliest activities in the Radiation Hazards Control Section under Dr. Ganguly was the induction of industrial hygiene activities under direct instructions from Dr. Bhabha. Dr. Bhabha rightly envisaged that while the radiation hazards unique to the atomic energy program is controlled to a large extent, the injuries and casualties due to conventional accidents are more of a concern. The person who was identified to oversee these activities was Mr. K. S. Somayaji along with Mr. A. Ramamurthy. Mr. Somayaji was recruited in 1956, after a brilliant academic career at the Presidency College, Madras University, to the Air Monitoring Section headed by Dr. K. G. Vohra. He initiated measurements of the concentration of radon/thoron daughter products at the then newly started Thorium Plant of Indian Rare Earths Ltd. (IRE) at Trombay.

Later, he underwent basic Industrial Hygiene training at the School of Public Health (SPH), University of Michigan at Ann Arbor during 1959-1960. The Industrial Hygiene Group was a vibrant group and made its presence felt not only in AEET/BARC but also in many other DAE installations. The posters such as "This need not have happened", imaginatively caricatured and designed by this Group, was quite helpful in making people aware of the importance of industrial safety. The Group later on extended their activity to providing advice on ventilation, lighting conditions and noise pollution in various plants. Their advice was much sought after by many DAE units.

Another activity Dr. Ganguly initiated from the early days was on standardization of radioactivity sources which was found essential to assure quality control of radiation metrology in health physics. UC Gupta, M G Shahani, and Srivastava and their team. Today it has grown into the national accredited center for radiation standardization.

1.6 GANGULY, THE REGULATOR

Dr. Ganguly was the Chairman of the Review Committee set up by DAE in 1968 to authorize the commissioning of TAPS reactors. The Tarapur Safety Review committee was later renamed as DAE SRC and given the responsibility for overseeing the regulatory aspects of commissioning the RAPS reactors in 1972-73. Its ambit was extended to provide regulatory supervision for all DAE plants in 1975, with Dr. Ganguly as Chairman, and this ushered in the atomic energy regulatory activities in India. L. V. Krishnan was selected to be secretary of DAE SRC by Dr. Ganguly. But after a few months, he had to proceed to Kalpakkam where the Reactor Research Centre (RRC) was taking shape under Dr. Sarabhai, for organizing, along with Dr. Gopinath, the health and safety activities there. Dr. Ganguly subsequently brought in Mr. P. Abraham as Secretary of DAE SRC. Mr. Abraham was the one who carried out the mandates from Dr. Ganguly in the successful setting up of many regulatory procedures and practices. L V Krishnan remembers that "AKG was keen to have a set of General Design Criteria established for our reactors in the manner of USAEC. Abraham executed the job. Mr. Abraham was a very effective Secretary of the SRC and a true disciple of AKG in spotting safety issues and insisting on the right measures".

Mr. Abraham in his memoirs mentions that the Tarapur Safety Committee had long sessions and heated discussions at Tarapur, often lasting till late hours in the night. Authorizations were given in stages. It may be noted that this was the first major step in the country to regulate nuclear facilities and many procedures

laid down by Dr. Ganguly are the cornerstones of the regulatory process being followed in India today. Similar procedures were then implemented for RAPS, MAPS and FBTR. Dr. Ganguly thus laid the foundation for regulating nuclear power-related operations in the country. When discussions on the creation of Atomic Energy Regulatory Board were in progress, Dr. Ganguly prepared several drafts for this purpose and submitted to DAE.

As a member of the Senior Advisory Group (SAG), constituted by IAEA, to coordinate the Nuclear Safety Standards (NUSS) program for preparing the safety codes and guides for nuclear power plants, Dr. Ganguly was involved with five different Technical Review Committees (Governmental Organization, Siting, Design, Operation and Quality Assurance), with members from many different nations. As a member of the TRC on Governmental Organization, Mr. Abraham could witness at first-hand the respect AKG had earned in the international arena. AKG chaired the Committee on Safety Codes and Guides, set up by DAE to coordinate the Indian contribution for the NUSS program. Mr. Abraham was the Member-Secretary of this Committee.

When Dhruva was being commissioned, the containment was required to be tested as per the regulatory norms. Mr. Kakodkar along with Mr. Seshadri approached Dr. Ganguly who was Chairman of the R5 (as Dhruva project was known) implementation committee and Director of Reactor Group, with this problem asking for a value to be prescribed for leakage. He looked back at them and suggested to conduct a comprehensive leak test at whatever pressure possible and that will be the basis of a standard for future. Gupta remembers that Kakodkar said that it was a fantastic proposal and "we never thought that way." These are the type of remarks which created respect for Dr. Ganguly in the minds of experts.

Mr. M. S. R. Sarma, who was a veteran reactor operator with a seventeen-year career as Station Superintendent of Rajasthan Atomic Power Station and who later on became the Vice-Chairman of AERB, was one whom Dr. Ganguly inducted into the regulatory set up from his high perch in RAPS. He among others was responsible for recasting the Canadian CANDU PHWR reactor into an Indian "INDU" PHWR, after the Canadians walked out of the nuclear collaboration with India in the aftermath of the PNE experiment undertook by India in May 1974. He reminisces that he had the privilege of interacting with Dr. A. K. Ganguly right from the initial days of his joining the department. They were in Canada together in 1956 and hence had closer interaction on personal issues as well. His experience with AKG was that he was a real teacher – Guru. He knew how to defuse a potential or confronting

and uncomfortable situation in meetings. During the framing of Technical Specification for RAPS, Sarma, who was then the RAPS Superintendent, used to have heated discussions and Dr. Ganguly demonstrated his knack to defuse situations without rancour, yet invariably ensuring the highest standards of safety. When Dr. Ganguly was heading DAE-SRC, Sarma also had the privilege of facing him from the utility side. Sarma notes that Dr. Ganguly had strong conviction on safety and did not compromise at any time during his tenure.

Mr. Muthukrishnan who organized health physics unit in Variable Energy Cyclotron Centre has an interesting anecdote. Almost 40 years back Dr. Ganguly had stipulated certain safety features conditional to start-up of the new K130 cyclotron which Mr. Soman was not aware of. VECC people took up the issue with Mr. Soman and secured his concurrence for start-up. During the next visit by Dr. Ganguly to VECC they touted the permission from Soman. Dr. Ganguly smiled and merely said "I cannot over rule him" and later before leaving reminded them the safety features required and thus prevailed upon his point without asserting his superiority.

Mr. M. S. R. Sarma remembers that Dr. Ganguly was the head of site selection committee, which prescribed limits for exclusion zone of 1.6 km and sterilized zone of 16 km with no growth. In the case of Narora, there was a proposal to reduce the exclusion zone and NPCIL announced its plans to that effect, but Dr. Ganguly didn't relent and when the file was put up to AEC Chairman, Dr. H. N. Sethna, he returned the same with a remark "both of you agree on a number and come to me for approval". Sarma recalls that the exclusion zone stands at 1.6 km till date. These distances were prescribed by Dr. Ganguly, based scientifically on the evaluation of releases and the effect on the surrounding areas/population for control in the Indian context.

Sarma recalls that the establishment of Environmental Survey Laboratory at each one of our installations is a unique feature in the Indian nuclear power program and Dr. Ganguly was the pioneer in this field. Dr. Ganguly was successful in veering around the feeling of some that these environmental sample analyses could be carried out externally. Here the two visionaries' views converged and Dr. Bhabha could realize the great merit of the proposition of ESLs and brought the hammer down as mentioned in this volume elsewhere. This is an institution that stands till date and serves the NPCIL well.

Another important aspect was that Dr. Ganguly insisted that the ESL should be operated by Health Physics Division, BARC, which is independent of the Power Station operators. It was also Dr. Ganguly, who prevailed upon Mr. Surya

Rao, who headed the PPED, forerunner of NPCIL, in having the health physics operations structured independently under HPD of BARC for all nuclear operations in India and succeeded in it as long as he was in power. And as the Head, HPD, and as Director of Health Safety Group, he carried conviction and ensured the highest standards of safety in nuclear operations in India. Besides ensuring independence of health physics operations it also facilitated easy adoption of the results of related R&D studies carried out in Health Physics Division BARC. However, there has been a shift in organizational set up during the post Ganguly era. Today the NPCIL oversees the health physics operations. With the expansion of the power program the question of viability of handling this by BARC, may have been a consideration in the shift in policies. But the sanguine spirit in ensuring independence of health physics operations which Dr. Ganguly had in mind had its own merit

Mr. S Vasanth Kumar, a pioneer in establishing fuel reprocessing in BARC, was another professional expert whom Dr. Ganguly brought into the regulatory profession under the DAE SRC. He later became a successful regulator as Vice-Chairman of AERB and also officiated later as Chairman of AERB for six months.

The regulatory aspects of nuclear fuel cycle facilities under the DAE were overseen by Health Physics Division under Dr. Ganguly. In the initial stages the Radiation Measurement Lab (later named Directorate of Radiological Protection [DRP]) under P N Krishnamoorthy started providing radiation protection services in the use of radiation in industrial and medical uses in addition to personal dosimetry services using Kodak film badges. This activity was purely advisory in nature until many years later responsibility to enforce was accorded. But it was well handled by PNK with his administrative acumen. He also foresaw the need for training personnel and began offering a full-fledged course in medical physics of one year duration and other related short term courses. They are still continued. As R&D activity in application of thermoluminescence initiated under Dr. Ganguly progressed, soon enough DRP introduced thermoluminescence dosimeters to all radiation workers in DAE and elsewhere in the country.

Quotes from AERB publication "25 Years of Regulation": "In 1963 the Directorate of Radiation Protection (DRP) was constituted for monitoring non DAE radiation industrial and medical radiation facilities with P N Krishnamoorthy as Deputy Director of DRP. In 1973 both HPD as well as DRP were brought under the Chemical Group of BARC headed by Dr. Ganguly. After promulgation of Radiation Protection Rules 1971 Director DRP was notified as competent authority. In 1972 after Sethna took over

as Chairman AEC following the demise of Sarabhai DRP was renamed as Division of Radiological Protection. In 1973 K G Vohra was made Head DRP in Health and Safety group of BARC and was notified as competent authority for enforcement of RPR 1971. U Madhvanath took over as Head DRP in 1987". Later the division was renamed as Radiological Physics Division. P N Krishnamoorthy's administrative skill found use as Secretary to Electronics Commission in 1972, later as controller of BARC and finally as Secretary to AERB under Prof. Dey as Chairman AERB. PNK was also an accomplished Carnatic musician and made notable contributions in the social fabric of Anushakti Nagar.

1.7 GANGULY, THE ENVIRONMENTALIST

Dr. Ganguly's outstanding contribution has been in the environmental sciences. His interests were deep, varied and diverse, encompassing nature as a whole, be it atmosphere, hydrosphere, lithosphere, or biosphere. Long before environmental issues became the bandwagon, Dr. Ganguly showed immense concern for environmental sanctity. Realizing its importance way back in 50s, he laid a strong foundation for environmental studies in the Department as soon as he joined AEET. The environmental survey laboratories (ESL) he set up at all nuclear power sites are a standing monument to the memory of Dr. Ganguly and his devotion to the environment. In the setting up of ESLs, he chose Mr. P. R. Kamath to implement his ideas and Mr. Kamath's persevering efforts in this context enabled the realization of the dreams of Dr. Ganguly. Environmental surveillance was given importance in atomic energy operations since 1958. In this Dr. Ganguly followed Dr. Bhabha's directives that the Health Physics operations in AEET should be evolved as "a path-breaking operation and should serve as a model to other industries".

Though the formal establishment of the first ESL was at Tarapur in 1962, Dr. K C Pillai notes that the seeds for these activities were already sown by Dr. Ganguly as early as 1958. The first pre-operational survey at a reactor site in the country was undertaken in 1959, prior to the start-up of the CIR reactor in AEET. The first pre-operational survey report was brought out in 1961. This was an innovation away from the system in Canada with whose collaboration the CIR reactor at Trombay and the PHWR program at RAPS were initiated.

When the proposal for setting up the first ESL at Tarapur was put up, there were some reservations in many quarters in the Department, but Dr. Bhabha wholeheartedly supported the proposal and wrote on the file "if there be no sanction for ESL, the reactors need not operate". So strong was the reaction

from Dr. Bhabha, that the ESLs in all Indian nuclear sites became an essential feature even after the departure of Dr. Bhabha from the scene. The ESLs serve the Department well in projecting the facts and figures to show that the impact of operations of nuclear facilities does not have any deleterious effects on the environment. That goes to speak tons for the environmental initiatives of Dr. Ganguly.

The location of the ESLs beyond the 1.6 km zone was a feature, which ensured that in case of any unforeseen releases, the laboratory will still be able to function. The chain of Environmental Survey Laboratories at all the DAE installations we see today is entirely due to his foresight and persistence. Today they serve as the backbone of the NPCIL to ensure that emergency preparedness for the site is in place.

Dr. Ganguly's contribution to the environmental sciences was not confined to the realm of Department of Atomic Energy alone. It extended to the entire national sphere. He organized the first national seminar on pollution and human environment in 60s and provided an effective forum for environmental activities at the national level. As a member of the several apex committees, he contributed significantly to the evolution of a national environment policy and the creation of the Department of Environment. Thus Dr. Ganguly fully followed the dictates of Dr. Bhabha through setting up an example in DAE. The details are contained in a section of Part II. The pioneering work of Dr. Ganguly in environmental impact assessment (EIA) too found national acceptance, and he was called upon to advice on the selection of sites for many chemical industries in India.

The scientific and straightforward outlook of Dr. Ganguly when it comes to environment can be clearly seen in a frank press interview he gave in 1987. The Maharashtra government had expressed its dissatisfaction about the report produced by the Ganguly Committee in February, 1987 on investigation of pollution threat posed by industries in the Batsai catchment areas that provided 80% of the water supply to Bombay city. He undertook perhaps this last mission in his life just a few months before his demise and in the midst of failing health. The main finding of the Committee was that the industries in the area were discharging unacceptable levels of toxic effluents into the Batsai River and putting the public to great risk and the report castigated the Government for not having an environmental policy in locating these industries.

Only rarely one comes across acceptance of technical expertise and integrity of Government authorities by 'activists'! The personality of Dr. Ganguly

was such that it was admired even by activists against the atomic energy program. Mr. Praful Bidwai, in his obituary of Dr. Ganguly in January 1988, qualifies him as an outstanding environmentalist of exceptional ability and integrity. 'He is described as the founder of a new discipline in DAE called health physics dealing with safety of personnel and the environment.' According to Mr. Bidwai, 'he (Ganguly) acquired a formidable reputation of being a stickler for safety norms. He is often described as a scientific dissident within DAE, who refused to compromise on safety, which made him a feared man of safety.'

1.8 GANGULY, THE TEACHER

The memoirs in Part II are full of reminiscences of his students to show how their first meeting with Dr. Ganguly invariably revealed him as a gentle, caring, great teacher. As mentioned earlier, the first concern of AKG when he was offered the placement in AEET, away from his cozy academic refuge in Notre Dame, was not so much about his future, not about getting back to India to be near to his family, not about his reduced emoluments, but his only concern was whether the uncharted waters he is entering will provide an academic atmosphere of a university for him to continue to grow as a teacher. Irrespective of the fact whether the institution (AEET) provided such an atmosphere or not, he did introduce that element into AEET, and collected a coterie of students around him and created literally a 'Ganguly School' in AEET. And transformed even ordinary individuals into a scientist! His personal warmth was mystifying to most of his students. He often made them understand their mistakes by not mentioning about it, and only by suggesting alternatives and through gentle body language.

One may say that Dr. Ganguly was lived a life constantly guiding his students and that was not confined to the laboratory. His students remember that many of his ideas originated in seemingly casual talks not confined to the work premises but during social outings and even traveling with him in his jeep after working late night at the labs. So he was a teacher in his heart trying to reach out to his students to give ideas, whenever or wherever he had a talk with them.

Dr. Ganguly used to tell Dr. K. C. Pillai, one of his first students in AEET that "you must know the environment well before you start working on it". They used to go around the Bombay Harbor Bay in a jeep and walking along the coast, explored the environs, particularly the salt pans around, which might get affected by the effluent released from the laboratories and plants, which

were coming up in Trombay. This was his preparation for evaluation of the possible consequential impact on the environment. The discussions during these visits were very revealing and once Dr Ganguly told KCP during these sojourns that "you must study the calcium intake through salt. We should study the specific activity concept of maximum permissible activity in sea water". This suggestion later led to important findings and publication of a paper.

As any of his students would vouchsafe, the seeds of many of the ideas, which flowered into successful scientific programs, were sown in his private talk with them. Once when M. A. R. Iyengar took Dr. Ganguly around the tailings pond at UCIL Jaduguda, where Iyengar was the environmental chemist, Ganguly casually remarked. "Ramanuja, don't you think the oxidant used in the mill at the leaching stage for converting uranium IV to uranium VI is doing a great job in controlling spread of pollution from tailing pond to the environment". This seemingly casual statement sunk in Dr. Ramanuja Iyengar, though it took some time for him to fully understand and gauge the depth and implications of the profound remark of Ganguly. What he meant was, that the Pyrolusite (manganese), a strong oxidizing agent, is playing a twin role, that of oxidizing Uranium IV to Uranium VI, which enhances the efficiency of leachability in acid medium in the milling stage, and has also the potential to trap and hold back all, or most of the toxic radioactive elements like Ra-226, Pb-210 Po-210 and hazardous heavy metals like lead, selenium, copper, which were noted for their significant presence in the Jaduguda ore body. The former was an intended role and the latter an unintended beneficial one! This idea, which Dr. Ganguly sowed in MAR Iyengar's mind one evening by the side of Tailings Pond of Jaduguda mines in 1970s, resulted in being used in effluent treatment plant in Jaduguda mines. Post-retirement Dr. Iyengar continued to work on this idea and perfected a technology to purify water. This led to commercial exploitation in developing a portable water purification plant and passing on the knowhow to M/s Eureka Forbes in 2014, and turned it into a financial venture for Dr. Iyengar! In this context, the editor was reminded of an observation by Mr. Sushil Ganguly that his brother did not make any big money for himself exploiting the outcomes of his earlier research. But some of his ideas sown into the minds of his students did that in many cases, which talks volumes for the vision of Ganguly.

One of his students Dr. M. V. M. Desai narrates about the lessons Dr. Ganguly taught him on how to go about selecting a topic of scientific research. He suggested that before embarking on a topic for research, one should ask himself questions on the subject of research (**what?**), relevance of the subject (**why?**), methodology to adopt (**which?**), the environment or site relevant to

the research (**where?**), and the time frame (**when?**). This became the famous "5 W's for research" which every student of science, for all time to come, should keep in mind. He further advised that every rule may have an exception and this exception opens up the path ahead for important research - a point worth noting for every research guide.

In his early research on soil chemistry in the Calcutta University, Dr. Ganguly found that many elements in the soil showed higher sorption and lower desorption indicating the retention of elements in the soil. This was attributed to humic acids of the soil. He had a fascination for this topic and was anxious to take up these studies further and apply it to the fate of the radionuclides in the effluents in sea water. He had allotted the research topic to Mr. T. N. V. Pillai and Mr. M. V. M. Desai and guided them personally for carrying out laborious work of separating humic acid to study organo-metallic interactions and showed that these are responsible for the fate of radionuclides in the environment. Dr. Ganguly set up a special chemistry laboratory to carry out this work in the First Floor of Modular Laboratories, adjacent to his office Chembur so that he can pop into the lab and work for himself, which he often used to do. Dr. Ganguly would daily arrive at the lab around 8 AM and work there till 10 AM before going to his cabin to take care of his responsibilities as Head, Health Physics Division. He would then return to the lab after 6 PM to take stock of the results of the day's assignments given to Mr. T. N. V. Pillai and his group. He used to tell anyone coming to see him for some official work while he was working in the lab, that the time beyond 6 PM is his personal time devoted only to research, and that they should go to him any time between 10 AM and 6 PM for official work. This work in the lab would go on till 9 pm. Even Sundays was not an exception. One or other of his students would be at his residence from 9 AM to 1 PM discussing their results, correcting the drafts of their theses and research papers and planning further work (see Annexure 1).

Like all fine experimentalists, Dr. Ganguly had an extraordinary ability in assessing the data generated. An anecdote from N B Nair illustrates the rare qualities of a scientist and teacher in him. Once in 1962 Nair analyzed gamma spectrum from an air sample that showed some peaks, indicating the presence of a nuclide which he was suspecting. With weak signals and using crude methods available in those days, he was excited to notice the characteristic peak. He took it to Dr. Ganguly to discuss. Dr. Ganguly poured over the spectrum turning this side and that side and asked him if he had rubbed off a few points. Nair answered in the affirmative and added they were probably due to electronic noise. Dr. Ganguly looked at Nair curiously and asked with

love and concern (definitely not with scorn and contempt), "You want to become an Artist or a Scientist?" And advised him to put those points back and added "Let them lie on your graph; never ignore an experimental point".

He was quite at home guiding students not only in Chemistry, but also in other subjects like Physics, Oceanography, Marine Biology, Mathematical Physics. He mooted many ideas in these fields, which resulted in pioneering work by his students. One instance is the application of solar algae ponds for sludge treatment for removal of pathogens and solar energy conversion. Another piece of his work was a mathematical one, initiated in the very early days to analytically arrive at the temperature distribution in radioactive solids. Some of his early students used to whisper that he may have multiple PhDs in Chemistry and Physics as well. He was a research guide of the Bombay University in (Physical) Chemistry since 1958. With all his bonafides, when he applied for being a research guide in Physics in Bombay University, it was denied! This was reportedly due to someone from the Physics community in Board of Studies of the University objecting to this, since Dr. Ganguly had a D.Sc. in Chemistry (!). This was despite of Ganguly's competence and publications in Physics. I became aware of this in 1966, when I wanted to register under him for PhD in Physics. Dr. Ganguly asked me to wait pending his application for registration as a guide in Physics of Bombay University. He was sphinx-like in dealing with this matter and told me with nonchalance to get a registration form from Gujarat University for registration. I did PhD in Fission Physics in 1971 at Gujarat University with him as my Guide and it led to a number of publications in the Physical Review and other international journals. Many of his 'physics' students followed thereafter. This illustrates how he weathered some of the mundane personal rivalries that he faced during his career. The lessons Dr. Ganguly taught me in my close association with him were useful when I had to face similar situations later. One of my students had a rough time getting his thesis formally forwarded by his boss, though I was the research guide, I had painstakingly corrected and approved that. Dr. Ganguly on the other hand was never bothered when some of his close associates were registered under someone else for their degrees and he was not at ease when he had to act as proxy guide in a few cases. As a teacher he was innovative and there were numerous occasions when he suggested solutions to the problems faced by his student even if it is not in his own area of expertise.

Dr. Ganguly used to point out to his students, how fortunate they are in BARC, which provided all avenues for academic growth with no restriction of resources for research. He used to mention that during his own research

days in Calcutta University, they had only 2 grams of ion exchange resin for their studies. At the end of the experiment, the resin had to be regenerated and would go back to Prof. Mukherjee to be kept locked for use by the next student. Dr. Ganguly had abundant skill to overcome hurdles in the research assignments of his students. One of the examples is how he suggested to me to use a movie camera to record counting of signals in a "Dekatron scaler" to study the decay of fission products in sub-second decay times to overcome the non-availability of suitable fast recording devices in 1962. The results of decay of fission products at less than a second, thus obtained for the first time by this innovation, led to it being presented at the III Geneva Conference in 1965.

Dr. Ganguly used to mention about his teacher Prof. S. K. Mukherjee in Calcutta University and describe him as the perfect gentleman and teacher. He himself was an embodiment of some of those virtues he ascribed to his teacher. One would have seldom seen him chiding, if one of his students is on the wrong path. He always bought home the mistake to his students by suggesting alternate methods and used make them realize their follies, which invariably left a lasting impression in the minds of many of his students.

Dr. Gopinath mentions that Doctor's advice to anyone approaching for a change of subject for research was that one can find interesting research problems in any scientific field including the area he is working and should continue to work there and surely would find interesting problems. But when Gopinath persisted, he relented and brought him under his umbrella. Dr. Gopinath in his memoirs brings out this characteristic of Dr. Ganguly. "Dr. Ganguly was a teacher par excellence. It is not that he was solving our problems, he was more interested in developing our ability to solve our problems, what endeared him most to his students is that we could always share with him our excitement and concern. He would listen to us with genuine interest, discern the little substance amid a lot of chaff and nurture the substance".

He was approachable to his students at any time. I have never seen him remarking "I am busy". If he had some urgent commitments for some meeting, he will briefly listen to his students and quickly give a remark and ask them to meet after 6 PM. The first experience of P. K. Sarkar illustrates this. Soon after joining, Sarkar wanted to meet the Head of the Division and was told by the APO, "You are new, so I must inform you, in BARC, a scientific assistant cannot hope to meet the Division Head just like that." After a few moments, he mumbled, "But then Doctor is different!" And Sarkar says he was different indeed! Later on when he approached Dr. Ganguly to take his advice on leaving BARC and joining a prestigious management course, he told him "If you are

very keen in doing research, as you claimed, then BARC would the most suitable place for you. You do not have a M.Sc. degree, but still you can do research, can do your M.Sc. and PhD." He looked up to Sarkar, who mumbled "I would love to get involved in research activities; but then what are the prospects here? Can I do my M.Sc. and Ph.D. while working here?" Dr. Ganguly replied, "Yes, you can in principle. But then you have to work very hard, not, hardly." His sense of humor was showing up, says Sarkar. When Sarkar responded that he will do his best, Dr. Ganguly replied "Let me see whether your best is good enough". He added with a smile, "If you are hardworking and sincere, you may even occupy this chair one day". He pointed at the chair he was sitting on. That was indeed a providential statement with premonition, since Mr. Sarkar did become Dr. Sarkar, and was also elevated to the post of Head of Health Physics Division later in 2008. Not only that, Sarkar did occupy the very same room and chair! The editor also nostalgically remembers his own exhilarating and emotional experience in 1987 in sitting on the same chair on which Doctor once sat and inspired him in creating an academic atmosphere as much as he could in his responsibilities. This would have been virtually impossible at any time for anyone joining as a scientific assistant in any other Division of BARC, more particularly so today. That sums up Dr. Ganguly the teacher!

When Dr. Sarkar came up with a conceptual design of a neutron spectrometer involving four different thicknesses of plastic scintillators, he needed extensive support from theoretical simulations involving computations based on condensed random walk techniques, of which Dr. Sarkar initially had no idea except that it was a highly computer intensive work and is very much different from the normal random walk used in Monte Carlo simulations. When he informed working on the problem to Dr. Ganguly, who had his tryst with Monte Carlo methods in his Notre Dame days, he was told, "Go, and find out yourself who can help you. There must be someone in some corner of BARC, hidden behind his desk, doing this type of work!"

Sensing strong criticism of Monte Carlo methods from his seniors, once Dr. Sarkar went to Doctor and asked him whether he should change his subject for his thesis. Doctor retorted: "No, you shouldn't; criticisms should motivate you to do better". Then after a pause, he told, "If you are not convinced about the advantages of Monte Carlo, read more and convince yourself. Then go ahead and try to eliminate the drawbacks". Dr. Sarkar following Dr. Ganguly's advice started reading research papers, textbooks and articles and discussed with his colleagues and Dr. Ganguly to seek clarifications and finally started working on Monte Carlo variance reducing techniques and made significant international contributions.

Pushparaja who was a health physicist attached to the Radiological Labs shares his reminiscences how he came to be registered for his PhD under Dr Ganguly. Soman was not keen on his registering for PhD from someone outside the Division and so he approached Dr Ganguly and apprised him of the situation. Dr Ganguly who knew his work at once told him to fill up the form for registration under him. He worked on problems on hafnium and zinc chemistry and got his PhD in 1977.

There were occasions when Dr. Ganguly got so engrossed in some points being discussed that he was blissfully unaware of somebody else waiting for him at his chamber door. If he were a senior person, he would go away with the impression that he has been ignored. But Dr. Ganguly would not allow himself to be distracted during his discussion with his students.

One of the entrants to the health physics profession during the sunset years of Dr. Ganguly was Y. S. Mayya, a theoretician who was harnessed by K S V Nambi to work on epidemiology in the post-Ganguly era. He was kind enough to share with me how the activities were started by late Dr. Nambi, a product of Ganguly School, in post-Ganguly era. Dr. Mayya divulged to me that he interacted with Dr. Ganguly twice. The last interaction was to discuss a model of columnar ionization, which Dr. Mayya was developing for alpha rays and he wanted to know from Dr. Ganguly about his 1956 spur propagation model with Magee. The teacher in Dr. Ganguly at once inspired Mayya to read S. Chandrasekhar's 1943 classic on stochastic phenomena. Mayya says that this became his life-long passion and he teaches it in IIT, Bombay even today. The editor made a remark that Mayya's tryst with Ganguly was somewhat late, otherwise Ganguly would have started another school with Mayya, coaxing him to put together the loose strings of his work on radiation chemistry in Notre Dame.

Dr. Ganguly had once severe problems with his already poor eyesight. After cataract surgery he suffered retinal detachment in 1969. There was no treatment available in India at that time. And preparatory to his being arranged to be sent to UK for laser surgery, he was blind folded and confined to a special room in BARC hospital ward for about a month with strict instructions that he should not be disturbed, from Mr. Sethna, the then Chairman AEC. The BARC hospital was located at the two leased floors of the JJ Hospital in Mumbai. I was working for my degree in fission physics with him and running several computer programs in the CDC 3600 computer at TIFR. He was anxious to see how the results looked like. And once he asked me to bring the results to the hospital. I was hesitating to go, as he was not to be disturbed in his medical advice of rest, but he sent persistent messages and I finally went to the hospital with my latest results to the consternation of many. I was deeply moved and

tears came to my eyes when he asked me to hold his forefinger and pass it on the plotted graph. And when he realized that our Order Disorder Model on fission had reproduced the asymmetry in fission, he was overwhelmed with joy. His treatment in UK was successful. He returned and resumed his duties and continued to guide his students, his foremost obsession. He was a chain smoker prior to this episode but stopped it overnight, a remarkable achievement demonstrating his firm determination. Toward the end of his life, the tobacco did take a toll of his lungs and he required an oxygen cylinder to ease his breathing. Even under that condition, he used to call his students and discussed science with them! Finally, his weak lungs gave way and he lost the fight yielding to the ultimate destiny at his 70th year.

The confidence he placed on his students was enormous. Our foray into research on physics of fission products led to very useful applications for AEET/BARC. Noticing the high energy gamma emissions from fission products at short times of decay, we had hooked up an activation method to analyze the enrichment of uranium in samples. The amount of sample required was only milligram range, and the time required was only a few minutes for this method. Thus, we had standardized a quick activation method to analyze uranium enrichment in samples and established 2 per cent precision with few mg of the sample. Fortuitously when this was ready and we were looking for applications, the Trombay Advisory Committee discussed the immediate requirement of analyzing large number of reprocessed depleted uranium samples, which were required to be fabricated as fuel pins for initial loading in RAPS reactor core for flux flattening. Dr. Ganguly lost no opportunity to announce our method and volunteered to carry out this. When in a short time he produced the results in some 80 samples, some doubts were raised by some members of TC. Dr. Ganguly confidentially asked them to send a few samples to France to carry out mass spectrometric analyses. When the results came out, there were a few discrepancies. Dr. Ganguly reviewed the results and was confident about our results and declared that the results produced by his students are the correct ones and that the mistake could be at the French end, which raised many an eyebrow. The samples were again sent to France for analysis and the results proved our measurements correct. Mr. Sinha from the Nuclear Fuel Complex, who was the ultimate user of the results, later commended me for the confidence Dr. Ganguly had in me. But true to his typical style, Dr. Ganguly did not elaborate much to me on this episode. This incidence also illustrated the statement made earlier "when somebody was looking for some result or information for application in the atomic energy program, he could turn to Dr. Ganguly to provide the necessary experts".

1.9 GANGULY, THE SCIENTIST

There was something rare in the personality of Dr. Ganguly, which enthused people around him to start thinking on scientific ideas sown by him. His tryst with radiation chemistry at University of Notre Dame and his earlier research at Calcutta University on ion exchange in soils reveal his inborn scientific acumen. He was known for his achievements in Radiation Chemistry and was the originator of Ganguly-Magee theory. When he decided to take up the offer of employment in AEET, what Radiation Chemistry lost, turned out to be the gain for Environmental Chemistry. He had great fascination of some of the basic ideas in chemistry and physics. From the beginning, he was fascinated by the asymmetry in fission and eager to find an explanation. Other areas that bothered him were photochemistry and radiation chemistry and he looked forward to apply some of these principles for uranium enrichment. He was also keen to apply some basic tenets in chemistry to nuclear physics. The ideas sown by him have borne rich fruits.

His role as environmentalist led him to starting research on some basic concepts in chemistry. Many of his works such as on organo-metallic interactions came out of his curiosity to do research on the fate of radionuclides in the environment. His great ability to innovate in any area of science was well known. And his ideas came on the field and off the field. Many of his scientific ideas came in social gatherings and even during commuting after work along with his students daily. It seems he was thinking and breathing science all the time. Many of these are brought out in the reminiscences of his students narrated elsewhere in this compendium.

The list of the disciplines he embarked upon will not be complete without mentioning his contributions to the understanding of the Uranium-235 laser enrichment technology. Many in the present generation may not know that Dr. Ganguly initiated preliminary studies on laser separation of U-235 in BARC as early as 1972. Still fewer would be aware that Dr. Ganguly got this idea based on his own work on radiation chemistry in Notre Dame. He had been discussing with many of us since the sixties on the possibility of selectively knocking out U-235 atoms from uranium matrix, in a manner similar to how molecules from compounds are separated by using radiation, if only such selective higher energy radiation sources are available. This was at a time when tunable lasers had not arrived on the scene and people elsewhere had only started thinking of this possibility. Dr. Ganguly persisted on this idea, and when he was made Director of Chemical Group of BARC in 1972, he got an opportunity to initiate work on this. Dr. Ramakoteswara Rao, who was working

in the Spectroscopy Division, went to meet Dr. Ganguly with proposals for new projects, as revealed to the editor in 2008 to share his reminiscences of Dr. Ganguly. One of the topics proposed by Dr. Rao was for studying selective absorption of molecules to radiation. This led to Dr. Ganguly forming a Section with Rao as the coordinator in his Chemical Group drawing experts from many disciplines in the Group – Spectroscopy, Laser, Chemistry, etc. and he set up a laboratory in the basement of Mod. Lab. The idea for the investigations on laser enrichment was thus sown in 1972 and the MDRS was formed in 1974, the first experiments started in 1977, and the first results of the investigations were achieved in 1988. By that time, seeing the success of the venture, the activity was transferred to the Physics Group. Meanwhile, Dr. Ganguly had retired by 1978 and passed away in 1988. Perhaps, Dr. Ganguly might have heard about the success of his laser enrichment concept initiative from Dr. Ramakoteswara Rao who was also a resident of Saras Baug, where Dr. Ganguly spent his last days. Many parameters required to start a laser enrichment plant were established by those early pioneering studies.

1.10 THE PERSONALITY OF GANGULY

Trying to capture and present the overwhelming personality of Dr. Ganguly will be a daunting task, and as editor, I have opted to paint the broad-brush picture here. Naturally, this may not be exhaustive; but taken along with memoirs recorded in Part II, and the contents of Annexures in this Volume, one is certain to be left with an immense impression of Dr. Ganguly's overall personality.

The editor had noted the crucial ability of Dr. Ganguly to steer around thorny issues. Once an IAEA Safeguards team had come over to BARC to iron out a joint project on isotopic correlation. The discussions could have involved giving out some data on the details of operations. The editor, who was asked to take down notes for preparing minutes, saw how Dr. Ganguly maneuvered around by stressing the need for taking care of some lesser issues before embarking on such a project.

Once when Dr. Ganguly wrote a strong note on some unsafe conditions, which might affect the environment, the Chairman, Dr. Sethna was upset and confronted him asking "how many people have died." Dr. Ganguly retorted "look, should we wait till that happens?" - A bold rejoinder, not commonly heard of and that too in an interaction with Dr. Sethna! Another quality I experienced from my close association with him was his perseverance and ability to veer around obstacles. He invariably found an alternate avenue, if proceeding further was not possible on any issues due to extraneous factors.

Dr. Ganguly was never satisfied with the work of his students and was always impatient to spur them to perform further work and scale greater heights.

Dr. Ganguly used to project his people and made them present the highlights of their contributions to the higher ups, something unique to science managers. He used to project his people to seniors. This was his way of training the staff for managerial positions. P. Abraham, K. C. Pillai, V. K. Gupta all have reiterated this feature of their experience with Dr. Ganguly.

In the absence of Dr. Ganguly, once Gopinath had to participate in the meeting of the Steering committee of RRC Kalpakkam, and forcefully presented his plans for a comprehensive health and safety operations similar to what Dr. Ganguly had done in Trombay and got it through. Later this led Dr. Sarabhai to remark to Ganguly "you have a fanatic follower in Dr. Gopinath".

Mr. Somasundaram, who was one of the earliest operational health physicists brought up by Dr. Ganguly, remembers in his role as the Secretary of the Plutonium Plant (PP) Safety Committee that Dr. Ganguly used to inspect the plant often and suggest many safety features. Full rapport between Dr. Ganguly and Mr. N Srinivasan was instrumental in evolving and implementing radiation and nuclear safety features of the PP.

Mr. Abraham notes that "The role of Health Physics was redefined, by Dr. Ganguly, to include the safety of the Station, the personnel, the public and the environment, instead of limiting it to radiation hazards control for the personnel in the Station" and this approach was quite unique to India. This was mainly due to his concern for the environment and his involvement with controlling the environment. The personal involvement of Dr. Ganguly went a long way to sort out the teething problems of radiation safety at TAPS. Once when he was out of station, Mr. Abraham was asked to be present in the meeting. Very hot discussions reportedly took place between Dr. Sarabhai and Dr. Sethna, who insisted that the reactors should be shut down for safety reasons. At the meeting, Mr. Abraham was asked by Dr. Sethna to prepare the minutes of the meeting. He was taken by surprise, as he was not aware that this responsibility will fall on him, and so he had not scribbled notes of the proceedings. However, as instructed, the minutes were prepared and circulated later. Dr. Ganguly appreciated the drafting of the minutes. This was one of several such instances used by Dr. Ganguly to project his junior colleagues to the higher ups, and train his personnel in the management responsibilities.

Kotrappa pursued his PhD in USA with the support of Dr. Ganguly. After completion of his degree and a year of post-doctoral stint, Kotrappa informed his professor that he is returning to India. The professor asked him why he was firm on his decision disregarding the offer for a lucrative post in the US University. The reason Kotrappa gave was the "Director with whom I intend to work in BARC in India wants me to return and work in India. I just cannot refuse. He is like a magnet to me".

S. Krishnamony, who was chosen by Dr. Ganguly along with Kotrappa to oversee the health physics operations in back-end nuclear fuel cycle facilities, summarizes in his memoirs the outstanding characteristics of Dr. Ganguly that changed the face of the health physics profession in BARC and how he commanded respect. Dr. Kotrappa too quotes several anecdotes to support this in Part II. Mr. Krishnamony summarizes the personality of Dr. Ganguly and brings out why he was so respected in his times thus:

- Robustly independent mind and never hesitated to express his firm conviction on safety matters even if these have to be expressed against the top management.
- Abundant sense of humor which "he used to disarm his opponents in meetings"
- Firm sense of conviction that eventually proved his judgment to be correct
- Consideration and respect for the views of his students and co-workers
- Person without pretensions with no inhibition to consult anyone openly including his subordinates on topics in which they may have acquired greater experience.

Gopinath, one of the more successful students of Dr. Ganguly, who became Director of Health and Safety Group in IGCAR, and later on Director of Health, Safety and Environment Group in BARC, has underlined Dr. Ganguly's ability to defuse tense situations in meetings using his sense of humor. Krishnamony too adds that Dr. Ganguly disarmed those who opposed him at safety committee meetings with his deep sense of humor. Once the problem due to stray cattle inside the PP complex came up for discussion in the PP Safety Committee. The Plant superintendent, to belittle the problem asked Dr. Ganguly "how many cows you think there are in BARC" and prompt came the reply "5000 plus". Everybody laughed but the joke went over the head of the questioner. He persisted that it is not easy to stop them. Dr. Ganguly responded "do not tell me that the cows are smarter than you" and that settled the discussion.

But he came down with a stern hand, when anyone tries to undermine the role of his people. Krishnamony narrates an incident when the CIRUS Reactor

Superintendent issued a circular to make the heath physicists report to him. Dr. Ganguly made a note on the minutes that read "Who is he? I do not agree" and forced a meeting with Mr. Surya Rao, the head of Reactor Operations and others involved, and bluntly asked "Since when have you decided to take over the Health Physics Division?" This led to the withdrawal of the circular.

Dr. Ganguly had prescribed the limit of discharge from PP as 1 curie Sr-90 equivalent on the basis of radio toxicity of all other radionuclides in the effluent. Mr. Krishnamony mentions that Dr. Sethna, who was in charge of Plutonium Plant operations at that time, was not very happy with the assumptions and at the same time Dr. Ganguly was not happy that effluents were to be discharged off the shore of Trombay bay through a pipeline. Dr. Sethna asserted that his effluents will be so clear that one can drink it, notes Mr. Krishnamony. Dr. Ganguly stood his ground and added that "you stick to yours and I stick to mine". Mr. Krishnamony notes that when the plant went into operation the concentrations in the effluent were higher than anticipated and it was not even possible to meet the specified discharge limit. These ultimately led to Dr. Sethna admitting that "we have goofed and let us face it", and Dr. Ganguly was proved right.

As Chairman of the DAE-SRC formed to initiate regulatory activities, he had shown astonishing independence on matters of safety and all were compelled to listen and respect him on account of his stature and lack of bitterness in his style of functioning. *He focused on issues and not on personalities no matter who were involved.*

Dr. Ganguly was an integrator of disciplines as everyone who has worked with him would testify. The dimensions to the vast field of his activities show no limits. Krishnamony was surprised to see the name of Dr. Ganguly after his retirement as the Chairman of a Committee of Sri Sathya Sai Baba Organization in Mumbai.

Dr. Ganguly's sense of empathy is also highlighted by many in their memoirs. One of the staff members, who was sent for training on special assignment in Germany, returned prematurely without getting prior permission, which is a grave act of omission at any time. When he reported for work in BARC his immediate supervisors castigated him and threatened him with dire consequences and made him almost break down. When he eventually presented himself before Dr. Ganguly, he was highly nervous about his future. Dr. Ganguly, in his characteristic manner, never uttered a word about his dereliction of duty but inquired sympathetically about his health and personal

problems and this made the concerned person leave the cabin again weeping, this time highly repenting his action.

Dr. Ganguly was concerned about the welfare and safety of all his associates. He was very unhappy about his close associates riding two wheelers. Once K. N. Kirthi and P. K. Sarkar went to his residence riding on a scooter to discuss the draft of a paper. When he learned that they had traveled by a scooter, he warned them not to repeat such adventures. I had a similar experience when Dr. Ganguly came to know that I had purchased a scooter and was commuting to office on that. He was so upset that he admonished me and stopped talking to me for a week. He was more concerned about my safety, much more concerned than even my family members. The narrations can thus continue on and on further. As cited at the beginning of this Section, the editor has tried to only give a broad spectrum of anecdotes to present the human side of Dr. Ganguly.

1.11 DR. GANGULY AND HIS ROLE IN BRINGING UP PROFESSIONAL ASSOCIATIONS

In 1968, a group from the Health Physics Division and the Division for Radiological Protection of Bhabha Atomic Research Centre initiated a proposal to set up a professional association to promote safety in the manifold uses of ionizing radiations in the country. After extensive discussions, the draft constitution was adopted in 1969 and the Indian Association for Radiation Protection (IARP) was registered as a public trust, under the Bombay Public Trusts Act. The Association had a total membership of about 300 specialists from different parts of the country. It was at first managed by an Executive Committee headed by Dr. A. R Gopal-Ayengar, the internationally renowned radiation biologist, as the first President of the Association. Dr. A. K. Ganguly succeeded him next. The First Annual Conference of IARP on Radiation Protection was held in Bombay in March 1973. Ever since, the association has been conducting annual conferences and now holds bi-annual national/ international conferences at various locations in India. IARP has decided to hold events to commemorate the birth centenary of Dr. Ganguly in January 2018.

IARP was affiliated to the International Radiation Protection Association (IRPA) in 1970 and gradually made its footprint on the international arena. The First Topical Meeting was held in Bombay in 1974 on the theme "Siting of Nuclear Installations" in which Dr. Ganguly had done yeoman work and established the basic standards from environmental and radiation safety aspects. The First Asian Regional Congress on Radiation Protection was held in Bombay, December, 1974.

IARP instituted "Dr. A. K. Ganguly Felicitation Prize" in 1986. Later after the demise of Dr. Ganguly it has instituted another award as Dr. A. K. Ganguly Memorial Lecture Awards. Many of his students have been honored with this Award by IARP. IARP held a conference on "Lessons for environmental risks from nuclear industry" in June 1976. The association started bringing out a journal Bulletin of Radiation Protection which has now graduated into a world class International Journal, Radiation Protection and Environment (RPE). RPE publication is web-based with online submission and processing of research papers, including peer review. This Dr A K Ganguly Birth Centenary compendium of memoirs is being brought out as a special issue of RPE by IARP.

Dr. Ganguly took interest in environmental safety and he supported and patronized the formation of the Society for Clean Environment, SOCLEEN which was formed by a group of environmental scientists of BARC in the seventies which fought the chemical pollution in Chembur area which was widespread in those days. The association as a non-governmental organization was instrumental for bringing down the pollution around the various chemical factories in Chamber area. They imaginatively spread public awareness by putting up banners which announced that "You are entering gas chamber of Chembur" when the pollution level in the chemical factories in the area became unbearable. Many veterans like Mr. Saranathan and Dr. Mahadevan had devoted their career in the service of this society.

Dr. Ganguly was responsible for the formation of the Indian Society for Radiation Physics (ISRP). As a matter of fact, he along with Dr. Gopinath coined the term "Radiation Physics" as has been described in these memoirs. Dr. Gopinath observes: An area which stands out as a monument to Dr. Ganguly's foresight and scientific pursuits is radiation physics. By mid 60s chemical and biological aspects of interaction of ionizing radiation with matter had developed as independent and active disciplines as radiation chemistry and radiation biology. However, study of the physical aspects in this area was still quite diffused. Different topics of radiation physics were being studied as supports to various other disciplines. Dr. Ganguly could clearly discern the need for and immense potential of developing radiation physics as a distinct discipline. Thanks to his foresight and initiative, Radiation Physics stands out today as a vibrant and active discipline. It was due to his incessant encouragement and guidance that the Indian Society for Radiation Physics took its birth in 1976 at Mysore. The exercise was so successful that it led to the formation of International Radiation Physics Society in 1985 at Ferrara in Italy. This is one of the rare instances where a scientific discipline which took a formal shape in India has firmly established itself in the international

arena. The new discipline took root further with Dr. Gopinath pursuing it and for many years. A Post Graduate course in Radiation Physics was offered in Mangalore University and Mysore University.

1.12 EPILOGUE

The Ganguly Birth Centenary Compendium is a collection of the memoirs of his students and co-workers. The volume contains the evolution of the numerous activities in several streams initiated by Dr. Ganguly, a hallmark of the Ganguly era. The logical continuation of the various investigations started by him, which is carried forward by his students in the post-Ganguly era, is also covered in this compendium to the extent possible. The editor hopes that this compendium will serve as a standing monument to the great personality of Dr. Ganguly and act as stimulant for scientific growth, scientific spirit and investigational zeal. Further, it is hoped to serve as a narration of the historical growth of the health physics profession in the country for the present generation, who may not have entered the profession when the great master was around. People who came into direct contact with him have all retired by now. The first attempts at chronicling the Ganguly era started in 2008 but success was partial. Thanks to this earlier attempt, it was possible to include a few memoirs of people who are now no more. When the Ganguly centenary year was around the corner, the editor decided to resume the attempt and sought the sponsorship of IARP in bringing out the volume. The enthusiastic support from many of the actors in the Ganguly era in making available their memoirs, in spite of some of them being in advanced age, is acknowledged. The editor in some cases had to record their interview, transcribe it and read to them to get it edited. In some cases, even that was not possible, since time had taken its toll! Many loose ends had to be tied up due to these factors.

The most gratifying aspect of this exercise is that we have this Volume now, as a professional homage paid to the memory of one of the greatest early pioneers who has left his imprint on the programs of the DAE through his seminal contributions in creating and fostering the health physics and environmental sciences and who won the respect of his contemporaries not just in India, but among the global community too. If this generates an awareness among the present leaders in this field about its glorious past and encourages them to follow in the footprints left by the Master, it would have eminently served the purpose.

A POETIC TRIBUTE: MY TEACHER

**(From Bouquet and Garlands,
by M R Iyer, Authors Press, New Delhi, 2007)**

My teacher was a noble soul
Who toiled in bringing out well
The best even in mediocre band
Students like fertilizing barren land

The ideas he gave bore fruits
Which he gave unselfishly
Make me realize follies
And guide me to right solution

He never fired students
But made them realize their follies
By being gentle and pleasant
Giving alternate line of thought

"Find one reason why it can be done
Rather than see hundred reasons not to do"
So goes his advice magic wand
Which makes me a thing done

PART II

Collection of Memoirs on evolution of various streams

2. INTRODUCTORY REMARKS

M R Iyer

2.1 Environmental Studies

- 2.1.1 K C Pillai, S Somasundaram
- 2.1.2 M V M Desai
- 2.1.3 M R Iyer, KC Pillai, LV Krishnan, R P Gurg, M A R Iyengar, P. M. Ravi, M P Rajan, V Shirvaikar
- 2.1.4 M R Iyer, K C Pillai
- 2.1.5 M A R Iyengar, A C Paul
- 2.1.6 K V K Nair

2. INTRODUCTORY REMARKS – A PEN PORTRAIT OF THE SETTINGS IN WHICH THE PROGRAM EVOLVED AND A PREAMBLE TO THE GREAT EVOLUTION.

M R Iyer

Part II contains the memoirs of those who had the benefit of working with Dr. Ganguly. Each memoir is a self-contained part and could have repetitions since they are the individual perspectives of different persons of their reminiscences, may be on the same aspects and reflects their impressions on the evolution of various topics. The editor has only edited it to make these contiguous and after editing got the concurrence in most cases. The views and opinion expressed therein are purely that of the contributors as also the authenticity of the events. In some cases I had to audio record their reminiscences, transcribe it and get their concurrence. A few memoirs were secured by me years back in my first attempt to bring out a volume on Dr. Ganguly. In a few cases my quest has led to blind ends since the persons concerned are no more. I have in some cases tried to fill up the blanks by referring to relevant publications, from my own memory and with the help of my friends. The DAE publication "50 years of Atomic Energy", published in 1995 has been useful in connecting the events. The memoirs cover not only the developments connected with activities initiated by Dr. Ganguly but also how his students carried it further, in order not to lose the opportunity of

recording history of evolution of the science of Health Physics in India. The editor thanks L V Krishnan and N Ramamoorthy for going through the edited versions and moderating these.

It would be appropriate to briefly describe how the theater of all actions in the Health Physics Division evolved before describing the achievements of the "Ganguly School" just to show that it all started from the scratch with very rudimentary facilities and grew from strength to strength. Health Physics activities in the Tata Institute of Fundamental Research (TIFR) before the formation of the Department of Atomic Energy (DAE), was confined to rudimentary radiation monitoring surveillance for safe handling of the few laboratory standard sources and S D Soman who started his career at the TIFR with Prof. Thosar in 1952 was identified to carry out those tasks. P N Krishnamoorthy, who was carrying out nuclear emulsion techniques for cosmic ray research, was asked to start radiation monitoring services using Kodak film badges. He also evolved the advisory services for radiation protection in industrial and medical use of radiation in the country. Dr. K G Vohra was given the task of carrying out environmental and radioactivity measurements in fall out samples and organized the Air Monitoring Section.

The Trombay premises identified by Dr. Bhabha, nestling between the Trombay hills and the Trombay bay away from the view of the city, was the seat of all these activities with the commissioning of the Indian Rare Earth factory in 1955 and Apsara reactor in 1956. Soon the Department of Atomic Energy was constituted and the research center was named Atomic Energy Establishment Trombay (AEET). Dr. Homi Bhabha was Chairman of AEC, Secretary to DAE and Director of AEET. It was told he took only one rupee as symbolic salary for being the Director AEET. It was at this time Dr. Ganguly arrived on the scene having been selected by Dr. Bhabha to carry out radiation protection in nuclear fuel cycle. Dr. Ganguly was given the task of organizing radiation hazard control (RHC) and waste management in Health Physics Division under the overall control of A S Rao designated as Deputy Chief Scientific Officer (DCSO) who was also in charge of all electronic developments in AEET.

The radiation protection activities in RHC Section started with a handful of personnel including Soman and by 1956-57 a few people were recruited before the launching of the AEET Training school in 1957-58. The Section having about a dozen Research/Scientific Assistants was located at Colaba in old military barrack sheds at the present TIFR building compound. Dr. Bhabha was then in the process of giving shape to his grand vision of TIFR building which was under construction.

All chemistry operations in the HPD were being given shape in two of those sheds by PR Kamath and KC Pillai. A Ramamurthy Jr. was trying to develop electroplating methods for making thin alpha sources for alpha spectrometry. S Somasundaram along with A Ramamurthy Sr. was assisting Dr. Ganguly in organizing hazards control operations and documenting health physics procedures. The physics group consisting of D. V. Gopinath, C M Suntha, D Kotewala and M R Iyer were sharing a portion of the unfinished basement of the TIFR buildings. Dr. Ganguly's office was in the Hot lab which was again under construction. T. Subbaratnam was organizing the initial steps for waste management along with A R Chinoy, A L Mohan, Victor Amalraj and using one of the two rooms in the Hot labs. S Hathwar used to go around collecting radioactive wastes from the chemistry laboratories. Parts of the unfinished basement and ground floor of the multistoried TIFR building under construction were occupied by various other divisions such as Reactor Control, Health Physics Instrumentation along with RHC Section. In another wing a Cockcroft Walton accelerator was in operation along with a noisy diesel generator to power the machine. In the area allotted to RHC Section sitting space was at a premium and we had to play music chairs trying to get the best of the breeze from few pedestal fans. At that time the Chemistry Division and Analytical chemistry division laboratories were located in some rented go-downs at Cadell Road in Prabhadevi in Central Bombay. Radiochemistry and Isotope division were taking shape in the Radiochemistry laboratories shed at Trombay south site, with air-conditioning which was in a better shape. The metallurgy division labs were in the ground floor of the Old Yacht Club building. The Chairman's office was also located in this building. It was also the seat of the DAE offices and is even so today with augmented buildings. The library run by TIFR was in the I floor with wooden flooring overlooking the Gateway of India.

In view of the rapidly increasing activities in AEET, by 1958-59 the HPD laboratories were shifted to the South site in Trombay and located in a relatively large newly constructed shed with cement sheet roofing. This was again a temporary arrangement pending its final destination at the Modular Laboratories and Radiological laboratories in the North site on which construction started by that time. There were two spacious sheds one called electronic shed and another bigger shed called electronics production shed. The first one was used by Health Physics division and the latter was used by Health Physics Instrumentation Division, Electronics Production Division, Reactor Control Division. The labs of Health Physics were moved to this bigger shed in later years to locate Purchase Division. Finally when the Mod

lab construction was completed in 1966 the activities of the Health Physics Division with all the other Divisions were shifted to this building. By that time the architect of this unique 800 meter long 3-storied completely air-conditioned building, Dr. Bhabha had met with an air accident and died in 1965. He had meticulously planned this unique building but could not see it completed. The radiological laboratories were then completed and all laboratories handling radioactivity such as radiochemistry, radio metallurgy and isotope division were all shifted into this complex. The administrative buildings, the office of Director BARC and also Group directors were all housed in the new 8 storied impressive building facing CIR on one side and a beautifully landscaped hill slope garden on the other side with two beautifully architecture high elevation water storage tanks. The construction of this beautiful huge landscaped garden on the side of the Trombay hills was not without the occurrence of an accident in which a few workers died due to earth collapse. This again was investigated by the Industrial Hygiene Section of Health Physics Division. The tanks were in line with the emergency cooling ball tank for CIR. Everything was carried out esthetically as per the blueprint of Dr. Bhabha in a grand style. Some of us have been fortunate to witness the evolution of this site from a chikkoo mango grove which served as hunting ground for the British with an old "Sandow Castle" into a beautifully architected modern site which conceals inside one of the bold and most imaginative programs on atomic energy. Today we can boast of this as perhaps the only Centre which covers not only the activities of the complete nuclear fuel cycle but all of radio isotopes applications in the country. And this was the Centre responsible for graduating the country into a nuclear power. I used to travel in the BEST bus from my apartment some 3 km away in sixties and one of the conductors, when asked for a ticket to Tata Power Station which was neighboring to AEET from the South side used to remark "*Bumb* factory?" Perhaps public were suspecting even at that time that something of that type was going on inside the barricades! By mid-sixties North site of Trombay was equipped with the CIR at one end the Mod Labs in the central, Van de Graaff accelerator at the other end, overlooking Central workshop, the engineering halls, and the Plutonium plant were all neatly in operation. And south site housed comprehensive front end nuclear fuel cycle facilities. It was exciting to see this quick transformation along with the procession of evolution of an array of outstanding scientists which the program produced.

Dr. Bhabha was busy with churning up nuclear facilities in Trombay one after the other which was incomparable to any such activities in the world except perhaps the Manhattan Project, but then that was only one aspect of

atomic energy viz. the weapon applications, but here was a grand scheme encompassing the entire fuel cycle operations. And part of it was his shrewd scheme of building up all these facilities around a 40 MW Canada India reactor the blue print of which was based on the NRX reactor at Chalk River. Thus Dr. Bhabha who was selected to preside over the first Geneva Conference of opening up of atomic energy science and technology to the world under the President Eisenhower's Atom for peace plan in 1955 actually became the only architect who put this into action and that is how the unique Indian center for atomic energy which he coined as AEET synonymous with the such national laboratories in USA such as Argonne national lab, Brookhaven National lab., Los Alamos national labor, Chalk River Laboratories. But AEET was unique that it housed the entire nuclear fuel operations under the same umbrella.

2.1 ENVIRONMENTAL STUDIES

2.1.1 Environmental studies at Trombay

K C Pillai

Dr. Ganguly, the budding environmentalist enlivened Dr. Bhabha's dream of India's sojourn into a nuclear power, in his responsibility of organizing environmental protection and Health Physics in AEET. This also signifies the quick transition of Ganguly the Radiation chemist to Ganguly the environmentalist. Dr. Ganguly initiated several programs beginning in 1957 soon after joining AEET, to lay the foundation for Health Physics science in the country. K C Pillai who joined AEET in 1957 was one of his first students in AEET, whom he selected for some of these key assignments.

2.1.1.1 Water flow studies in Trombay Bay and estimation of dilution factor for setting up the discharge limits.

The study of tidal movement and water renewal rate in Bombay Harbour Bay and in the Thana creek was one of these earliest studies. This study was aimed at analysis of the impact of possible radioactivity releases from the CIR reactor and other nuclear facilities that were being set up at Trombay. As K C Pillai recalls Dr. Ganguly had the knack of bonding himself with the environment under study before evaluating it vis-a-vis impact of pollutants into the environment. So he undertook a good survey of Trombay and environs along with KC Pillai, P R Kamath, I S Bhat, J R Naidu and others to study the nature of the creek and the surrounding areas. AEET was located on the banks of Bombay Harbour Bay facing Elephanta caves which was the beautiful site selected for the upcoming nuclear Centre by Dr. Bhabha. Dr. Ganguly studied the terrain by actually exploring it and one of the things that struck him was that when radioactive effluents at low levels are released to

the marine environment the normal intuition that it will get well diluted with the tidal flow in the sea may not hold good for this terrain since it is a land locked bay with one side opening in the south to the Arabian sea. He refused to be sidelined by taking the figures provided by the designers of the Canada India Reactor instead he embarked upon to study the nature of dilution that this system will offer for any effluent releases form the multifarious nuclear facilities which were being planned for the site by Dr. Bhabha. Dr. Ganguly proceeded to fix the limits of any radioactive discharges so that taking into account the dilution offered by this partially close system it will not give rise to any significant radiation dose to the public. He decided to carry out computations based on large scale field experiments he had planned and schemed. So the tidal movement studies were part of this grand scheme. One need to appreciate such elaborate studies can only be the result of thinking of a visionary, that was Dr. Ganguly. The Trombay bay and Thana creek were connected and so he planned the studies to be carried out at both the locations. And Dr. K C Pillai was the immediate commandant he selected to put into action this grand scheme. This was the genesis of the whole school he created for environmental radioactivity studies which spread its fangs into many areas of investigations with innumerable players and these are chronicled in various sections of this volume. These studies on water movement in Trombay bay resulted in the evaluation of permissible limits for discharge of radioactive effluent into the Bombay Harbour. Later he carried out such studies at the Kota nuclear power reactor site in Rajasthan located in the banks of the Chambal River and Rana Pratap Sagar water body which was the source of the cooling water for the first PHWR power reactor being built up at that site. These studies were also implemented by K C Pillai. He remembers Dr. Ganguly getting directives from Dr. Bhabha to initiate these studies once the site was selected by the Site Selection Committee. The second site at RAPS was the first site to standardize these studies at a fresh water lake site in contrast to Tarapur, a coastal site.

It was realized early that environmental aspects of nuclear power developments will assume significance in the context of the proposed plans for reactor operations and other fuel cycle developments at Trombay site. A series of investigations were initiated to obtain radioactivity background data and physicochemical and biological characteristics of the environment around the Research Centre, for this purpose during early 1958. A number of field trips around the Research Centre were undertaken to get familiarized with the environment. These were the prelude attempts to initiate preoperational studies at nuclear sites in the country.

Maps of west coast of India-Bombay Island & outlying areas, were obtained from the Indian Navy. The bay is a land-locked mass of water connected with the main Arabian Sea in the south and Ulhas River through the Thana creek in the north. The Ulhas River flows mainly into the Arabian Sea through the Bassein creek at the north-western end of Salsette Island and part of it flows through the Thana creek into the bay. The water movement in the bay was observed to be subject to semi-diurnal tides.

In order to estimate various parameters like area of the bay, water volumes, tidal volumes etc., the bay was divided into different areas on a map by drawing lines 1 to 30 beginning from the entrance to the bay to the tip of Thana creek. The soundings data obtained till 1953 from the map were used to draw the cross sections across these lines. The area of the bay, the volume of water and the tidal volumes were estimated from this laborious exercise. Dr. K C Pillai who was carrying out this exercise notes that the low tide level as 4.2 ft. above the datum. The area of the bay was assessed as 83 sq. miles at high tide level and about 63 sq. miles at low tide level. The total volume of water in the bay was calculated as 32E9 cu. ft. The average volume of water flowing past the entrance to the bay in any single tide was calculated as 17E9 cu. ft. (Note the units which were the ones in vogue in those days!)

Tidal flow patterns in the bay were studied and three streams were identified which flow during both high and low tides. The average tidal rise in water level was 0.28 inches per minute. Such slow rate of rise of water could result in pushing back a good part of the existing water into the remote areas of the bay and it was noted that the water in these areas may not be available for mixing with the tidal water. It takes 6 such complete cycles for 90% of the old water to get out of the bay. As a result, the net dilution available during a particular tide will be considerably reduced and during the period of a tidal cycle the dilution factor may lie between 150 and 300.

2.1.1.2 Saw dust experiment

To substantiate these laborious computations Dr. Ganguly designed elaborate field experiments. Preliminary experiments were carried out using fluorescent dye as a tracer to study the dilution patterns in the bay. Since the dye patch faded after some time due to absorption on silt, the tracer could not be followed for long. Later saw dust was tried as a visual tracer. It was also not quite suitable as a visual marker since it was affected by wind. Therefore it was decided to carry out a radio tracer experiment in the bay to study immediate dilution factors and transport of activity in the bay. The study was coded as "Operation Saw dust" (1959) Considering various aspects like irradiation time required, convenient

gamma energy for in situ measurement, half-life, no pick up by silt, low radio toxicity, etc. it was decided to use Na-24 as a tracer for the study. The isotope was prepared by Radiochemistry division by irradiation of sodium carbonate in 1 MW Apsara reactor.

The Radiochemistry - Isotope labs at south site had also a waste hold up tank for diluting and discharging radioactive effluents using hoses into the bay. Dr. Ganguly had prescribed the lines to be put far into the bay beyond low water line. The pipe was extended by 600 ft for discharge of Na-24 activity. The tanks and lines were useful for dissolving the Na-24 activity and making up to the desired concentration and discharging into the sea at the peak of high tide. About 2 Ci of Na-24 activity was discharged into the bay.

The tracer solution was discharged near the low water line between Pir pau and Stanvac jetty for a period of 3 hrs. Waxed saw dust was dumped at the discharge location as a visual marker. The tracing of activity was done by 'in situ' measurements using under water probes at different locations and by measuring the gamma activity of collected samples in the laboratory using gamma spectrometers. The activity at different locations in the bay were expressed in terms of dilution factors.

Sampling was done by several batches each of 3 people moving in dinghies and some in boats. Sextants were used to know the exact location of boats. Practically whole of RHCS section (60 scientists) participated in these experiments. It was from sun rise to sun set and also offered a social occasion as well with snacks being distributed from a supply dingy. I was in one of those dinghies as a junior scientist. I had the satisfying nostalgia of participation and was even part of a team given the job of designing a depth water sampler before the field experiment was undertaken. After several trials a few samplers were fabricated using a lead weight to make an empty bottle sink in the water. Then came the problem of opening the stopper only at the required depth where sample needs to be drawn. For this a stopper attached to a string which was operated from the boat was used. This shallow water sampler was used for sampling of water in the bay.

The hundreds of bottles with the sampled water need to be assessed for activity. S W Kale, an electronics engineer in the HPI division was given this assignment by G H Vaze, Head of the HPI division. The extent of importance Dr. Bhabha had given for the electronics support for Health Physics was evident from the fact that he organized two divisions, one named Health Physics Instrumentation Section and another named Electronics Production section. The other unit that

dealt with electronics instrumentation development for reactor operation was the Reactor Control Division. Dr. Bhabha envisaging the need for indigenously developed instruments for the grandiose atomic energy program foresaw the importance of instrumentation and structured the activities into these divisions. The Electronics Production Section whose mandate was to produce the instruments developed by these divisions for eventual deployment in the program. This last mentioned division was very successful and the numerous instruments produced were popular not only in the Health Physics Division but also in other divisions such as Nuclear Physics for their research work. These evolutions are dealt in another section. As narrated by Kale, Mr. Vaze had ordered some large plastic scintillators which came in handy for this work. A 3" photomultiplier with a machined light guide was coupled to the 4 inch plastic scintillator all machined in the divisional workshop. Along with homemade pre amplifier the scintillation detector housed in a lead shield assembly was hooked up to a counting system. All these instruments, developed in-house were already in production in the Production Section. Hundreds of sample bottles were assessed for activity and manually data acquired.

It was observed that the tracer activity moved about 4-5 miles at the end of the following low tide. The dilution factors obtained were of the order of 10E4 and 10E5. The data was evaluated manually by several people. Somasundaram in his memories narrated elsewhere had tried to develop some model to fit this data. In all these Dr. Ganguly closely scrutinized the data processing and gave suggestions and he would give a feeling of acceptance of our own suggestions as many anecdotes elsewhere in this volume also would vouchsafe. On the basis of the above observations it was tentatively concluded that the limit of fission products released to be 3 Ci per day to achieve a permissible concentration of E-8 uCi/ml.

Further to the above work, a study was planned to evaluate the movement of water through the Thana creek which connects the Bombay Harbor Bay with the Ulhas River. At the Thana creek in low tide, water from Ulhas River enters the bay and at high tide flow is reversed. Sodium chloride present in sea water was used as a tracer to study the mixing processes in the creek. Tidal heights were measured from the center point of the Kalwa Bridge at regular intervals of 15 or 30 minutes using the plumb line. The speed of water flowing under the bridge was determined by using bottle floats. Another tracer experiment using the natural K40 activity was used to estimate the order of diffusion velocities available in the bay. Such home grown innovative ideas being inducted into research in all the topics developed by Dr. Ganguly was a hall mark of the era as narrated by his students elsewhere in the compendium.

These measurements were made during the month of June, July and August to obtain the water movement patterns during pre-monsoon and monsoon periods in 1960. The results indicated that during pre-monsoon period maximum flow from creek to Ulhas river was 3% of tidal water flowing near Trombay shore whereas in Monsoon condition it was only 0.6%. It was concluded that the removal of waste effluents discharged from Trombay by inflow into Ulhas River through Thana creek will be insignificant compared to the removal between the bay and the sea.

In order to assess the capacity of the bay to receive activity, work was initiated to evaluate Maximum permissible concentration (MPC) of different radio nuclides in sea water. Though sea water is not directly consumed, consumption of salt from salt pans using bay waters and fish harvested from the bay could cause radiation exposure to the public. On the basis of the ICRP dose assigned to the population, trace element concentration in fish and salt and consumption figures of these items in Bombay, MPCs were derived.

Dr. Ganguly often used to say "you must know the environment well before you start working on it" and accordingly along with PRK and KCP visited the Bombay Harbor bay in a jeep and walking along the coast, explored Kalyan, Mumbra, Mulund, Bhandup, and Trombay. They also visited many salt pans in the area which might get affected by the effluent released in the laboratories and plants which were coming up in Trombay and AKG was preparing for this. The discussions during these visits were very revealing and once AKG told KCP that "you must study the calcium and trace elements intake through salt". AKG suggested using the specific activity concept for arriving at the maximum permissible radioactivity in sea water. This suggestion later led to the publication of a paper. Dr. Ganguly arranged for a naval boat INS Krishna to go around Bombay Harbor environs to collect water, sediment samples for analysis of radioactivity. The work was the first attempt to derive maximum permissible concentrations of radionuclides in the sea waters of Bombay. On the basis of the above studies it was tentatively concluded that the limit of fission products that could be released into the Trombay bay to be 3 Ci per day so that a permissible concentration of E-8 uCi/ml will not be exceeded.

All the above investigations around the Nuclear Research Centre at Trombay laid the foundation for environmental studies at future nuclear sites. KC Pillai got his MSc in February 1963 having registered in 1961 on the work he had carried out on the 'Radioactive and inactive tracer studies in Bombay Harbour Bay.' The first batch of students of Dr. Ganguly in Trombay were K C Pillai,

A Ramamurthy, T N V Pillai and M R Iyer and they all got their MSc degree on various topics working under Dr. Ganguly between 1963 and 1964.

2.1.1.3 Environmental surveys at Trombay

Dr. Ganguly told the new entrants to the Health Physics Division to go to the library and get involved with collection of literature on various topics as noted by many including Somasundaram, K C Pillai, Kalyanasundaram and others and allotted various topics to each, such as handling hazards of Plutonium, Thorium, etc. He asked KC Pillai to study radiation safety aspects related to fuel reprocessing and to get an idea on those topics by referring to available literature at TIFR library at OYC and AEET library at Cadell Road laboratories. He also suggested KCP to write a manual on handling hazards of plutonium. At that time only Apsara and Indian Rare Earth factory and Radiochemistry Isotope laboratories were in operation at the South Site in Trombay. Not many even knew about the plans by Dr. Bhabha for setting up a fuel reprocessing plant in Trombay. K C Pillai and P R Kamath were asked to visit the IRE plant and study the effluent discharge scheme and analyze the effluent samples. K C Pillai prepared two reports in July 1958 on Pu Handling hazards and IRE effluent analysis. This is how KCP gradually started working on radioactivity analysis in environmental samples and later specialized in Pu analysis. TNV Pillai also started working on environmental radioactivity analysis and prepared a report on handling hazards of thorium. In order to differentiate between the two Pillais KCP and TNVP Dr. Ganguly used to call them as Plutonium Pillai and Thorium Pillai in early days.

As mentioned earlier KCP and PRK were asked to visit the IRE plant and radiochemistry labs and analyze the effluents. KCP took interest to analyze the low levels of Pu, possible in the RC lab effluents since there were labs handling low amounts of plutonium and work was going on standardizing procedures for separation of Pu from irradiated uranium samples in Apsara. These were the earliest Pu chemistry work carried out in radiochemistry labs. And KCP followed it up by looking into the possibility of small amounts of Pu in the effluents. He and KN Kirthi who was the health physicist in RC Labs used to concentrate the effluents and do some preliminary separation and do a gross alpha counting and noticed very small amount of alpha radioactivity in the effluents.

Intense preoperational survey of radioactivity started in 1958 in and around AEET by collecting environmental samples in which KC Pillai, J R Naidu and P R Kamath set the procedures for environmental sampling and analysis which became the practice in the innovative setting up of Environmental survey laboratories later at every nuclear, plant sites in the country. Regular environmental sampling and assessment of possible internal dose to a member

of the public were meticulously analyzed and annual reports produced by the Environmental group organized by Dr. Ganguly. These analyses showed that the dose received by the public very minimal for the population around the Trombay Centre.

KCP remembers some lighter side of these early ventures in environmental sampling. Once during their field trip, they encountered near Uran some people who were preparing illicit liquor and they took the sampling party to be police and were preparing to attack them with weapons Dr. Ganguly was un-nerved and told them they are only scientists trying to collect samples for analysis and not the police. Environmental survey which was started in Trombay was the first environmental survey done in the country and the various procedures established during those days formed the basis for the intense environment radioactivity analysis program around nuclear power plants in the country.

2.1.1.4 KC Pillai's work on plutonium analysis in Scripps Institute

Dr. Ganguly wanted K C Pillai to study latest techniques and methods in analysis of environmental radioactivity and arranged for an IAEA fellowship program for training at the world famous Scripps Institution of Oceanography, University of California, San Diego in May 1963. He also perhaps had in mind to mold Pillai as an expert in environmental Pu analysis, impressed by his collection of reference materials for the preparation of the report earlier on Pu handing hazards.

Dr. Ganguly had chosen Pillai to be trained under the famous scientist Dr. T. R. Folsom on Marine radioactivity. He also attended courses given by the University of California for graduate programs which included, Nuclear Geochemistry and Chemistry of sea water. Pillai started experimental work on analysis of Mn-54, Zn-65 and Cs-137 in sea water and marine organisms. Of these, Zn-65 assumed significance in view of the fact that large quantities of the nuclide enter the Pacific Ocean every day at the mouth of the Columbia River from Hanford. At the Scripps Institution of Oceanography, they had procedures for analysis of low-level of these nuclides in sea water and KCP was given the assignment of analyzing these samples. 200 liters of coastal sea water were collected at Scripps pier in a plastic precipitation tank and transported to the lab using an electric trolley. They were using gamma spectrometry for these analyses after collection of Cs-137 on Ammonium phosphomolybdate. This procedure was further refined by reducing the settling times of AMP by the addition of a flocculating agent like Fe^{+3}. KCP also got opportunity to analyze some of the sea water samples for Cs-137 from areas close to the nuclear submarine accident location.

During this period, Arnold Joseph, Director in US AEC, who was the funding authority for AEC projects, came to Scripps and had discussions with Folsom and inquired about the possibility of initiating work on Pu in marine environment. KCP volunteered to take up the chemistry part of the work and sought support on instrumentation especially alpha spectrometer. Fortunately Dr. R. C. Smith, a Physicist who had wide experience with accelerators, instrumentation, spectrometers, etc., who joined Folsom's group was ready to give support on the instrumentation side. Studies on Plutonium in the marine environment were thus initiated. Thus the tryst with Pu analysis came in his way and he fulfilled the confidence which Dr. Ganguly had on him. He was able to connect his training at Scripps Institute of Oceanography to his very first assignment given by Dr. Ganguly of writing a manual on the handling hazards of Plutonium when he joined AEET 6 years earlier. KCP had his initial experience in analyzing the alpha active effluents at the radiochemistry lab in Trombay by gross alpha counting along with K N Kirthi who was the health physicist at the laboratory. But those analyses were only by gross alpha counting and not specific to Plutonium in the absence of alpha spectrometers.

At that point of time no data on fall out Pu present in the marine environment were available. Though the fall out levels of Pu in air, soils are only about 1% of the levels of Sr-90/Cs-137 it is one of the most toxic elements. Concern over Pu in marine environment had increased since the development of SNAP generators for space vehicles since some of these uses Pu-238 as a source of auxiliary power and in case of a failure the likelihood of this Pu being deposited in the ocean. In fact it was reported in May 1964 during the period of KCP's stay at Scripps, a SNAP using Pu-238 as fuel failed.

The experiments for concentrating Pu from large volumes of sea water were initiated. At this point of time there was a person from Hazelton Nuclear Science Corporation, Palo Alto, California visiting Scripps who was measuring Fallout in air, urine and environmental samples as a USAEC contractor. Folsom suggested KCP to visit his laboratories and see what they are doing for Pu analysis. KCP visited the lab and found they were following Bismuth phosphate precipitation procedure, which was the first procedure followed by Seaborg in his pioneering work for separating plutonium. KCP modified the procedure by adding to the acidified sea water, tracer, phosphoric acid and bismuth nitrate at about 80 deg C in that sequence and beautiful precipitate of Bismuth phosphate which co precipitates plutonium evolved. Pu-236 was used as an in-situ tracer for estimating the yield of Pu separation. The analysis required 45 liters of sea water. In those days the fall out Pu in sea water was much higher than what is today as a result of incessant weapon

testing. Coastal Pacific Ocean water was collected from Scripps jetty. Pu co-precipitated on Bismuth phosphate was isolated through sequential steps of Lanthanum fluoride precipitation and anion exchange. After separation of Pu the sample was electroplated using the method followed by Mitchell, for alpha spectrometry. An alpha spectrometer with high resolution and low background was used for measurement of Pu activity by counting for periods ranging from 100 to 140 hrs. Sea water from off shore locations, deep ocean waters, algae and different trophic level organisms were taken up for estimation of Pu-239 and Pu-238. The concentration factors obtained was highest for plankton and lowest for fish. The ratio of these isotopes were 30 in plankton which was same as in fallout.

During KCPs visit to Woods Hole Oceanographic Institution, Bowen discussed his results on the Atlantic Ocean sediments in which fallout Ce-144 and Pm-147 were detected. He desired to get one core sediment at 3 depths analyzed for Pu at Scripps. Thus KCP started analysis of Pu in sediments. KCP noted that there was no problem about resources for work - Folsom told him "if you want anything, chemicals or whatever, go ahead and get it, funds are no problem". The work done by KCP at Scripps Institution on Pu, during the IAEA Fellowship period, was published in Nature. (K C Pillai, R C Smith and T R Folsom, Nature, Vol 203, 1964)

2.1.1.5 AEET becomes an important international center for Environmental Pu analysis

On KCPs return in 1964 AKG appreciated the pioneering Pu work done by KCP and supported and enabled this work to be continued in Trombay. This, in short was the beginning of the low level Pu analysis work in which the Environmental lab, Health Physics Division, BARC became one of the internationally recognized laboratory for estimation of ultra-trace quantities of Pu in environmental matrices. To start with the need for a multi-channel analyzer was keenly felt to continue this work. Dr. Ganguly arranged for a 100 channel analyzer fabricated by Patwardhan of the Electronics division for use by KCP though it was not very reliable. Incidentally the only multi-channel analyzers available in the Centre was a 100 channel analyzer developed by P N Ramarao for Fission Physics experiments at Apsara and another later developed by Raghupathy in Air Monitoring Section for fall out analyses. Patwardhan in the Electronics division had also made one few of these later. These first MCAs were of valve type using Dekatron tubes. HPD also had a 512 channel imported analyzer procured under the IAEA aided Project Marina which had heavy workload of environmental sample analysis involving long times of counting.

By the end of 1964, Fuel reprocessing plant at Trombay started its operations. This led to further extensive studies on Pu in marine environment of Trombay bay by KCP along with his colleagues Elizabeth Mathew and Vasanthi Matkar. The procedure for Pu analysis and other Transuranics were developed further and refined in Trombay. A sequential radiochemical procedure was developed for estimation of Pu, Am and Cm in marine samples. Accumulation of Pu and Am in organisms and sediments, speciation of Pu in coastal waters, and leachability of Pu in sediments were studied. Pu interactions with organic constituents in sediments and its possible mobilization were studied on a suggestion from Dr. Ganguly. AKG had already initiated studies on organic matter interactions with trace elements with TNV Pillai, MVM Desai and Elizabeth and a whole school resulted on these investigations. AKG organized a separate laboratory for carrying out these investigations in the I Floor of the Modular laboratories, very near his office room. He used to spent lot of time in carrying experiments along with his students in that laboratory. These are covered in separate memoirs.

In later years KCPs group was a regular participant in the inter laboratory comparison exercises conducted by IAEA Monaco laboratory and with V. T. Bowen of Woods Hole oceanographic institution. Later Pu-242 tracer for the analytical methods developed by KCP was made available by USAEC Health and Safety Laboratory, New York, thanks to the personal contacts established by him.

Dr. Ganguly deputed KCP for a conference on Transuranium nuclides in 1975 in San Francisco for presenting his transuranics studies in Trombay. As a member of the IAEA panel of Experts meeting at Vienna for 'Reference Methods for Marine Radioactivity studies' in 1972, KCP contributed a landmark paper on "Determination of Plutonium in the marine environment". On the basis of the work carried out on 'Plutonium in the Marine environment' KCP was awarded PhD degree by University of Bombay. Later as Principal Investigator of an IAEA co-ordinated project on "Transuranics cycling behavior in marine environment" detailed findings obtained on the behavior of transuranics in Bombay Harbor Bay were reported (1979).

KCP went as a participant of an IAEA 'Study tour on Waste management Techniques and Environmental protection which included visits to some nuclear facilities in USSR in 1973. At one of the nuclear facilities during the briefing session, the speaker mentioned that there is someone from Scripps who has done Pu in marine environment and Balu who was along with KCP in the study tour characteristically announced that the man is right here pointing to KCP. Thus KCPs work on Pu in marine environment was highlighted.

At Trombay low level effluents from the Plutonium plant were being discharged initially into shallow bay water and the shore was getting exposed to this. The high and low tide points were quite separated in this part of the Trombay bay and thus during low tide when the shore gets dried up there was a possibility of Pu getting re suspended. Pu in water at low levels is tolerated to a larger extent than airborne Pu which is more of a hazard. Based on the analysis work carried out by KCP the discharge point was suggested to be located at the same location where treated effluents from Centre are discharged. This was accepted and resulted in a single discharge point for the research Centre. Dr. Ganguly deputed KCP to explain the findings to higher ups which was done in a convincing manner. This is an instance of how be projected his students to the higher ups. The issue was convincingly settled.

Work on specialization carried out by KCP on Pu analysis came in handy on many occasions. One such occasion was narrated by KCP. In 1978-79 the Cabinet Scientific committee had expressed concern over the news item that the Americans had planted on the Nanda Devi a device which was powered by a Pu battery. A high level committee was appointed to investigate this under Atma Ram, the Director General of CSIR. The analysis requirement ultimately came down naturally to Dr. Ganguly. AKG sent a message to KCP and Abraham to go to Delhi immediately and they were taken in an air force helicopter to the location from Hindon air base in Delhi. From there they hitch hiked to the river Sarada flowing from Nanda Devi along the Nepal border, the suspected spot where the device was planted. KCP went there and collected water and sediment samples from the river at different points. Back in Trombay with the samples he used his techniques to minutely analyze the samples for any trace of Plutonium. Everyone was anxious to get the result but KCP explained that these analytical procedures for ultra-trace quantities of Pu are lengthy and time consuming. KCP had an occasion to explain to the committee how it is done. However no trace of Pu was found. KCP said that there is no possibility of contamination since this is a power source and Pu used is likely to be in an immobile form.

2.1.1.6 CIR Hazard Evaluation Report

In mid-1959 when the CIR reactor was under construction Dr. Bhabha telephoned from Canada that he wanted immediately a hazard evaluation report before commissioning the reactor. Dr. Ganguly co-ordinated the effort to prepare the report. Since environmental preoperational radioactivity survey and setting up of the limits of discharge of radioactivity was an important feature of this report KCP was involved in the draft preparation. Once AKG wanted KCP to read the draft to him and it was going on into late night and

people were dozing off. S L Kati remembered this incident and recalled it to KCP once. Many other people Shirvaikar, Gopinath, A Gopalakrishnan, Veeraraghavan, and A D Sharma were also involved in the preparation of the report in respect of maximum credible accident analysis. Nobody had any idea about preparing a hazard evaluation report. Many in the Research & Development group were also involved in these computations (as no computers were available in those days) for assessing the impact of any release of radioactivity from the containment into the environment in case of a reactor accident. M R Iyer remembers his spending in AEET for 3 days continuously working on the calculations on Friden electrical calculators along with Gopinath Kalyanasundaram, Shirvaikar and others. The starting of the research on fission products suggested by Dr. Ganguly to M R Iyer which is described elsewhere in these memoirs was actually a result of these exercises. As a result of these efforts organized by Dr. Ganguly, the draft of the hazard evaluation report was sent in due time to Dr. Bhabha in Canada. Actually this was the genesis of preparation of Safety analysis reports for all nuclear plants which became the procedure to be followed in the development of regulatory activities. The editor (MRI) had contacted Mr. S L Kati on phone in March 2017 to share his reminiscences of Dr. Ganguly but was unable to record those due to his indisposition and he passed away in August 2017. He was the first MD of NPCIL.

Dr. Bhabha at the time of evolving the design for CIR had insisted to have a steel containment for the reactor to avoid impact of any radioactivity releases considering the location nearby a metropolis. CIR was constructed on the model of the NRX reactor which had just started operation in Chalk River Canada. And true to his aesthetic sense he arranged to cover the containment with aluminum by Godrej Company. Another change in the specification was that Dr. Bhabha had suggested the use of sea water for secondary cooling, another innovation on which the Canadians had no experience. The NRX used cooling towers. This innovation led to some problems later such as fouling of the coolant by algae which the Canadians could not solve and they left. It was the useful suggestions of Dr. Ganguly, Dr. Shankar and other senior chemists who strived to solve the problem by suggesting various methods.

2.1.1.7 S Somasundaram memoires on Operation Sawdust

Somasundaram recalls that in 1958-59 work on CIR was in progress and AEET had started planning a reprocessing plant for the fuel discharged from CIR (Project Phoenix) along with a uranium metal plant and a fuel fabrication plant for manufacturing of uranium fuel for CIR at Trombay. Thus Trombay was gearing up to become a complete fuel cycle Centre. Dr. Bhabha recommended

that there should be a centralized waste treatment facility for low level liquid radioactive wastes generated in Trombay before discharge into the Bombay Harbor Bay. Much later after the demise of Dr. Bhabha, Dr. Ganguly pursued Dr. Bhabha's concept of single point discharge to overcome some difficulties that were encountered in the operation of the Plutonium Plant and eventually Waste management facilities sprang up in Trombay.

Dr. Bhabha asked Dr. Ganguly to arrive at Maximum permissible activity in the low level liquid radioactivity wastes that can be discharged into the Bombay harbor after treatment that will not lead to any un-acceptable radiation exposure to a member of the public. Somasundaram reminiscences that he accompanied Dr. Ganguly and visited the Indian Naval headquarters in Ballard estate to obtain data on pattern of movement and renewal rates of seawater in Bombay harbor bay from diurnal tides. KC Pillai and Somasundaram accompanied Dr. Ganguly to visit the solar evaporation ponds of salt pans on the eastern shoreline of Mumbai harbor and slushy shoreline of Ulhas river estuary in Thane creek which formed a continuous water body connecting Bombay harbor bay that surrounded the Trombay Island. He organized the collection of data on salt production and discharge of water from Ulhas River into the Bombay Harbor Bay. On this KCP did extensive water movement studies at locations such as Kalwa Bridge and produced the required data.

With Dr. Ganguly's guidance Somasundaram evolved a model on water removal rates in Bombay harbor bay to set the maximum permissible activity from radioactive discharges from AEET. Not satisfied with the collected data alone, Dr. Ganguly wanted to conduct an experiment using Na-24 as tracer. Accordingly Dr. Ganguly planned to carry out this unique experiment by discharging a small quantity of Na-24, a short lived radionuclide, through the effluent discharge point.

Innovatively he planned to observe the movement of the activity by spraying saw dust on the surface of the seawater at the discharge point and going by the pattern of dispersal of saw dust, sea water samples would be sampled at various points downstream during a complete tide cycle. Isotope division supplied the required activity of Na-24 by irradiation in Apsara reactor. RHC section took up the responsibility of the discharge. SS remembers how he liaised with the Indian Navy to provide the vessels with crew and equipment for the experiments. RHCS staff members on board collected sea water depth samples in bottles identifying the location and time of collection. The Indian Navy also arranged the transport of all samples and delivery at the Electronics Division Labs at the South site of AEET. A team of scientists from Electronics Division and Air Monitoring Section of AEET provided necessary instruments

and measured the Na 24 activity in the collected samples and reported the results to Dr. Ganguly. A K Ganguly PR Kamath and KC Pillai on the basis of these dilution studies submitted a proposal for the maximum permissible activity of low level radioactivity liquid effluents waste that can be discharged by AEET into the bay.

This experience enabled Somasundaram to develop an analytical model to assess radiation hazards in hydrological studies using radioactive tracers conducted by A C Eapen and his team of Isotope Division in various water bodies in India. The experience he thus gained also helped SS in organizing RHC section members in providing health physics coverage for tracer experiments at Cochin Harbor, Tungabhadra Dam and Hooghly River. The editor remembers his providing health physics coverage for the first such experiment at Cochin harbor along with Somasundaram. The saw dust experiment involved organizing a large multi-disciplinary scientific work force and liaising with external organizations such as Indian Navy. Thus SS showed his mettle for organizing large team work similar to that he did in the collection of data for the Indian Standard Man.

2.1.2 Dr. Ganguly and evolution of research on organo-metallic interactions

MVM Desai

2.1.2.1 Introduction

MVM Desai joined the Health Physics Division of AEET under Dr. Ganguly in 1961. Desai during his initial days approached Doctor to allow him to do MSc noticing that many of the initial crop of recruits doing MSc by research under Dr. Ganguly. He said "join first and then you will do MSc later". Desai like many of Dr. Ganguly's students started his career as an operational health physicist at the research reactor Apsara. He started carrying out activity analysis of the Apsara reactor pool water which was one of the stipulated duties of the health physicist there. Desai did a bit more investigation on this by following the gross decay of beta activity of the evaporated water samples for a long time and detected the presence of many radio nuclides by the subtraction method. And in his over enthusiasm he suspected the possible presence of Pu. Desai ventured to show the results to Dr. Ganguly who appreciated his efforts and was inclined to allow him to do MSc. However when Desai was about to leave, Doctor asked him if he has analyzed the sample for alpha activity. Desai realized his mistake and drawback of his conclusion about Pu and apologized. Dr. Ganguly told Desai that "it is your interest in the work that I liked" and gave him clearance for registering for his MSc. That was how Dr. Ganguly put Desai on the path of research. The editor remarks that this was another instance

of premonition of Dr. Ganguly since Desai later on worked on speciation of many elements including Pu in the marine environment.

2.1.2.2 Speciation studies

Desai worked on the speciation of Zn, Mn, Fe, Co and Ru in the marine environment under the guidance of Dr. Ganguly. It was shown that under growing conditions of an algal culture of Microcystis littoralis in simulated marine conditions in the laboratory, all these elements were converted to non-cationic and neutral species with time. The concentrations of these elements were higher by two orders of magnitude compared to that in natural marine environment. These findings of Desai were the subject matter of his MSc thesis. Dr. Ganguly used to tell Desai how they were very fortunate in having abundant resources for research in BARC. He used to mention that during his research days in Calcutta University they had only 2 grams of ion exchange resin for their studies. At the end of the experiment the resin had to be regenerated and would go back to Prof. Mukherjee to be kept locked for use by the next student.

2.1.2.3 Studies on Humic acid and organometallic interactions

Later when Desai was asked by Dr. Ganguly to join the environmental chemistry lab and work with TNV Pillai, he was overwhelmed. TNV Pillai was working under the close supervision of Dr. Ganguly on the preparation of humic acid and on its complexing properties. Desai notes that Dr. Ganguly had his initial research as a soil chemist under the guidance of Prof. S. K. Mukherjee in Calcutta University whom Doctor used to describe as the perfect gentleman and teacher. In these studies many elements in the soil showed higher sorption and lower desorption indicating the retention of elements in the soil. This was attributed to humic acids of the soil and because of his interest in continuing his earlier work, Dr. Ganguly wanted TNV Pillai to take up work on the preparation of humic acid and study its complexing properties. He wanted to apply the results of these studies to marine sediment humic acids as part of his investigations on environmental speciation and pollution. This was also a corollary and the follow up of the evolution of the work K. C. Pillai had done under Dr. Ganguly on the study of Pu in the marine environment which in turn was necessitated for monitoring liquid effluents from the reprocessing plant. This is narrated elsewhere in this volume. Gradually the team of TNV Pillai was strengthened with M V M Desai, V V Kulkarni and Elizabeth Koshy. Dr. Ganguly had great personal interest in this work since through this he found a continuity of his research work at the start of his career in the Calcutta University. Desai remembers that Prof. Mukherjee was his examiner for his PhD degree thesis later. Dr. Ganguly initiated humic acid preparation through T N V Pillai and

the purification of this humic acid by dialysis and electro dialysis went on for several months and finally separating a stock of absolutely pure humic acid for further studies. Humic acid is a principal component of humic substances, which are the major organic constituents of soil (humus), peat and coal. It is also a major organic constituent of many upland streams, dystrophic lakes, and ocean water. It is produced by biodegradation of dead organic matter.

Humus was meticulously separated from sea water containing some low level of cobalt and cesium radio activities and its complexing characteristics studied. The experiments conducted with algal culture have demonstrated that organic constituents produced in sea water as a result of culture growth and decay influence the fate of dissolved trace elements. When the concentration of elements were increased by several orders of magnitude compared to those present in sea water it was observed that the organic matter already present continues to solubilize higher quantities of the trace elements. The significance of this observation in the marine environment is to be understood in the context that algae is a major contributor of organic matter in the sea water. These findings were important for studying the mechanism of movement of trace amounts of radioactivity discharged from nuclear plants into the marine environment.

In the studies conducted by TNV Pillai, M V M Desai and Elizabeth Koshy on the fate of radionuclides the marine environment, Barium was found to be solubilized more than expected in seawater despite the presence of large amount of sulfates. This was attributed to the dissolved organic matter and humic acid. These observations led Dr. Ganguly to initiate studies on organo metallic interaction in the marine environment. In these studies it was observed that marine humic and fulvic acids solubilized practically all elements but their binding sites were different. Alkali elements were solubilized and held at exchangeable cationic sites in humic and fulvic acids. Trivalent rare earth and heavy elements solubilized by humic acid and were complexed in non-cationic, anionic and neutral forms. These investigations led to a large number of publications and a few PhD theses, which provided the insight into the complexing processes of heavy elements in the environment.

Under Dr. Ganguly, Dr. Desai had also carried out radioactive Cesium analysis in marine sediments. From 100 gm of marine sediment he separated a shiny material on observation under an infra-red lamp. This material weighed only 3 mg. The bulk sediment had 20 Bq Cs137 per gram, whereas the 3 gm of separated material showed a concentration of 19,000 Bq per gm. of Cs 137. Dr. Ganguly asked Desai to find out if this was Cs-alum but Cs alum was found to be highly soluble. Then

Dr. Ganguly suggested that it may be Cs rich mineral formed in situ. On analysis this material mainly contained Al, Si and Mg and possibly a clay mineral. In speciation studies Desai found that Cs gets trapped in the inter layer spacings of clay mineral in the presence of K. With time this Cs is isomorphously bound replacing Al and Si from clay mineral structure. These important observations were reported in 1978. However work was not pursued after Dr. Ganguly's retirement and taken to its logical conclusion in environmental applications.

2.1.2.4 Dr. Ganguly's advice on what constitutes research

Desai narrates about the lessons Dr. Ganguly taught him on how to go about selecting a topic of scientific research. He suggested that before embarking on a topic for research one should ask himself questions on the subject of research (**what?**), relevance of the subject (**why?**), methodology to adopt (**how?**), the environment or site relevant to the research (**where?**) and the time frame (**when?**). This became the famous "5 W's for research" which every student of science, for all time to come, should keep in mind. He further advised that every rule may have an exception and this exception opens up the path ahead for important research - a point worth noting for every research guide.

2.1.2.5 Lessons of Humic acid research pursued in Germany

Desai was deputed to work in the GKSS Institute, Germany under the Indo German exchange program. Desai notes that perhaps this was the last deputation from BARC facilitated by Dr. Ganguly to enable his students to work in foreign laboratories; Desai started his work in GKSS on the same day Dr. Ganguly laid down his office in BARC on superannuation. For Dr. Desai, his work in GKSS under Dr. Koske was a continuation of his pioneering work on speciation under Dr. Ganguly. He worked on separation of dissolved organic matter from Elbe River and Ni speciation. In a substantial contribution, Desai proved that the large amounts of mercury released to the Elbe River were totally immobile due to the presence of humic acid in the sediments. The work initiated by Desai enabled Dirk Walls Lager of GKSS to get his doctorate degree.

2.1.2.6 Dr. Ganguly and Social forestry

In continuation of his interest in Social forestry, once Dr. Ganguly took Desai and V V Kulkarni on a visit to Bharatiya Agro Industrial Foundation (BAIF) at Uruli Kanchan near Pune. After surveying the forest there, Dr. Ganguly noticed Subabul trees were grown on rocky terrain. Dr. Ganguly deeply thought of social forestry as a solution to fuel problem and submitted a research proposal on social forestry for a 5 year cycle at village level. This

formed the subject for a research project under DST initiated by Dr. Ganguly post-retirement as a DST fellow along with V K Gupta, who registered for PhD on this topic as his last student. Desai and Kulkarni also often assisted Dr. Ganguly in this project. Dr. Ganguly suggested Kulkarni to work on the transport of rocky material from Khandala hills in Western Ghats through rivers. The corrosion took place with the action of CO_2 and water. The pathways and mode of breakups of rocks formed the subject matter of the thesis submitted by Kulkarni.

2.1.2.7 Reminiscences of Dr. Ganguly

At the start of his work on environmental chemistry in 1958, Dr. Ganguly allotted work on investigation of the fate of a particular element in the environment to each of his students. Thus KC Pillai came to be known was Plutonium Pillai, TNV Pillai as Thorium Pillai, Ramamurthy Jr. as Uranium man. And Desai later came to be known as "Humic Acid Desai".

Dr. Ganguly set up a special chemistry laboratory on the I floor of Modular Laboratories (all other chemistry labs of HPD were on the III floor) adjacent to his office chamber so that he can pop into the lab and work for himself which he often used to do. He put TNV Pillai and his team on the work in this lab. Dr. Ganguly used to come to the lab around 8 AM and work there till 10 AM before going to his cabin to take care of his responsibilities as Head, Health Physics Division. He would then return to the lab after 6 PM to take stock of the results of the day's assignments given to T N V Pillai and his group. Such was his personal involvement in the work on humic acid. He used to tell anyone coming to see him for some official work while he was working in the lab, that the time beyond 6 PM is his personal time devoted only to research and they should go to him any time between 10 AM and 6 PM for official work. This work in the Lab would go on till 9 pm and after checking if any of his colleagues are working late in Physics or TLD labs which was invariably the case and leave in his jeep with the whole retinue. The editor remembers the number of the jeep Dr. Ganguly was provided by BARC since his early days; it was 8855 and the driver was Thimmappa. The drivers, in spite of their long working hours, used to stick to HPD duties because of the incentive of overtime. Later when Dr. Ganguly became Director of the group it was a car 1441. He used to comment that the new vehicle has not enough space to take home late working students. He would leave all of them nearby to their destinations on the way and finally go to his residence in Ghatkopar. The editor has fond reminiscences of these jeep trips when Dr. Ganguly would review the work of each student and suggest further work and many ideas evolved in this jeep 8855. It was like Gurukulam of yesteryears. On the way

the driver would stop the jeep at the traffic island adjacent to the TISS where under a huge Banyan tree a paanwalla had set up his shop peddling pans. He knew the prescription of pan required by Doctor and kept it ready on seeing the jeep headlight. The editor noted that the tree till very recently stood where it was with only the paanwalla missing. Only in January 2017 it was felled to remove the obstacle to traffic. The tree used to remind the editor of the days he evolved under Dr. Ganguly and served as an emotional stimulant often. And Sundays were no holiday for Dr. Ganguly; the forenoons were reserved for his students and afternoons for the family. One or other of his students would be there from 9 AM to 1 PM discussing their results, correcting the drafts of their theses and research papers and planning further work. Though the afternoons were for the family, the editor has a few instances of Doctor asking him to come back in the evening to continue the discussions when some interesting developments took place in the investigations. The editor remembers how around 1 PM the pungent smell of oil would emanate from the kitchen and Dr. Ganguly would in a lighter vein whisper that the fumes have started coming and before the "sound and fire follows" let us quit.

T N V Pillai remained a bachelor keeping aloof, dabbling in his research only, and neglecting his personal needs, possibly due to some personal frustrations. Dr. Ganguly, the gentle fatherly figure, perhaps had sensed it and even coaxed him to share the morning tea. Such was the care he bestowed on his students. When TNV Pillai was diagnosed with brain tumor in 1970 he kept vigil at the BARC hospital (located in JJ Hospital) during his operation along with KCP, Desai, Kulkarni and the editor. Soon after TNV Pillai passed away prematurely leaving his stock of humic acid for others to work and Desai took charge of the lab and the work continued.

As part of his responsibilities Desai was also made in charge of the Health Physics Division library which was initially brought up by Somasundaram. Those were the days the divisional library was the responsibility of the scientific staff of the division and the central library had not taken over these. Once Dr. Ganguly summoned Desai to his office in the Central Complex 6th floor (Dr. Ganguly was by then the group director and shifted to Central Complex building, as was required) and there was a guest with him. Dr. Ganguly introduced him as Praful Bidwai. Dr. Ganguly told Desai to give copy each of all our reports in the library to Bidwai remarking that this will give him enough information to write an article in the Times of India. Dr. Ganguly told Bidwai to fill his vehicle with the publications, read them and then write what he wanted to write. Praful Bidwai, it may be noted, was in the front of the group of journalists who were somewhat critical of the atomic energy operations and

thought more transparency was required. Dr. Ganguly did not lecture to about his impressions of safety in atomic energy and Bidwai was impressed with his approach to Public Relations. Dr. Ganguly told Bidwai that all these reports were published in the open and there was no secrecy whatsoever. Many of the reports concerned the results of the environmental radiation analysis around NPPs by the ESLs which was a creation of. Dr. Ganguly. Eventually, Bidwai wrote an article which was discussed all over and had praised Dr. Ganguly in the article. Elsewhere in the memoirs the editor has noted the respect Bidwai had for Dr. Ganguly when he wrote an obituary on the demise of Dr. Ganguly.

Once Dr. Ganguly sent Desai to H N Sethna, Chairman, AEC to brief him about the work on humic acid. When Desai entered the Chairman's Office, he was taken aback when Sethna spontaneously said "You are humic acid Desai, Are you?" And he continued in his characteristic style "How is Rollo?" Again Desai blinked. Sethna clarified that Rollo is Ganguly! This episode illustrates the intimate relationships Dr. Ganguly maintained with everyone. This also reveals another noble nature of Dr. Ganguly; he used to project the work of his students to the higher ups and often directed them to explain the salient features of their contribution. This aspect of his personality also noted by many of his students.

Desai compered the 5th National Symposium on Environment in Calcutta. Prof. Mukherjee was the chief guest. When Desai was introduced to him Prof. Mukherjee asked "Are you Anil's student on humic acid. Desai replied "Yes" and was overwhelmed by his warmth and intimacy.

2.1.3 Environmental Survey Laboratories

Contributors:
M R Iyer, K C Pillai, L V Krishnan, , R P Gurg, M A R Iyengar P M Ravi, M P Rajan

2.1.3.1 Introduction

Environmental surveillance was given importance in atomic energy operations since 1958 by Dr. Ganguly. Later on how it led to being an example for pollution control in other industries are described in other section of this volume and in fact led to the formation of Dept. of Environment DOE (present Department of Environment and Forests (MoEF)).

Though the formal establishment of the first ESL was at Tarapur in 1962, K C Pillai notes that the seeds for these activities were already sown by AKG as early as 1958. The details of these are contained in the memoirs of KCP

elsewhere in this Compendium. The first preoperational survey at a reactor site in the country was undertaken in 1959 prior to the start-up of the CIR rector in AEET and the first pre operational survey report was brought out by P R Kamath, K C Pillai, J R Naidu, AEET/HP/Environ/1 in 1961. All these operations were carried out from an environmental laboratory operating from a temporary shed in the South site of AEET. The procedures and protocol for carrying out environmental surveys were gradually frozen from these operations and paved the way for formalizing ESLs operations at all nuclear power sites in the country.

2.1.3.2 How the first ESL at Tarapur was launched

Compiled by M R Iyer

On the heels of the pioneering environmental investigations undertaken by Dr. Ganguly in Trombay, the establishment of ESLs was indeed a logical conclusion and turned out to be an ever lasting contribution to the Indian atomic energy program. The work on site selection in which Dr. Ganguly was deeply involved revealed to him how important was establishing environmental radioactivity measurements around NPPs before they go into operation to establish a base line so that when the station goes into operation even minor impact of the operation on the environment could be detected. This led Dr. Ganguly to propose setting up of ESLs around NPPs. Late M S R Sarma, former vice Chairman of AERB in his memoires states that "The establishment of Environmental Survey Laboratory at each one of our installations is a unique feature and Dr. Ganguly was the pioneer in this field". Dr. Jagdish Shankar in his INSA Memoirs on Dr. Ganguly mentions that establishment of ESLs was one of the achievements of Dr. Ganguly and that "he organized at each site a laboratory to continuously monitor the environment in that area on a regular basis throughout the life of the reactor". The ESLs should serve as a lasting memorial to Dr. Ganguly.

I quote from the book on "Atomic Energy in India – 50 years" by M/s. C. V. Sundaram, L. V. Krishnan and T. S. Iyengar (1998) and also from my own memory of hearsay, since we do not have the benefit of reminiscences of stalwarts like P. R. Kamath and I. S. Bhat who initiated this program. They have all now disappeared behind the screen of Time. During the exercise on selection of sites for India's first nuclear power plant at Tarapur, it became clear to Dr. Ganguly that detailed survey of site environment is required after the site is selected. The objectives for this were several. The environmental pathways through which the possible release of radioactive material could spread and reach the population had to be established. From knowledge of the chemical properties, radio toxicity of the radioactive materials and the food

habits of the population around, "critical groups" among the public had to be identified who have a higher probability of receiving radiation exposure if any. Further, the baseline studies are of importance to discern any small increase in environmental radioactivity possible from the operation of the station. With the commissioning of the power station it was also necessary to verify by continuous monitoring of the environmental radioactivity the validity of estimates of population exposures made at the design stage. Through a careful study of the flora and fauna of the site indicator organisms were to be identified so as to obtain an early warning should the operation result in any rise in levels of radioactive material in the environment. Finally the estimate of the annual population exposure is possible only by undertaking such extensive survey and through the uptake factors and population distribution. In the context of the above requirements Dr. Ganguly proposed to DAE the strong grounds for establishing Environmental survey laboratories for all NPP sites.

A proposal was made to DAE by Dr. Ganguly for establishing an ESL at Tarapur in 1962. It may be noted that there was no precedent for such a laboratory in any of the conventional industries. Nor was there a parallel for such a lab at nuclear sites in other countries. It was purely an Indian initiative under Dr. Ganguly. It was no surprise that the support for such a lab in middle and top levels in DAE was lukewarm. However the file was finally referred to Dr. Bhabha in 1964 and it came back with a noting to the effect that "if there be no sanction for ESL the reactors need not operate". This was the high level of importance given by Dr. Bhabha on safety matters and he fully supported Dr. Ganguly in these. With this green signal, the path was cleared for setting up of ESL to be an integral part of all NPPs in India, which has stood the test of time and provides the feedback on the impact of the operation on the environment to substantiate to the public with numbers, that there has been no noticeable impact. Without ESLs, this area in public relations would have been void to allay the fears of the public. In 2011 when the editor served as a member of the committee appointed by GOI to allay the fears of the public in Kudankulam area the enormous database available with the ESLs was the main stay to achieve the task.

In 1964 by the time the construction of TAPS began, the ESL already began functioning in a temporary location in the township. P. R. Kamath was the person whom Dr. Ganguly selected to oversee the installation of ESLs and I S Bhatt was the environmental chemist who was selected by Dr. Ganguly to head the first ESL at Tarapur. He also facilitated getting the necessary support from DAE such as providing quarters for the ESL staff, setting up laboratory building and infra-structure support for the operation of ESL. As a result of

this, the ESL at Tarapur moved into its new premises in 1969. Dr. Ganguly insisted that the ESLs should be located at the Township far away from the plant to provide support even in the eventuality of widespread contamination around the plant. Further, the ESLs were also freely accessible to any member of the public to satisfy themselves about the safe operation of the power station with no detectable impact on the environment and the public. Dr. Bhabha who readily supported the idea of ESL propounded by Dr. Ganguly once visited the Tarapur ESL in its temporary location and was shown the layout plan and design of the final lab and was fully satisfied. But he did not live to see the full-fledged laboratory established in its final premises.

Considerable thought went into the design of the ESLs and in the preparation of the laboratory's program of activities. Based on the experience gained, India was able to make effective contribution to the WHO when they undertook publication of a booklet on routine surveillance for radioactive substances in the environment. Later WHO decided to follow this up by providing advice to its member countries on minimum requirement for such a laboratory. The Indian ESL concept was selected as a model and India was invited to prepare a guide for design, operational requirement and equipment's to meet those objectives, which were meticulously prepared by P R Kamath. This blueprint was also useful in enabling NPCIL for making provision for setting up ESLs at all new nuclear sites. It became mandatory for NPCIL to provide funding for ESLs at the start of construction of the power project. However the staff of ESL even today reports to HPD, BARC in order to demonstrate independent nature of the ESL operations. ESLs publish annual report on the results of measurements and estimates of the dose to a member of the public for each NPP site. This guides the NPC in controlling plant discharges, if required. It was also envisaged that ESLs would provide extensive monitoring in case of any accidents. ESL studies on dispersion of coastal effluent discharges provided evidence of possibility of recirculation of condenser coolant water that would impact plant efficiency. This information helped NPC to take corrective actions.

The investigations of the ESL showed that sea weed present near shore in Tarapur was a good indicator organism for I-131. The organism selectively concentrates Iodine. Further, goats' thyroid served as a concentrator of iodine in the nearby environment of NPPs when they graze on the grass around. This enables detection of deposit of I-131 in case of an accident. The techniques were perfected under the guidance of Dr. Ganguly and it was thus possible to detect even very minute levels of radioactivity of iodine. The technique also became useful to measure the radioactivity carried by global circulation of debris from nuclear weapon testing by other countries particularly France and China.

All ESLs reported small quantities of radionuclides from the fallout from these atmospheric nuclear tests, the last of which was carried out by China in 1980. Likewise the infra-structure of ESLs were found to be invaluable following the Chernobyl accident when India could detect I-131 enabling analysis of the local impact of the accident. Subsequent to the Fukushima accident also, ESLs carried out compressive analysis of air, water and food items for any possible debris in India. This study demonstrated that there is no impact of Fukushima accident in Indian environment. The data generated was provided in public domain on a daily basis which helped to allay the fears of general public.

As a result of extensive studies, marine organisms that concentrate various other radioisotopes from sea water were identified. Radioactivity in common salt produced in the region led to understanding this pathway to human beings and this was considered for evaluating population dose.

Metrological survey laboratory was made functional at the TAPS site directly under the supervision of Shirvaikar along with the start of construction of the reactor. It carried out studies on micro meteorology of the site to study how radionuclides if released from the station would be dispersed and deposited and helped in planning the sampling program of the ESL and also became part of the emergency preparedness for the various installations at the Tarapur site. A special Met tower of 100 meter was erected at the site for the purpose. The met Lab also carried out various research work related to these studies and was manned by Adiga under Shirvaikar. Later on it became part of the ESL operations. Micro meteorological measurements became a feature of all ESLs both preoperational and postoperational. In fact whenever a site was being earmarked for setting up nuclear plants the first step is to study the micro meteorology of the site and this is being done for all the new sites in various parts of India being earmarked after the Indo USA nuclear collaborations program was launched.

2.1.3.3 Environmental Survey Laboratory at RAPS, Kota

2.1.3.3.1 Introduction

After Tarapur, the second ESL was set up at the RAPS reactor site, the program being re-oriented to take care of the specific factors of the inland site; the water requirement for RAPS reactors and the township was met from the Rana Pratap Sagar Lake, a freshwater body. KC Pillai recalls that after a visit to Canada in early sixties to work out the details of setting up PHWRS at Kota, Dr. Bhabha directed Dr. Ganguly to start preparations for establishing an ESL there. Dr. Ganguly started initiating pre-operational surveys in the Kota site and in 1965 deputed KCP and MVM Desai to proceed to Kota and undertake

the background surveys of Chambal River and RPS Dam near the proposed RAP site at Rawatbhatta. Extensive studies were carried out during the two season's winter and post monsoon and gave data on background radio activity and trace element distribution in the environment which facilitated evaluation of permissible levels for discharge of effluents in the aquatic environment. The system in Kota was different from that in Tarapur in that it was an inland site and the effluent discharge was into a fresh water system which catered to the drinking water requirement of the population. Discussion for establishing ESL at RAPS site was initiated by Dr. Ganguly with the project authorities in1969 and the ESL was established in 1971. R P Gurg was appointed as the Head of the ESL RAPS Kota and he was assisted by a team of chemists.

To strengthen these activities Dr. Ganguly set up a separate Section Environmental Studies Section (ESS) to oversee the operation of all ESLs including that in AEET Trombay with P R Kamath as Head of the section in 1973. On the retirement of P R Kamath, K C Pillai headed ESS in 1981.

A study of the pathway through fresh water fish was established at this ESL. The thermal pollution from the condenser water discharge was also studied at this site along with the possible influence on fish due to this. As effluents were discharged into the lake by other industries monitoring of oxygen levels was also initiated.

2.1.3.3.2 ESL Kota

R. P. Gurg

R P Gurg who was the first Officer in Charge (OIC) to head the ESL at RAPS, notes in his memoirs, that RAPS, Kota is the first Indian NPP, based on Canadian PHWR System. It is situated on the banks of Chambal River and uses fresh water from Rana Pratap Sagar reservoir for its cooling purposes. The condenser water cooling results in large amount of heat energy discharged to reservoir, conforming to the limit of the temperature difference between the input and output water viz. 9 deg Celsius. In addition, low active radioactive effluents after treatment are also discharged into the lake-river system. The station has large inventory of Tritium laden process streams. A Heavy Water Production Plant using Dual Temperature Hydrogen Sulfide Exchange Process is situated at the site and hydrogen sulfide laden process waste effluents (water) after dilution is released to the same reservoir. The Reservoir waters are the main source of drinking water to residential colonies around. The water from the reservoir is utilized for irrigation purposes and cultivating fish in RPS reservoir and vast areas up to about 100 Km downstream for drinking water supplies. Being the first In-land Nuclear Power Plant, meticulous environmental surveillance

program was planned for monitoring the concentration of radio-nuclides in environmental matrices and movement of radionuclides under the guidance Dr. A. K. Ganguly and P. R. Kamath. The main emphasis was on monitoring of environmental matrices for concentration of radionuclides, utilized by local population by consumption of food items, drinking water and air.

At construction stage of the Nuclear Plant, experiments were conducted in different seasons to ascertain dilution factors available for liquid waste discharged to water body as noted by K C Pillai in his memoirs. The dilution pattern in the reservoir was studied by using Rhodamine B Dye. For 3-5 years prior to commissioning of the Plant pre operational surveys were conducted and samples of different environmental matrices like, water, soil, air particulates, food items like cereals, milk, fish, etc., were collected round the year and analyzed to establish the back ground level of radionuclides in these matrices for future references. During the operational stage of the Power Plant, these analyses were continued to assess the impact of the operation of the reactor. Simultaneously, surveys were conducted on local population to find dietary pattern of food consumption and annual intake of different food items like different cereals, milk, vegetables (Leafy, roots and others), meat, eggs, etc., to establish the pathways for assessing the annual intake of radionuclides and estimate the radiation dose received by the public and to ensure that these are (kept) much below the stipulated limits. Surveys and experiments were conducted in the lab and field to find if any natural process involved in concentration of the radionuclides in food items like vegetable, fish, etc., which can act as indicator/fore warn any inadvertent release of probable radionuclide to environment. Radio-iodine in goat thyroid, which is regularly analyzed, is a good indicator of release of iodine. Similarly, in PHWR system, presence tritium in water streams and air is good indicator for release of radioactivity through water or air route. The different locally produced/ consumed food items were analyzed for trace elements like Strontium, Calcium, Zinc, Nickel, Cobalt, Iron, etc., in order to study the tendency of food item to concentrate similar radionuclides. It was observed that fenugreek has higher concentration of Zinc in comparison of other vegetables.

During the discussions Dr. Ganguly, Dr. C. Banerjee, Medical Superintendent of RAPP, indicated that in RAPS families, the infants are frequently suffering from diarrhea and dysentery. Dr. Ganguly sensing the source of infection is water borne, directed the ESL to gear up for the regular monitoring of the water supplies for chlorination and domestic sewage effluents for different parameters. The effluent treatment process was modified and efficiency improved. As result of continuous monitoring this problem could be rectified.

This was later taken up as a regular program in all ESLs at other NPPS.

Another aspect of RAPS that drew the attention of Dr. Ganguly, was relating to the considerable inventory of tritium-laden liquid effluents, which when discharged to the lake, could lead to some radiation exposure to the public. It struck to Dr. Ganguly' s perceptive mind, that given the scanty rainfall in the area, and good sunshine and ambient temperatures in the area, that a solar evaporation facility would be an ideal recourse to bring down the tritium and other contaminant levels in the lake waters and consequently minimizing the public exposures. To reduce the release of tritium to Rana Pratap Sagar Reservoir Dr. Ganguly suggested to plant authorities to set up a Solar Evaporation Plant and the tritium laden process effluents are allowed to evaporate, reducing the tritium concentration in the liquid discharges. By setting up of Solar Evaporation Plant at RAPS release of tritium and other radionuclides to the Reservoir was eliminated through this route. The sludge containing long lived radionuclides was collected and disposed of as solid waste in Waste Disposal Area.

The requirement for a boat to monitor flora and fauna in the RPS reservoir, a 34 feet in-board engine boat with driver was procured on lease from Fisheries Department of the MP Government by the ESL. The Director Dr. G. P. Dubey of the Fisheries Dept. then suggested that a suitable boat with laboratory table and storage facilities can be constructed at their boat building yard, Bhopal for use by ESL and gave a very reasonable quotation for the boat and equipment. Dr. Ganguly accepted the offer and sanctioned the procurement of the boat for ESL. He also sanctioned the post of a Boatman Cum Laboratory Assistant for operating the boat. The boat available with ESL was also used by the station authorities for Security/emergency and other requirements and they extended all help and support for its operation and maintenance.

For assessment of public dose due to annual intake of radionuclides a suitable empirical model was developed by Subbaratnam under guidance of Dr. A. K. Ganguly for each NPP Sites.

Since a large amount of heat is discharged to water body during operational stage, a study was initiated on thermal pollution to map the spread of hot plume in all three dimensions from discharge point and its cooling pattern in environment round the year in different seasons. A device was developed by P. V. Vyas at ESL RAPS to measure in-situ water temperature in reservoir at different depths. The device was duplicated at all ESLs to study thermal pollution. Experiments were also conducted to assess the fish growth

pattern in coolant discharge areas. IAEA awarded a 3 years international co-ordinated project on study of thermal pollution and its environment impact assessment to ESL RAPS along with 8 laboratories from different countries. The project was operated by R P Gurg under the guidance of Dr. Ganguly and P. R. Kamath.

A program to study the possible dose to family members of DAE employees arising from the likely intake of low amounts of tritium by the radiation workers, leading to an enhanced tritium in the atmosphere in their dwellings from their breath was undertaken under instructions from Dr. Ganguly. The conclusion was that a very slight dose was discernible, though it was much below a fraction of the dose limit for public. The various programs and studies initiated at ESL RAPS became a template for ESLs at all other PHWR power plants in India.

A Micro meteorological lab was also functional at ESL Kota with L N Sharma and his team making these measurements to characterize the site and these operations formed part of the emergency preparedness at the center.

2.1.3.4 Environmental Surveillance Program at Kalpakkam

M A R Iyengar

2.1.3.4.1 Introduction

M A R Iyengar after his tenure at UCIL Jaduguda was identified to lead the ESL program at Kalpakkam in 1973, which was taking shape there to carry out the pre operational environmental survey for the commissioning of MAPS PHWR reactor. S. Ganapathy, E. K. Viswanathan, V. Kannan, M. P. Rajan joined the ESL Kalpakkam. As the ESL, Kalpakkam was the third in series of ESL's being set up by BARC, the template for its program of activities was already cast with the commissioning of the first two ESLs. Kalpakkam followed the model of ESL Tarapur being a coastal based site. Further, this was the first purely indigenous PHWR reactor after Canadians withdrew their support. Additionally, the Kalpakkam Nuclear Complex hosted a large number of major and diverse nuclear installations and support facilities, including the Fast Breeder Test Reactor facility and allied utilities of the Indira Gandhi Centre for Atomic Research (IGCAR) such as the Centralized Waste Management Facility (CWMF) and others. This has further expanded in recent times, with the setting up of PFBR, KARP, and ATRF. The environmental program and activities, at ESL, Kalpakkam had thus a relatively larger contextual frame work, to cater to the operational requirements of an array of nuclear facilities at site. Thus the surveillance and measurements program, in vogue at other ESLs had to be strengthened to meet the objectives of the Kalpakkam Site.

The primary objective of the environmental protection policy, followed at the sites of all PHWR's, that the dose to a member of the public should be ensured to be always kept much below the dose limits following ALARA principle and the operations do not disturb the ecological balance of flora and fauna around. Given the above mandate, the Environmental Survey Laboratory organizes a sequence of environmental activities, which involves assessing the radioactivity in all environmental matrices and their seasonal trends establish various pathways to man with the objective of assessing the dose to a member of the public. Assessment and investigations are also regularly carried out on other environmental indicators like animal thyroids, oysters, and sea weeds, etc., which assist as markers of possible radioactivity release due to their ability to concentrate certain radionuclides. The ESL has also served to monitor radioactivity due to fallout from global events. Thyroid monitoring for Iodine-131 activity provided striking information on the global fallout aspects of the French, Chinese nuclear tests, besides the fallout contamination reaching India, from the Chernobyl accident, after 26th April 1986. Besides background radiation environment studies, dietary consumption data of local groups of populations, which enable in arriving at a reasonable estimate of the public dose, in the neighborhood environment are also collected, which are useful in evaluating doses in the pre-operational and operational phases. The radiological exposure aspects of the gaseous components, arising from stack releases of MAPS and other units at site, are also computed, using the micro-meteorological data, generated by the Micro-Met. Laboratory at Kalpakkam site and the gaseous effluent release inventory data. The doses which are computed on a quarterly and annual basis are further assessed sector-wise, for different radial zones. The annual doses received by the population groups in different sectors, are computed utilizing the comprehensive data collected by ESL, following round-the-year monitoring surveys of the environment, which forms the environmental performance report card for MAPS.

Among other supporting activities and investigations, the coastal water movement and dilution studies were carried out by using dye tracer studies in the Kalpakkam coastal waters, on the lines of the earlier experiments at Tarapur and Rajasthan. Detailed analyses and conclusions from the study, enabled to set up low level effluent discharge location at the coastal area. Also, it was Dr. Ganguly's wish that the community water supplies and the treated sewage effluents, being discharged to the environment at the residential colony sites, at each DAE facility should be monitored by the local ESL Unit, as part of the HS&E program.

2.1.3.4.2 Enhanced radiation background Surveys

Following the start-up of the ESL pre-operational environmental radiation measurements at site were started sometime during April-May of 1973. The survey team was surprised to find radiation background around the ESL of a higher order in the range of 100 to 200 microR/hr. compared to expected reading for a land terrain of the order of 10 to 40 microR/hr. This greatly puzzled Iyengar and he even suspected in the instrument functioning. On their venturing across nearby beach locations at Sadras and Pudupattinam, they recorded similar readings, with an irregular and highly shifting radiation profile in the beach regions. A close scrutiny also revealed a large number of scattered patches of black sand and in their vicinity, the readings were significantly higher. Soon the measurements and readings were conveyed by reports to Trombay, as it was a highly unusual phenomenon, not experienced either at Tarapur or Kota. Soon after, during a visit to Kalpakkam site, Dr. Ganguly personally got interested and visited the beach locations, registering enhanced natural radiation levels. He felt that the beach sands must have considerable association with the monazite mineral, although of a lower grade than in Kerala beach sands. He very enthusiastically asked Iyengar to pack samples of beach sand which he personally carried to Trombay for a study. Within days, message came from M. R. Iyer, who was asked by Dr. Ganguly to investigate and identify the source responsible for the enhanced recordings which he also identified as due to monazite, a radioactive mineral of Thorium. Iyengar says that Iyer followed up, with an immediate visit to ESL Kalpakkam, and he along with Iyengar conducted extensive detailed radiation survey at a number of locations on the beach, recording highly varying natural radiation levels, ranging from 10 to 400 microR/hr. At the end of the survey a radiation map of the area was prepared which revealed that the background radiation terrain often in patches of black sand, was prevailing particularly all along the beaches of the Kalpakkam coast, in the 32 Km radial zone and even beyond. Core samples were also taken and later on analyses, it showed the typical characteristic of monazite deposits in Kerala coast viz. a near surface monazite deposits. Detailed analysis of the samples was carried out back in Trombay which confirmed the occurrence of monazite. However the thorium content was less than that in the west coast of India. This was an important facet of ESL findings very early at site, which paved the way later for an enhanced focus on investigations of the occurrence and distribution of natural radioactivity. A report was published on the findings entitled "Monazite deposits on the Kalpakkam site" by M R Iyer, MAR Iyengar and S Ganapathy was immediately prepared. The editor remembers that later Dr. Ganguly called for Dr. Udas, Director of AMD and sprung a surprise on

him by asking the editor to present the report. This was the first time AMD had any data on the monazite deposits on the east coast of India and he promised to investigate further. Thus the ESL operations was instrumental in revealing monazite source in Kalpakkam area, which had also implications in pre-operational environmental survey in that the elevated background are to be reckoned with in discerning effect of the operation of the power stations. During his next visit to site, despite his busy schedule, Dr. Ganguly personally went around the beach locations at Sadras and Pudupattinam, and also MAPP site, only to witness enhanced background radiation levels at several locations, using the portable scintillometer instrument. Dr. Ganguly remarked to Iyengar, "Your environmental surveys now should be more inclusive, i.e., both natural and man-made radioactivity studies" and pointed out that this is a unique opportunity. Looking toward the restless sea of the Bay of Bengal, with a twinkle in his eyes he remarked "Maybe FBTR is sitting on its own fuel thorium." But perhaps he also felt a little disquiet, when he observed relatively higher natural radiation background, at the Kalpakkam Complex site environs, could become a debating issue with the public groups, some of whom were opposing nuclear power projects, in the country. Subsequently Iyengar received intimation about the proposed visit of an Atomic Minerals Division team from Bangalore, for a detailed surveys and assessment of the type and scale of monazite deposits at Kalpakkam and whether they had a significant commercial viability, like those in Kerala, and elsewhere in South. They arrived soon with their camping gear and specialized radiometry equipment, and carried out detailed surveys at Sadras, Mahabalipuram, Pudupattinam areas of the beach, on instructions from Dr Udas. However AMD surveys concluded that the monazite was of moderate concentrations, highly scattered, and non-viable for any large or even modest scale mineral processing. Such deposits of varying grades appeared to occur all along the east coast, from locations starting from Kanyakumari, in far south and stretching all along the Waltair-Vizag regions of Andhra Pradesh, and further beyond to the Orissa Coast. Our surveys at ESL, backed by the incisive thinking and conclusive efforts by Dr. Ganguly, further helped to establish many domains of high background radiation environmental zones, occurring along the East Coast of India. Investigations on the monazite deposits and distribution of radium was another dimension to the activity of ESL undertaken at Kalpakkam and led to many research projects by BRNS of DAE, in collaboration with academic institutions. Besides these, the involvement of non-DAE Research Groups, have also been very successful in carrying conviction with the public and acceptance, relating to the on-going Nuclear Power Projects, including those at Kudankulam.

2.1.3.4.3 Radium Project, a Coordinated Research Project Program of IAEA

A direct spin off of the above was that Dr. Ganguly, was keenly looking for an opportunity to pursue the environmental ramifications of the observed monazite occurrence at the site, by way of a good research program. In fact, during his Kalpakkam beach jaunts Doctor had humorously, remarked to Iyengar, "Hey Ramanuja, your radium is chasing you here too, from Jaduguda." But I was clueless as to what he meant, then. But within a few months of his visit, he had proposed a Coordinated Research Program from India, to IAEA Vienna, on aspects of Radium occurrence and movement dynamics in the Indian environment. Around the time IAEA also was actively planning to sponsor a Coordinated Research Project, on environmental Radium, involving some select member countries, including India. P. R. Kamath was asked to prepare a research proposal, by Doctor, which was finalized during Kamath's visit and further discussions at Kalpakkam, for submission to IAEA. But the surprise element of the Research Proposal to IAEA, was revealed by Kamath, by announcing that Dr. Ganguly, has proposed Iyengar as the Chief Scientific Investigator of the project, from India and he warmly complimented me. On learning this, MARI could decipher Doctor's earlier remarks, that why Radium is chasing him in Kalpakkam too, after Jaduguda. Such was his sagacity, large heartedness, connective bonding, support and above all, giving fine encouragement to youngsters working around him! Iyengar states that it was an unforgettable moment for him! The Coordinated Research Program on Radium of IAEA, Vienna, titled "The Behavior of Radium in Inland Waterways and Aquifers", consisting of six countries, namely, France, Australia, Yugoslavia (formerly), Czechoslovakia, Japan, India, USA and Brazil, took off sometime in early 1974, and Coordination Meetings were held at various locations and wrapped up in Vienna. The reports from India were presented, consisting of R&D results and field data from Kalpakkam (MAR Iyengar), Jaduguda (Raghavayya) and IRE Alwaye sites (A C Paul), which were well received by the participant countries and IAEA. This was a unique Program, as conceived by Dr. Ganguly, a highly successful R&D and field survey project, resulting in a good number of research papers and scientific publications. Three IAEA documents, of considerable reference value to present day Research Groups, working on environmental Radium aspects, were published by the Agency as IAEA tech docs and technical reports. A significant piece of work carried out by LU Joshi under direct supervision of Dr. Ganguly was the study of radium ratios in off shore waters of Western India was also referred to by Iyengar. The results from India were well received in IAEA circles

2.1.3.4.4 Manganese fiber studies and applications, in environmental investigations and waste treatment aspects

Sometime during 1976, a CRP meeting of IAEA was held in USA to review the progress of the IAEA project on Radium, and to chart out the concluding phase of the program, before publishing its research and survey findings.

During this CRP meeting, Iyengar had the opportunity to meet Prof. W. S. Moore, an expert on Radium measurements and distributions in the on-shore and off-shore marine waters who took interest in the findings from Kalpakkam, as he had carried out some research investigations on Radium and some natural radionuclide, off-west coast of India, in collaboration with the Marine-Geochemistry Group of TIFR. During these discussions, Dr. Moore gave Iyengar a sample of a chemically coated synthetic fiber, which he said had wonderful analytical features and possessed great potential in radium studies in the environment both in a marine and freshwater environments to. On return to Trombay, Iyengar met Doctor, and showed him the fiber material and narrated his interactions in US. Dr. Ganguly pleasantly shot back, saying "You go back to your Jaduguda days, it's the same manganese stuff doing the job on radium, and enriching it on the fiber. This can work in fresh water or marine or any environment. Go back to Kalpakkam, prepare some fiber stuff, and let me have some good data, from your site environment." MARI returned to ESL, carried out quite a few radium measurements using the Manganese Oxide coated acrylic fiber, it worked on radium beautifully. On apprising the same to Doctor, Iyengar could see a passing glow in him!

Further on, large quantities of the Mn-acrylic fiber were prepared at ESL, Kalpakkam, and besides Radium they were also used to adsorb and strip or enrich Fission products (Cs-137, Sr-90) and Activation products (Co-60, Mn-54, Zn-65, Ce-144, etc.) from LEMP waste streams of MAPS, with a rather high efficiency. Collaborative work between ESL, Kalpakkam and CWMF, Kalpakkam also confirmed the relatively higher efficiency of the Mn-acrylic fiber based lean waste decontamination. Also, trial studies Using Mn-acrylic fiber in conjunction with KCFC (Pot. Hexacyanoferrate) Fiber coated material on a batch of lean radioactive effluents of MAPS, showed its ability to isolate nearly pure Cs-137, activity. These can be considered as forerunner of the current day achievements in Trombay of removal of radioactivity from high level waters.

The ESL Kalpakkam innovated a feature of weekly interaction with the public due to the initiative of D V Gopinath who was the Director of Health and Safety at IGCAR. In order to convince the public about the safety of nuclear

power, this feature was recommended to be adopted by ESL Kudankulam by the author in his report as a member of Kudankulam Expert Group in 2011. Kalpakkam ESL has also demonstrated the advantage of integrating ESLs with emergency control centers. The ESL was also an accredited center for giving certification for the radioactivity content in food materials which are to be exported.

2.1.3.5 Environmental Survey Laboratory, Kaiga

P M Ravi

2.1.3.5.1 Introduction

ESL Kaiga was started in post Ganguly era and demonstrates how the momentum of the ESL movement started by Dr. Ganguly still continues vigorously. As in earlier cases, ESL Kaiga started well before the station went into operation carrying out pre operational radiation surveys.

2.1.3.5.2 Special features

The unique feature of Kaiga Nuclear Power station is that it is located in a hilly terrain amidst natural serene forest of Western Ghats. The PHWR reactors in this site use fresh water supply from Kadra reservoir for cooling water supply. Along with the warm cooling water low levels of radioactive effluents are also discharged into this water body. It is necessary to demonstrate that the operation of nuclear plants at Kaiga will not affect the environment and the rare species of flora and fauna in the area. The operations of the Kaiga ESL were fine tuned to take care of these special requirements. Pre operational radioactivity survey of the environmental matrices and study of food chain pathways for which the methodologies and protocols evolved in the earlier ESLs at Trombay, Tarapur, Kota under the direction of Dr. Ganguly were followed and further fine-tuned to suit the site characteristics for undertaking detailed aquatic and terrestrial ecological studies at Kaiga site.

In addition, a major challenge this site posed was to understand the dispersion pattern of the gaseous effluents from the stack of the reactor, since the reactors are located in a bowl formed by the hills surrounding it. The effect known as "Bowl effect" was the subject of wide discussion and study in many groups in the HPD in BARC. Some of the hills are more than twice the height of stack itself. B. B. Adiga who was involved in the micro meteorological studies of the Tarapur reactor site under Shirvaikar earlier, carried out a detailed study of Kaiga site with multiple meteorological stations and a SODAR (Sound Detection and Ranging) system which enabled the vertical profiling of meteorological parameters. A very interesting aspect of the site was extremely low speed wind, wind shearing with height and

wind channeling guided by the valley formed by Western Ghats. All these factors were taken into account for assessing the dispersion and dilution of the plume from the stack to arrive at the external dose and deposition of radionuclides to enable assessment of the dose to the public. These investigations also provided useful inputs to the emergency preparedness at Kaiga site. The editor was associated in inducting the SODAR systems for studying the atmospheric parameters in various nuclear sites without use of the stack. This had the advantage of measuring these parameters to a much larger height with the flexibility of moving it from location to location within the site.

2.1.3.5.3 Evolution of Environmental surveillance through Universities

One of the innovations initiated at this site was the close involvement of Universities and Institutes in the environmental monitoring program and it was considered more optimum as the atomic energy program evolved. Further, with advancing time and resources, the activities of the universities were also fine tuned to the national requirements and priorities. Sensing the need for involvement of universities in the atomic energy program, a Board of Research in Nuclear Sciences (BRNS) was instituted by BARC which became the co coordinating agency for BARC to undertake such collaborations with Universities. And the environmental science collaboration with universities was anchored as part of Board of Research for Nuclear Studies (BRNS) program of BARC. The BRNS has also special committee directing collaborative research in the area of environmental sciences. ESL Kaiga had extensively been benefited by these collaborations and the Mangalore University played a significant role. The editor adds that, as a matter of fact the involvement of Mangalore University had already evolved under Dr. Gopinath in eighties. Under this, the editor has reminiscences of being involved in conducting a special MSc course in Radiation Physics in the Mangalore University and provided faculty and instruments for carrying out practical training. A Microtron for research in radiation physics was set up at the University under the initiative of Dr. Gopinath and patronage of Dr. Chidambaram. And naturally when the formalization of this took place under BRNS, Mangalore University became more active. Recently a Centre for Advanced Research in Environmental Radioactivity (CARER) was established by the Mangalore University as a National Facility through the financial support of BRNS. The Centre provides advance analytical facilities for research on environmental radioactivity.

Thus the requirement of multidisciplinary studies at Kaiga site evolved a new model of collaborative study with universities, coordinated by site ESL. First time in the DAE history, ESL was recognized as a research center by

the Mangalore University. Dr. Ravi had guided many students from this university for their doctoral work. This model also helped to establish a perfect support from academic community. This model was actively supported by Dr. Kakodkar, the then Chairman, AEC. The support of the coordination and monitoring committee of Thermal ecological studies sponsored by BRNS, under Dr. S. K. Apte, then Head, Molecular Biology Division, BARC is also worth mentioning. This can be considered as the legacy of Dr. Ganguly who was a strong proponent of academic collaborations for environmental studies. Ravi who was the OIC of Kaiga ESL since its inception in 2000 directed these research programs locally and feels fortunate to be associated with the establishment of ESL, KGS, Kaiga.

2.1.3.5.4 Findings on environmental radioactivity at Kaiga

An interesting observation, while establishing the base line radioactivity levels at Kaiga site, was the elevated levels of fall out radioactivity, especially Cs-137, in Kaiga environment. This was established to be due to the wet deposition of air borne fall out radioactivity due to heavy rain fall and recycling of the radionuclide in the forest eco system. This, along with study of cosmogenic radionuclide Be-7, gave an opportunity for ESL to establish ecological half-lives of radionuclides. Without these studies during pre-operational stage, the elevated Cs-137 in the environs of Kaiga would have been construed as due to releases from the station.

As part of the R&D program on the environmental transport of radionuclides, several studies have been conducted. This included

1. Development of environmental transport model for tritium including the formation of organically bound tritium (OBT) which was validated through an IAEA interlab comparison program.
2. An in situ study to estimate the transfer of iodine from forage to cow.
3. Development of an environmental chamber to carry out simulation studies on environmental transport
4. Application of cosmogenic Be-7 to estimate site specific environmental model parameters such as deposition velocity and mass interception coefficient.

2.1.3.5.5 Thermal ecological studies

ESL, Kaiga also initiated thermal ecological study to demonstrate the safety of Kadra reservoir aquatic system due to possible thermal pollution from the release of warm condenser cooling water from the reactor. Detailed three year long studies on phytoplankton, zooplankton, fishes and bio-geo-chemical cycle established that there is no any irrecoverable damage to the aquatic ecosystem of Kadar reservoir due to the thermal effluents.

This led to detailed program on the effect of fish rearing on the thermal pollution carried out by ESL, KGS in collaboration with the Central Institute of Fisheries Education, Mumbai, a reputed institute under Indian Council of Agricultural Research (ICAR). A fish hatchery was established at Kaiga near the discharge canal to study the effect of temperature on fishes at different stages of its growth. The study indicated that the temperature observed at discharge canal will not lead to any hazardous impact on fishes and the fish was noticed to breed better with a slightly warm water.

The editor remembers that the results of these studies were very useful during his involvement in the Kudankulam Expert Group to allay the fears of the public on atomic energy, when one of the issues raised by the anti-nuclear groups was their concern that the fishing operations near the site would be affected.

2.1.3.5.6 Status of Environmental Survey labs today.

P M Ravi who is the presently Head of the Environmental Studies Section oversees the operation of all ESLs. Ravi notes that the Section operates a chain of Environmental Survey labs at all DAE sites including mining, fuel fabrication, reactor operation, fuel reprocessing and waste management sites. The labs have standard methodologies and are well equipped with state of the art instruments for the measurement of radionuclides. These labs adapted benefits of technology development in instrumentation and communication. These labs satisfy the regulatory requirement of DAE establishments from AERB, MoEF and State Pollution Control boards with respect to radioactivity release. All the laboratories at NPCIL sites are accredited by AERB. They participate regularly in inter-laboratory comparison exercises and participates in related IAEA activities such as EMRAS, MODARIA and ALMERA (Environmental Modeling for RAdiation Safety, MOdeling and DAta for Radiological Impact Assessments and Analytical Laboratory for Measurement of Environmental Radioactivity).

At present, the environmental modeling and monitoring are two facets being pursued for the understanding of natural processes. The environmental studies pursues physical, chemical and biological understanding processes involving the transport of radionuclides. Simulated experiments are being pursued to validate the hypothesis. Physicochemical speciation of radionuclides in environmental matrices, a good understanding of environmental transport of tritium and C-14 and the formation of their organically bound compounds can be considered as some of the notable achievements of Environmental Studies Section. The findings of these labs are supporting documents for replying the

queries from general public and parliament members. There is a good support from BRNS to address many environmental related challenges through tie up of universities. A good example of such a model is the national level mapping of uranium in ground water. ESLs have marked its presence in activities of societal benefits such as certification of drinking water for radioactivity and public awareness programs.

2.1.3.6 ESL Kudankulam
M P Rajan

Kudankulam is the NPP site that houses the largest power reactors of 1000 MW each of the VVER type in the country today. Already 2 units are in operations and a total of 6 reactors are envisaged and is one of world's largest cluster of NPP sites. Thus the environmental surveillance calls for special approach. The reactors are cooled by normal water which is provided from desalination plants, in the absence of natural water resources. The condenser cooling is using sea water and outlet water with slightly elevated temperature is discharged into sea along with low radioactive treated effluents. One of the concerns of the public is if the warm sea water would affect fishing which is the principal vocation is in the villages nearby.

The ESL Kudankulam operated by Health Safety and Environment Group BARC carries out evaluation of environmental impact of operation of the power station. This Laboratory is equipped with most modern, sophisticated, state of art nuclear, meteorological and chemical instruments which are operated by trained and experienced scientists.

At Kudankulam site, the ESL had started operation since 2003 at the very beginning of construction activities at site. This has helped in collecting the baseline data around Kudankulam Project site on a continuous basis which proved useful during the operational phase of the NPP from 2013. Similar to the elevated background patches observed in Kalpakkam site, the pre-operational surveys revealed many high background areas in Kudankulam site also. During the preoperational surveys the local beach sands showed radiation levels of 1–24 μGy/h at some places which were comparatively higher than the normal background of 0.1–0.2 μGy/h observed in interior villages. The elevated background is due to natural occurrence of monazite. The observation of the relevant peaks in the gamma spectra corresponding to the daughter products of ^{232}Th confirmed the presence of traces of monazite in the beach sands. Concentration of ^{40}K in the soil is found to be lesser than the world average by a factor of two while concentrations of ^{232}Th and ^{238}U are higher than the world average by a factor of 10 and 1.5 respectively. Percentage

contribution of ^{232}Th, ^{238}U and ^{40}K to the background external radiation dose rate are 85.2%, 10.8% and 4.0% respectively which is comparable to that in Kalpakkam.

Radiation survey around Kudankulam environment during the operational phase of the reactors revealed that the background gamma radiation field in most of the villages within the 30 km radius around Kudankulam area is in the range of 0.05 to 17.8 μGy/h. The annual external exposure due to natural sources of radiation in some key population centers ranged from 0.79 to 2.54 mGy. The fall out radio nuclides like Cs-137 and Sr-90 were not detectable in terrestrial food produce and fresh waters while in sea waters and sea foods they were at ambient fall out levels and are comparable to pre operational levels observed around KKNPP.

The results of the environmental surveillance program carried out during 2015 and 2016 at Kudankulam showed that the dose received by a hypothetical man staying at fence post (1.6 km) is only 0.075 μSv, which is far less than the (0.008%) ICRP/AERB dose limit of 1000 μSv prescribed for the members of public and much less when compared to the annual global average dose of 2400 μSv from natural background. At farther distances the doses are insignificant, demonstrating compliance with regulatory limit.

2.1.3.7 Evolution of Micro meteorology in AEET

V Shirvaikar and M R Iyer

The need for micrometeorological studies of nuclear sites became clear to Dr. Ganguly in the very early days of our nuclear program when he was called upon by Dr. Bhabha to prepare a hazard evaluation for the CIR reactor in 1959. The person whom he had selected for this assignment was V Shirvaikar. He was one of the first to join the Health Physics Division in the very early years of its formation. As a matter of fact the earlier crop of scientists who formed the backbone of the health physics program, as was the case with most other programs of AEET, were absorbed from the TIFR - S D Soman, P N Krishnamoorthy, K G Vohra and V Shirvaikar all belong to this group. Dr. Ganguly later joined in 1955, having been identified by Dr. Bhabha to head this program.

Shirvaikar originally joined the Cosmic Ray group in TIFR under Dr. Bernard Peterson in 1954. Later in 1955 he was transferred to Air Monitoring Section headed by Dr. K. G. Vohra under A. S. Rao. He was given assignments on measurement of natural radioactivity in atmosphere and preparation of numerical tables for computation of Radon and daughter products. Somayaji

joined this group and was initially working on thoron daughter product measurements at the newly started Thorium plant in Trombay. Dr. Vohra who joined TIFR in 1954 had already worked on natural radioactivity for his thesis work in the Wilson College Bombay under Dr. Taylor and was selected by Dr. Bhabha to head the group to monitor air for natural radioactivity and radioactive fallout. Shirvaikar remembers that after him V. S Bhatnagar and C. Rangarajan joined Vohra. The three measured and studied natural and fallout activity in rain showers from the widespread testing of nuclear weapons by USA and USSR. Rangarajan along with Bhatnagar continued to work in this field, but the latter left AEET and joined the Physics Dept. of the Atomic Minerals Division in Delhi. Rangarajan continued his pioneering work on radioactive fallout until he retired in 1990. U C Mishra joined Dr. Vohra from the first batch of AEET Training School in 1958. Mishra gradually worked his way up first by heading the fallout measurement group, then the Air monitoring Section, then was head of Training Division for some time before getting back to his original field and headed the Air Monitoring Division. Finally he was Director of the Health, Safety and Environment Group from 1993 to 1996. S Raghupathy joined in 1957 provided instrumental support to this group and fabricated the first multichannel analyzer in HPD for gamma spectrometry work. Sarada joined this group in 1959. Subba Ramu initiated work on aerosol physics in 1957. In 1958 when CIR was being constructed, the need arose to study the behavior of the spread of the radioactive stack effluents (especially Argon-41) from its 400 ft. stack, which required the quantification of micro meteorology of the site. Shirvaikar was assigned to lead this group with two trainees from the Training School, R N Sachdev and V. Sitaraman. After CIR was commissioned the group routinely monitored the ground level concentrations at three air monitoring stations and also established a surface meteorological station in AEET for routine met data acquisition.

Dr. Bhabha had called for a hazards evaluation report for the CIR reactor before commissioning the reactor. Prior to commissioning CIR, a Hazards Evaluation study group was formed under V. Surya Rao, Chief Superintendent of the CIR Project. Dr. Ganguly was the member in charge of the Health and Safety aspects. He inducted other junior colleagues depending upon the topics involved. These included Soman for Health and Safety operations, L. V. Krishnan, A. D Sharma and others on the nuclear side. Shirvaikar was inducted into this group for dose impact assessment using plume dispersion studies from stack releases. For these calculations initially he adopted Sutton plume model, which is a Gaussian plume model and used graphical algorithms for plume gamma dose evaluation, the only ones available at that time. Based

on these models impact of accidental release from CIRUS was computed. This work corroborated the need for micrometeorology studies for dose estimations and Dr. Ganguly established a micrometeorology group which Shirvaikar progressively strengthened.

The computational work of the Hazards Evaluation group was a very strenuous one using mechanical calculators and Slide rules as no computers were available at that time and they had often worked throughout the night sitting at CIR offices and at Mod labs sometimes even up to 5AM and many in the Radiation Hazards Control Section headed by Dr. Ganguly remember participating in the work. This group consisted of Dr. Ganguly, Veeraraghavan, Gopalakrishnan, Shirvaikar, and A D Sharma, K C Pillai and others. The editor remembers assisting this group as a junior member in fission product activity calculations which was labor intensive. Shirvaikar's work on evaluation of I-131 release during accidents was appreciated by the Canadians. It might be recalled that Dr. Bhabha had insisted on the erection of a containment shell for the reactor located near to the mega polis. For the calculations the leakage rate from the containment was carefully measured for the maximum pressure conditions and was the basis of the evaluating the dose under the MCA conditions.

Some of the experience from CIR hazards evaluation was applied to the new power reactor site at Tarapur. As a sequel, after discussions with AKG, Shirvaikar analyzed the offsite doses due to mixed fission product gases in the containment. Based on this analysis the shield design which was to have uniform thickness was changed to be of varying thickness such that 4.5 ft. concrete shielding was available in all directions for slant paths to the receptors.

After CIR was commissioned it was found that Ar-41 release would be 400 Ci per day. Dispersion model adapted to the hilly terrain of Trombay was used to estimate doses and were found to agree well with the measured doses at the Air monitoring stations. The study showed that for westward flow of wind the high stack was not effective and for those sectors the effective stack height was as good as zero, consistent with the principles of fluid dynamics.

While selecting the Trombay site for BARC Bhabha had suggested that the hill would provide considerable shielding for direct radiation in case of a nuclear accident. While this was true only for direct radiation and releases near ground level but not for dispersion of radioactive gases from the stack. To be extremely conservative for some time there was a ban on building heights in the neighboring Chembur areas exceeding 4 floors by the Bombay Municipal Corporation. This was found to be too conservative and the restrictions were

permitted to be removed later on a re-evaluation of the site consequences and was technically shown that no off-site consequences are possible with such a low power research reactor with containment.

Soon after the report was submitted Shirvaikar was deputed to Brookhaven for training in Micrometeorology in 1960. By this time TAPS site was already selected with in-depth involvement from Dr. Ganguly, P. R. Kamath and J R Naidu. It was proposed to build CANDU type reactors in India with Canadian collaboration. After Shirvaikar returned he was assigned the Site selection work for CANDU type reactors. He led the HP team consisting of Y. M. Bhat (Biology), M. C Mehra, Ramamurthy (both chemists). The team visited many sites suggested by the State governments that included Kota, Narora, Kalpakkam which were selected and a few others in Karnataka and Andhra which were not selected. The parameters they studied were population distribution, terrain, Vegetation, Farming, etc., Water resources that are related to environmental protection and impact of any activity release in case of accidents. Dr. Ganguly based on the work of the group had tentatively fixed 1.6 Km as Exclusion distance and low population within 10 km and no large city within 30 km.

The site selection group consisted of V N Meckoni, RP Mehta (electrical engineer) Vengurlekar (Civil) and Dr. G. R Udas from Atomic minerals Division. The committee was headed by Mr. Hayath, Chairman of the Karnataka State Electricity Board. Ganguly was a member of this committee. While this was going on a proposal for a 400 ft. tower for meteorological measurements and a Micro meteorological laboratory at Tarapur and Rajasthan was initiated by Dr. Ganguly. Shirvaikar was called upon to organize these activities. Simultaneously the group also started developing anemometers and wind wanes for the use on these towers. Shirvaikar on directives from Dr. Ganguly started organizing an instrumentation group to take care of these developments. A few electronics people were recruited like Sastry for these efforts. A wind tunnel was also set up at Tarapur Met Lab for calibrating anemometers. Eventually micro meteorological laboratories at all nuclear sites were set up and made part of the ESLs the concept for which was being frozen on the initiative of Dr. Ganguly.

In 1966 CDC 3600 mainframe computer was installed at TIFR and made available to members of BARC. At RAPS the staff routinely read met data and transferred it to punch cards from which it was transferred to tapes for inputting into diffusion model calculations using this main frame computer. Shirvaikar and his group developed Plume dispersal and plume dose programs

in Fortran for this computer. The programs for practical considerations were converted to BASICA and QuickBasic languages that could be used with simple desk computers available in those days. Using these programs Shirvaikar and his group wrote manuals of dose evaluation from atmospheric releases and computed offsite doses under accident conditions. The evacuation distances in the case of accidents were evaluated and presented in a seminar at Kalpakkam based on the estimated release data evaluated by NPC with whom HPD had a close cooperation. The concept of sterilized zone, evacuation zone, etc., were frozen from the analysis of this group which are followed even to this date. People who later contributed to these activities were Sitaraman, R K Kapoor and T M Krishnamoorthy.

Thus Shirvaikar's working with Dr. Ganguly really started with the CIR Hazard evaluation group. Shirvaikar notes that Dr. Ganguly had the quality that he was always open to discussion on any topic. Shirvaikar recalls that he enjoyed total support from Doctor in all his work, though he was partly working with Dr. Ganguly, Dr. Vohra never came in the way of his association with Dr. Ganguly. Later on, the micrometeorology group was transferred from Air Monitoring to Health Physics Division under Dr. Ganguly. AS Rao also always supported the work.

2.1.4 Dr. Ganguly and his contribution to the evolution of Ministry of Environment.

M R Iyer and K C Pillai

Vikram Sarabhai while inaugurating the Seminar on "Pollution and Human Environment" in August 1970, noted that when India was preparing for the Stockholm conference 1972 found that *"what interest there was (on environment) - there was a quite bit of it - was from the industrially advanced nations only"*. Under-developed nations including India remained silent. This, he analyzed was due to the widespread belief that problems of human environment was purely an affliction of the industrially developed societies and they felt that India was still quite far remote from this problem and there were more pressing problems to be attended immediately. In retrospect today, we must admit that this has been the attitude both in the public as well as in political circles, be it in the introduction of TV services in India in 1972 or computerization in public activities as banking, etc. The agitation against computerization on the pretext of losing number of jobs was wide spread in those days and encouraged by many political parties. No wonder this was also the case with safeguarding Environment from pollution, during the preparations to the Stockholm conference. And the debate on pollution would not move into the political sphere for more than a decade.

But when the conference did take place, it turned out to be a watershed in controlling human environment and with universal repercussions both for the developed and under developed world. Significantly, Prime Minister Indira Gandhi observed at the Stockholm conference. "Are not poverty and need the greatest polluters?"

It was here the Indian Prime Minister Indira Gandhi introduced the question of development vs. pollution control which took the front stage later. But it seems that it took some time for the Government to realize this, thanks to the initiative of Sarabhai and when combined with political will eventually enabled India to play a pivotal role in the Stockholm conference. And the conference turned out to be a watershed in deciding the policies at stake for the under developed world.

At that time, in India there was nobody or group which was concerned in this matter, so Dr. Sarabhai raised the matter before the Committee on Science and Technology (COST) of the Union Cabinet GOI of which he was a member. It was significant that in this mission Sarabhai chose none other than Dr. Ganguly and gave him the role of bringing together various interests and stake holders and to form a nucleus for an organization. The Seminar on "Pollution and Human Environment" which Dr. Ganguly organized within 4 months after given the directive by Dr. Sarabhai was the first step in that direction. And it proved to be a watershed in scientific administration of controlling pollution in India as can be testified by it leading to the eventual formation of a separate Ministry of Environment. Bhabha Atomic Research Centre (BARC) was the nerve center of this thought machinery, having done yeomen work in taking care of the environment in so far as the radiation safety was concerned by the pioneering work of Dr. Ganguly. As Dr. Sarabhai observed in his inaugural address to the COST seminar *"that only when this problem is faced in its starkest and most brutal form (as in atomic energy) that man wakes up to do something about it."* He further observed that *"containment of radioactive wastes is a thing in which we need this pragmatic approach while making containers which have the required integrity for hundreds of years"*. This is what precisely Dr. Ganguly envisaged in 1959, 12 years earlier, in initiating and undertaking work on temperature distribution in radioactive solids in a visionary initiative. At that point of time India did not have even an operating nuclear power reactor, let along the nuclear back end facilities except a 1 MW research reactor, though Dr. Bhabha had set the blueprint. What I want to stress is the visionary zeal of Dr. Ganguly at that point of time in initiating this work. He used to mention that he wanted to set the limit of loading radioactive waste in glass spheres so that the temperature will not

reach its melting point or will result in any structural damage. He first did this theoretical work on beta active spheres and later on extended it to gamma emitting wastes also. Not having satisfied by using spherical geometry, he thought the cylindrical geometry is what might be used eventually and so he tackled the mathematically more difficult problem of radioactive heating in radioactive cylinders. One has to keep in mind in those days without the service of computers such problems need to be dealt with analytically. Waste management was one of the mandates of the Health Physics Division in those days. Incidentally these were the first papers on waste management presented in an international conference from India.

In a reference to Dr. Ganguly's pioneering work on setting up limits for release of radioactivity into the marine environment as early as in 1960, Dr. Sarabhai significantly observed that *"I think it is here in the Health Physics Division, BARC and Dr. Ganguly and his group have laid down foundation of a very systematic study even before Tarapur plant came into operation"* and called for many more studies. On the basis of these findings Sarabhai enabled India to make original contribution to the Stockholm conference. Dr. Sarabhai at the inauguration of the seminar even foresaw the question of heat balance between the equator and the poles as not a far off fantasy and touched upon the importance of thermal pollution, a topic on which Dr. Ganguly initiated work much earlier. One of the declarations at the Stockholm conference was: "The discharge of toxic substances or of other substances and the release of heat, in such quantities or concentrations as to exceed the capacity of the environment to render them harmless, must be halted in order to ensure that serious or irreversible damage is not inflicted upon ecosystems". This was foreseen much earlier by Dr. Ganguly in that he laid stress on studying and controlling thermal pollution from the out falls of reactor coolant into the sea.

H N Sethna in his address observed that *"in atomic energy we set limits on release based on the safe recipient capacity of the environment and control is achieved by effective method of treatment containment"*. And "this is the only industry which set norms as a part of the operational responsibilities." The concept of recipient capacity of the environment was originally introduced in the Ganguly-Pillai study of the environment in 1960, which set limits for discharge. As divulged by K C Pillai, Dr. Ganguly believed in studying the environment before embarking on study of pollution by exploring the Thane creek environment. The small team of Dr. Ganguly, K C Pillai, JR Naidu made extensive survey of the Thana Mumbra creek which is the recipient of the possible release from the Centre which was taking shape. Having analyzed the environment they proceeded to

embark on the pioneering work of setting the limit for discharges from the nuclear facilities.

Sarabhai at the seminar also introduced the benefit vs. risk concept. He brought the issue of pollution of rivers which will affect the country at large much beyond the boundaries of industrialized areas. We should appreciate that this is the problem now the country is facing in its starkest form. The benefit vs. risk concepts became one of the base lines in formulating the Stockholm declaration. It was Indira Gandhi who first brought the idea of sustainable developed based on the inputs from the scientific community in India

Subsequent to the seminar Dr. Ganguly organized collating the effluent data from chemical industries in Bombay by issuing a detailed questionnaire for assessment of pollution and human environment. A report on the analysis of the data along with recommendations was communicated to COST which was one of the inputs based on which PM Indira Gandhi formed a separate ministry of Environment to foresee and preserve the Human Environment in India.

2.1.5 Environmental surveillance in front end of fuel cycle

2.1.5.1 Setting up of Environmental Survey Lab in UCIL Jaduguda

M A R Iyengar

2.1.5.1.1 Introduction

MAR Iyengar reported for joining AEET in 1961 at OYC and was told that he will be working with Dr. Ganguly, a great scientist. MARI felt greatly elated as it looked like a lifetime opportunity for him. He eventually reported on Jan 10th 1961 at the Electronic Shed at South Site in AEET and met Dr. Ganguly in his unassuming office. He looked at his papers and called for Somasundaram and asked him to take MAR Iyengar in his group. Somasundaram in turn allotted him work as a health physicist at the Apsara reactor. Iyengar mentions that at Apsara he was guided through the various facets of the duties of a health physicist by M R Iyer who was overseeing the health physics operations there. The editor notes that including himself as many as 5 students of Dr. Ganguly started their career in this "nursery" of Health Physics at Apsara. MAR Iyengar noticed that M R Iyer was also carrying out some physics research work doing fission product activity calculations and at times trying his hand at some experiments. He seemed to be carrying out his research assignments under the direct guidance of Dr. Ganguly. Noticing this MARI longed to do research under Dr. Ganguly one day. But except for analyzing the gross activity of Apsara coolant water samples there was not much of any analytical/radio chemistry work at Apsara. Iyengar

mentions that he was rather disappointed to work as a health physicist as he did not notice any chemistry work for him waiting there. After a year or so MARI approached Dr. Ganguly and expressed his desire to join a Chemistry group due to his background as a chemist. Dr. Ganguly eventually asked MARI to join P R Kamath's group devoted to environmental and bioassay chemistry studies. There were many chemists working on different problems in that laboratory and MARI felt a bit relieved. As Kamath was abroad he reported to I S Bhat and started his career as a chemist in the bioassay laboratory devoted to radio chemical analysis and assessment of intake of radionuclides by radiation workers through excretion analyses. MARI worked there from 1961 to 1966. Sometime in 1962 a seminar took place at the Institute of Science Bombay and MARI was asked to be ready for presenting a paper on safety aspects in a radiochemical laboratory authored by him and P R Kamath along with Dr. Ganguly. MAR Iyengar was nominated for participating in the seminar. While attending this seminar from morning, sometime around noon he was told not to present the paper as it stands withdrawn. MARI was somewhat disappointed and partly relieved as this was his first attempt at presentation. Later he came to know that as it was felt that the symposium was not up to expected standards and there were some criticisms and hence the paper was not presented. Later when MARI met Dr. Ganguly in his office, he said Ramanuja, let us aim a little higher, as these conferences come and go. This was a balm, for MARI for the disappointment he faced at the early stage of his career.

MAR Iyengar later on was selected by Dr. Ganguly to carry out environmental chemistry work at the UCIL Jaduguda mines where he got the benefit of working directly under Dr. Ganguly's supervision and contacts with him became more close and intense. In 1973 there was a further shift in his assignments and Dr. Ganguly asked MARI to proceed to Kalpakkam and take up the charge of the Environmental Survey Laboratory being set up there. This was for carrying out first the pre operational environmental radioactivity analysis at the site of the second nuclear power stations being set up based on PHWR technology. MAR Iyengar continued to carry out the mandatory environmental impact assessment of the operation of the power station till his retirement in 1998.

In his very first encounters with Dr. Ganguly he noticed that his dress sense was quite interesting. The huge bush shirts he used to wear, looked quite outsized, with oversized pockets and anything close to that was jocularly addressed as Doctor's fashionable outfit. But he was very comfortable with that, it was like a signature attire, and sometimes used to be a lively topic of discussions amongst close friends of MARI, A. Ramamoorthy Jr., and

a friend from DRP, S. V. Parthasarathy (alas he is no more), as the three formed a close trio at Trombay. Doctor's very physical frame was quite a robust one, and his even bigger attire made an impressive sight, and even in a gathering one could catch his presence easily from a distance. In a western suit which he occasionally wore during International seminars, he looked outstanding, and brilliant, and when he spoke in his characteristic unhurried extempore style, even gesticulating with a whiff of his thumb and mid finger sometimes to stress a point, he looked brilliant and delectable indeed!

Another interesting sidelight of Doctor was his penchant for the paan, a diehard and ritualistic obsession, more commonly seen among colleagues from North and particularly from Bengal, and Doctor was no exception to this habit. But he refrained from this habit during official engagements and would make it a point not to carry the stock of paan with him, but he would easily meet his requirements from another close colleague of MARI. That was Ahmed Ali Khan, a M.Sc classmate of MARI from Hyderabad, who was working in Kamath's lab in Trombay, and who was an abundant repository of paans, not just to meet his own robust demands, but also the occasional requests from Doctor. Another source of procurement was Dasgupta, the health physicist colleague of MARI at Apsara, who had even a greater passion for Paans.

Although Doctor was a chemist by training, he specialized in radiation chemistry as a post-doc, doing advanced research, along with prof. Magee, at Univ. of Notre dame in USA. But in AEET he dabbled with not only chemistry but was quite at home directing research in physics and Mathematics and brought up many disciplines into the health physics stream. As a matter of fact he was quick to grasp any subject which became relevant in his investigations. In the earlier days some beginners under him was so impressed by his broad based knowledge that they thought he must have be a double or triple PhD degrees!

His attitude to colleagues was one of genuine warmth, and affection, transcending all stiff official attitudes, which are usually observed in an office or departmental environment. But Doctor was a rare and exceptional exception, and most of us felt much endeared to him. But this did not mean that he was lenient with his juniors in their work sphere, or take it easy on scientific issues, or be relaxed on meeting on deadlines. However, he had his unique way of enforcing strong discipline in very sober manner and achieving his targets. That made everyone feel very free with him and all became more motivated to achieve targets much better than what they thought they are capable of. MARI felt personally it was great delight, and a rare opportunity to seek an occasion to meet and discuss with him the findings/results and data, for which the wait

was enormous at times, and show him with a degree of pride, and he would be in tune with the problem, in no time.

2.1.5.1.2 Setting up of ESL at UCIL Jaduguda

MARI was given the responsibility to organize and carry out environmental chemistry operations at UCIL, Jaduguda uranium mines in 1967 when Dr. Ganguly felt the need for a chemist there to control the effluent discharges from the plant and to assess its impact to the public. The environmental laboratory in the NPPs was a more streamlined operation and under the guidance of Dr. Ganguly. But the environmental surveillance came as an afterthought after the start of the operation of the uranium mines and mill at Jaduguda and Ramanuja Iyengar was given the responsibility to carry out this by Dr. Ganguly. Iyengar went about setting up the environmental surveillance operations at Jaduguda where till then only operational health physics operation were in place by the Health Physics Division. And Ramanuja Iyengar had more close contacts with Dr. Ganguly in his role of an environmental chemist at Jaduguda and he has very rich anecdotes in his contacts with Dr. Ganguly. The support he got from K C Pillai in Trombay who was overseeing the environmental surveillance operations of the Health Physics Division after P R Kamath retired also need to be mentioned. With the persistent efforts of Dr. Ganguly a separate building for the Health Physics and environmental safety operations at UCIL was realized and was inaugurated in 1975. When some questions arose in the press about the effect of Tailings pond on the public it was this environmental laboratory which came to the help of UCIL to provide data and allay the doubts of the public on the safety of Uranium mill operations.

MARI recalls that once during his visit to Jaduguda after going through his work, Dr. Ganguly told him "Ramanuja, you have a wealth of data, from your studies, but you don't know how to apply your findings, for a better conclusion". This greatly upped his confidence, and also prodded to go deeper into the issues, and apply a strategy for better pollution control, in the Gara River, adjacent to the Uranium mill at Jaduguda. He remarks "Very inspiring to think, the words ring in my mind, even to this day. A quintessential scientist to work with and every interaction with him was greatly motivating and rewarding".

2.1.5.1.3 The story of pyrolusite and its dual use

During one of his visits in 1971 to the Uranium Mill, Iyengar took Dr. Ganguly to the Tailings Pond which was the repository of residual wastes after Uranium recovery as Yellow Cake. Doctor stood on the bund wall abutting the tailings reservoir in a reflective mood, and called Iyengar, "Ramanuja, don't you

think, the oxidant used in the oxidation process at the mill leaching stage, for converting Uranium(IV) to Uranium(VI), prior to leaching from the crushed ore matrix, is doing a great job, in controlling spread of pollution from tailings pond to the neighboring environment". It took some time for MARI to understand and gauge the depth and implications of this profound statement. What Dr. Ganguly implied was, that the Pyrolusite mineral, an oxide form of manganese which is a strong oxidizing agent used in the milling operations was playing a twin role. By design it served the primary role of oxidizing Uranium (IV) to Uranium (VI), which then became easily amenable to leaching by the acid medium with high efficiency. But what dawned on Dr. Ganguly, the great environmental chemist, was that unintentionally when the plant operators dumped the excess manganese mineral into the pond as waste along with the radioactive effluents it had the great potential to trap and hold back all or most of the toxic radioactive elements like Ra-226, Pb-210 Po-210, and hazardous heavy metals like lead, selenium, copper, etc., which were also present in the Jaduguda ore body. It took some time for MARI to fully realize the implications of the message that Dr. Ganguly was trying to convey. The principle was used later to treat the effluents in Jaduguda mines when, on the recommendations of Dr. Ganguly, a waste treatment plant was set up to remove not only most of the radioactive components but to trap many toxic minerals also. When MARI understood what Dr. Ganguly had in mind he was astonished to see how such important scientific suggestions get revealed to him during seemingly casual visits.

It was not only in suggesting scientific innovations that Dr. Ganguly excelled but he was a task master in enforcing environmental protection measures at DAE installations. Iyengar has narrated an episode to prove this point. The environmental aspects particularly, at the mill in the beginning were a bit tardy and needed improvement. Following the HPU routine reports to the Mill functionaries, when the situation needed further improvement, this was brought to the attention of Dr. Ganguly. In his very cogent response, Doctor lost no time in communicating to the authorities at the helm that the situation demanded immediate redress and all measures as well as follow up action. In fact he stressed on the DAE philosophy that the responsibility of the Site Management does not stop at the fence post, but goes well beyond that, in the domains called environment where the general public has a right to safety, right to their health and feeling of well-being, and the sanctity and adequacy of our operations are judged at this level and that should be the guiding criterion for all operators of DAE facilities. This had the desired salutary effect on the management to enforce better environmental safety.

In later years during MARIs tenure as the Officer in charge of ESL Kalpakkam the suggestion by Dr. Ganguly on the side of the Jaduguda tailings pond came focused in his mind, when he happened to come across some research papers on using manganese di oxide coated polymers for pre concentration of radium from bulk sea water while leading the ESL programs at ESL Kalpakkam. In those days MARI was participating in an IAEA coordinated research project on Radium in the environment. Iyengar developed the methods based on the earlier suggestions of Dr. Ganguly and extensively used it for analyzing radium in water bodies under the Radium Project. This enabled him to contribute significantly to the Project. When MARI discussed this new development with Doctor, he was delighted, and could see a happy glow on his face which is still fresh, to recollect.

2.1.5.1.4 Idea sown by Dr. Ganguly turned into a commercial venture

And again the interaction of the student and the teacher came as a great fillip much later. Post retirement Dr. Iyengar continued to work on a technology to purify water based on that idea of 1970 and succeeded in developing potable water purification plant to treat community water and passed on the knowhow to M/s Eureka Forbes and turned it into a financial venture. This resulted in a purification plant for effluent treatment had found application in 2010. Thus a simple idea planted by Dr. Ganguly in the mind of MARI took root and grew and resulted in developing and passing on the knowhow for commercial production of "Aquaguard Miracle" a device highly efficient for Arsenic and lead purification in ground and industrially polluted drinking waters". But Dr. Ganguly was no more around for MARI to share his excitement!

He acknowledge the success of this venture to Dr. Ganguly thus "the water purification technology developed by me some time back, has been further leased to M/s Eureka Forbes for another 7 years, based on its good field success. I owe this achievement to that great visionary scientist Dr. Ganguly, who sowed that idea in me during a discussion and field visit at Jaduguda, during 70's, which I could pursue with passion and succeed, during my post-retirement years. I wish to salute him, the visionary that he was, for this humble contribution of mine for resolving one of society's challenging environmental issues relating to water."

It may not be out of place to quote a remark made by the younger brother of Dr. Ganguly in 2016 which is included in Part I of this volume. Sushil Ganguly remarked that "In his tryst with radiation chemistry at University of Notre Dame and his earlier research work at Calcutta university on ion exchange of soils, he could have found avenues easily to work his way up in United States

as a successful academician or an entrepreneur with potential for earning "not thousands of dollars per month but per hour", but his nationalist temperament made him anxious to get back to India to serve, where his base existed. So if he did not make money but his ideas sown into the minds of his students did then that talks volumes for the vision of Ganguly.

2.1.5.2 Environmental Studies at IRE Plant, Alwaye,
A. C. PAUL
2.1.5.2.1 Setting up of ESL at IRE Plant Alwaye

Dr. Paul shifted his work theatre from being a water chemist at CIR to the role of an environmental chemist in 1972. He opted for posting as Health Physicist at the Indian Rare Earths plant at Alwaye, where Dr. Ganguly felt an urgent need for carrying out environmental surveillance, combined with Health Physics activities. Thus Paul got his second assignment of his carrier from Dr. Ganguly, of being a reactor water chemist to an "environmental chemist". The assignment that Paul got resulted in basic studies on pollution assessment of River Periyar, which hosted several industrial units on its banks. As noted elsewhere, the last assignment Dr. Ganguly himself undertook was heading a Committee on controlling pollution of Batsai River in Mumbai region and the results of studies he initiated at Alwaye would certainly have been in his mind when he insisted on sustainable policy for locating industrial units on the banks of Rivers.

It was in 1974 that Dr. Ganguly visited the Indian Rare Earths plant at Udyogamandal, Alwaye, Kerala to see the plant and environment, with the River Periyar flowing by its side. Following his tenet that one should study the environment before trying to work on environmental pollution, Dr. Ganguly wanted to have a first-hand feel of the River ecosystem, take cognizance of its being the source of drinking water in the region, assess the pollution status and shape-up a future plan for systematic study of the water body as a model for future investigations in fresh water eco-systems.

2.1.5.2.2 Dr. Ganguly visits the ESL and initiates work on environmental studies at the Periyar River

Dr. Ganguly's visit to Alwaye was a very special one, Paul recalls, not only for the resident Health Physicist but also for the IRE establishment. The founder Managing Director of IREL, Col. Rajagopal Menon, specially came from Bangalore to greet him. Along with the General Manager of IREL, B. P. Nair he received Dr. Ganguly with a rose studded garland at the airport. K. C. Pillai, Head, Environmental Studies Section accompanied him on this visit. As they were travelling from the airport, through the Wellington Island Bridge,

he recalled his earlier visit to the city for attending a seminar. He was then taken round the IRE plant and he showed keen interest in all the operations, especially the ball mill, TSP bagging area and drum plant. A live demonstration of drum making was specially arranged in the Drum Plant. Impressed with its working, he took the flat lid of the 200 liter drum and passed it on to Paul with a mischievous remark "aap ka thaali banaya". After the plant visit he was taken to the Guest House, where Col. Menon was waiting. That evening witnessed an unusually warm get-together of the two old friends. They went on chatting and merry making, like two school boys of their mischievous exploits, till late in the night. Finally, when he retired to his room he did not forget to tell Paul about the assignment the next day-visit to the Health Physics Unit and River Periyar!

Doctor's visit, the next day, completely changed the scope, profile and responsibilities of the Health Physics Unit at IREL. The unit was, till then, attending only to routine monitoring of the operations and was housed inside the plant. He expressed his total displeasure in the arrangement and explained to B. P. Nair the need for a separate and independent facility to undertake all studies related to Health Physics surveillance, including bioassay and environmental monitoring. Nair was instantly convinced and suggested some alternate locations to house the H.P Unit. Doctor zeroed in on the top floor of the main Administrative building, which was soon geared up to exclusively house the Unit.

2.1.5.2.3. Sampling Cruise through Periyar River and an environmental program takes shape

The afternoon was devoted to a boating cum sampling cruise in Periyar River for an on the spot assessment of the pollution status of the pristine water body. The River hosted a number of large and small industrial units on either side of its banks, which poured out their effluents through a number of outlets. Doctor did not conceal his displeasure to such a scenario. Paul mentions the fact that, credit goes to Dr. Ganguly for pioneering the idea of a common effluent park catering to all industrial units - a theme endorsed by the authorities after 3 decades!

Doctor was actively involved in the sampling, asking the crew to take special samples from some locations. He seemed to have so emotionally got involved in the whole mission that at times he would himself take samples and examine them for color, odor and even taste, apart from measuring the acidity/alkalinity by pH paper! His total involvement in the sampling Cruise, with missionary zeal, had an invigorating effect on all to bring out their best. What he demonstrated was too deep for words; however, it conveyed the strongest and most appropriate message

of a true scientist and rare leader. The boat cruise had its lighter moments too! He used a binocular to spot distant objects and whenever he spotted a bathing ghat, he would ask the driver to go fast, lest the over-enthusiastic youngsters in the boat would become too eager to go closer for taking a sample! With a mischievous twinkle in his eyes he remarked that the detergents in the water would spoil the results! The boat cruised up to Alwaye, 10km upstream from the starting point at IRE jetty, where the boating was terminated as the River was getting shallow. Dr. Ganguly seemed to have thoroughly enjoyed the cruise through Periyar and was marveled at the natural beauty of the serene water body, flanked by tall coconut trees dancing to the sway of westerly winds. Paul reminisces that the cruise through Periyar, with Dr. Ganguly at the ore was one of the most memorable events in his scientific life. It was a rare event that combined scientific study in all its seriousness, suggesting how to combine a technical mission with pleasure and excitement - a rare legacy of the late Guru!

2.1.5.2.4 Pilgrimage to the Adi Shankaracharya Math at Kalady

Dr. Ganguly's visit to the Holy Math at Kalady, the subsequent day, had the fervor of a rare pilgrimage. Since the boat could not go up there through the River, the journey was undertaken by road. When the vehicle was crossing the bridge at Kalady he asked the driver to stop and got out. Holding the railings of the bridge and leaning forward he seemed to enjoy the breath taking view of Periyar, flowing thunderously below, in all its full majestic charm. The Adi Shankaracharya Math was close by. Paul narrated the mythological story of Adi Shankaracharya entreating the River to change its course for the sake of his ailing mother to continue her daily bath in its waters. Doctor keenly listened to the tale with all seriousness and asked Paul to mention the episode in the introductory part of his thesis. His visit to the Math was filled with solemn reverence, serenity and adoration. He stood at the holy place, eyes closed in silent prayer and asked Paul to do the same. Thus, Paul was witness to his Guru's absolute obeisance to the great Acharya of the Advaita. Paul considered it as a natural reflection of Dr. Ganguly's own version of Advaita, which he relentlessly pursued in his profession. After going through the Math and keenly listening to the guide, explaining the life and teachings of the Acharya, he moved to the library and scanned the various literary works exhibited there. He purchased a few of them. He then advised Paul to visit the Math whenever he went there for the sampling. This advice made Paul understand that science does not confine itself to the four walls of a laboratory, a great truth prophetically divulged by the great Guru.

Dr. Ganguly left a lasting impression on everybody he met at Alwaye. B. P. Nair whispered to Paul, "He seems to be a great scientist!". By the time he

left Alwaye, Doctor was in full awareness of the potential of the area for an exciting scientific work on environment. Paul says that his parting words still ring in his ears: "You have a gold-mine here and you may go mad!" Paul and his team did go mad indeed, carrying out intensified environmental studies at Periyar River in subsequent years.

Though Dr. Ganguly instituted Environmental Survey Laboratories (ESL) in all NPP sites from the very first nuclear power station at Tarapur, system of environmental laboratories at the front end of the fuel cycle came about from his visits to these sites. UCIL Jaduguda and IREL Alwaye are examples of these. Many may not realize that it was solely due to the vision of Dr. Ganguly that these facilities serve as corner stone installations which provide convincing answers to the public concerns about the environmental impact of the operations, whenever such questions are raised

2.1.5.2.5 Studies in Periyar River

The studies to be carried in Periyar River were planned as per the broad guidelines provided by Dr. Ganguly. He told K. C. Pillai to be closely associated with the work. Paul also registered for his PhD in Bombay University under Dr. Ganguly on the topic "Radioactivity and Trace Metals in Aquatic Environment". Paul recalls that while working under Doctor for his degree, he retired from service; however it did not affect his association with the work as he continued in BARC as a National Fellow. The main venue of discussions with Doctor during Paul's occasional visits to Bombay moved to the lawns of "Saras Baug" in Deonar, where he spent the evening of his life.

The studies in Periyar River, hailed as first ever reported on a tropical river, were published in many international journals and received wide scientific acclaim. The thesis submitted by Paul, based on the studies, entitled "Distribution of Radioactivity and Trace Metals in Aquatic Environment" was awarded PhD from Bombay University in 1980.

Periyar is the longest River in Kerala, having a catchment area of about 5000 sq. km. The River originates at the scenic game sanctuary of Periyar Lake at Thekkady in Western Ghats and winds its way down 300 km stretch through the valleys and thickly populated plains of central Kerala before discharging into Arabian Sea at Cochin Harbor. The River is the chief source of drinking and irrigation in central Kerala, including the Corporation of Kochi. The reported monthly run-off in the River at Kalady, during 1970, ranged from 50 Mm^3 in March to 2500 Mm^3 during monsoon season. The run-off in Periyar was estimated at 30% of the total run-off in the state of Kerala, which signifies the

major role of the River in shaping the ecology of the entire region. The River hosts a number of chemical industrial units on its banks at the Udyogamandal-Edayar industrial belt, near Alwaye. The units depend on the River for their water requirement and discharged their effluents into the River. Due to lean flow in summer the River also experience tidal influx, especially in its lower reaches.

Systematic investigations were conducted in the River by dividing the stretch into Background, Industrial and Backwater zones, depending on the topography and utilization. The study phase was also sub-divided into that in monsoon and non-monsoon seasons. Such division made it possible to decide on the locations and the sampling protocol.

The studies confirmed diastrophic changes in the catchment area as a result of the turbulent conditions in monsoon. Meandering of the River reduced the flow velocity resulting in the silting of the lower reaches of the River, especially the backwater area. The studies also found significant variation in the water quality in the river at the industrial zone due to the effluent discharge and tidal influx. The environmental monitoring in the stretch threw light on the general water pollution from industrial units, which did not attract much attention from the pollution control authorities at that time.

2.1.5.2.6 Radium in the River

The River had a higher background concentration of natural radium nuclides, in agreement with the occurrence of higher natural radiation background in the area. The qualitative and quantitative changes observed in the distribution of Ra-228 and Ra-226 underscored the influence of industrial activities on the banks of the River. Study of the nuclide activity ratios, in different matrices, provided information on the source, species, uptake and biological transfer of the radio-nuclides. Nuclide availability, determined by the extent of mineralization, played an important role in the uptake process and in that respect the shorter-lived Ra-228 had a higher role than the longer-lived Ra-226. In the tropical water body the radium isotopes showed a dynamic adsorption-desorption cycle in sediments, which was a significant observation in the context environmental migration of pollutants from fresh water to the coastal marine environment.

2.1.5.2.7 Trace elements in the River

The operations of a wide spectrum of chemical industries on its banks made the River a potential recipient of several trace elements. Detailed investigations were carried out to assess the pollution status of the pristine water body. Trace elements investigated in the River were Cu, Mn, Zn, Ni, Fe and Hg, based on

the chemical operations undertaken on its banks. Since these elements were also of natural origin, studies were undertaken to assess their background concentration levels in the River environment.

The concentrations showed natural variation by an order of magnitude. However, the impact of effluent discharge, on their concentration levels, could be distinctly identified in the River environment. Studies on detailed aspects such as chemical species, organic complexes, geochemical transport, etc., could identify and quantify the industrial pollution of the River. The River sediment was identified as the primary sink of the pollutants. This observation was important in determining the uptake and toxicity of pollutants to the benthic organisms in the water body.

2.1.5.2.8 Geochemical transport as a tool to quantify pollution

Geochemical transport was studied as a tool to quantify pollution of the River. The run-off amounted to 90% of the reported value. The total solids, transported through the River were estimated at 0.6 million tons in a year, mainly from the drainage area at the fluvial zone. The data indicated the quantitative value of the physical natural erosion caused by the River run-off. Incidentally, it quantified the natural degradation of the eco-system and provided a useful input for environmental planning for sustainable utilization of the water body.

Geochemical transport of Ra and trace metals has been worked out in the River to estimate the natural and technological contributions. Thus it was possible to quantify the industrial pollutant discharges, eliminating the need to probe each effluent outlet. In geochemical terms, the methodology offered a useful tool to estimate River discharges, in-land erosion, sediment transport and their impact on the coastal marine environment. This was indeed a novel approach to quantify industrial pollution in water bodies.

2.1.5.2.9 Release of radioactivity from phosphate fertilizer industries

Dr. Ganguly had a wide range of scientific interest as is evident from his foray into diverse objects. One such area was the study of radioactivity related to phosphate fertilizer industry. He knew that the Alwaye settings provided a good opportunity to study this aspect. He, therefore, contacted the Chairman and Managing Director of Fertilizers and Chemicals Travancore Limited (FACT) and his request was immediately translated into action. FACT provided all necessary help and assistance for undertaking the work and the senior staff took special interest in the task. The work has been acclaimed as the pioneering environmental radioactivity investigation in a conventional fertilizer plant.

The work was planned systematically for radioactivity inventory in the whole process. For this, the samples of raw material, products and effluents were analyzed by a proportionate sampling method. Ra-226 was the marker isotope for all the radiochemical analyses. The study revealed that nearly 60% of Ra-226 in rock phosphate was accounted by phosphogypsum waste of the main process.

Application of phosphate fertilizers enhances the soil radium inventory. This was revealed in a study in paddy fields subjected to regular application of phosphate fertilizers and those in which only natural organic fertilizers were used. The enhancement of Ra-226 in agricultural soils in the phosphate fertilizer applied fields amounted to 30% above the normal natural background levels.

It was revealed in the studies that natural leaching of Ra-226 from phosphogypsum constituted the largest single source of this nuclide in the environment of the fertilizer plant. Leaching of the radionuclide from the source depended on various environmental factors such as rainfall, acidity, salinity, consolidation of the sludge bed, vegetative cover, physical disturbances and aging. The studies conducted were helpful in providing guidelines for environmentally safe disposal of the solid waste from fertilizer plants.

2.1.5.2.10 Uptake of radio-nuclides through food chains

One of the major areas of concern in environmental radiation exposure is the concentration of radio-nuclides in food chain resulting in intake by humans. In order to understand this it is necessary to know the uptake and concentration factors in different species and entities that act as vectors in the food chain. A large data bank existed on these aspects related to the marine environment, generated globally. However, there was dearth of such information in fresh water eco-system. Dr. Ganguly foresaw the need to fill this gap, especially in the context of establishing nuclear power plants in interior parts of the country. Studies undertaken in the tropical River Periyar offered a unique opportunity to generate such data and it became part of his visionary approach in environmental investigation.

The work involved extensive data collection and analysis in the aquatic ecosystem. Profiling of water and sediments were carried out by speciation studies, which involved determination of ionic entities, organic complexes and humus matter. The humus content showed a distinctly increasing trend toward the lower reaches of the River. However, concentration of both Ra and trace metals in the humus matrix showed a source related chronology. Incidentally, this observation offered a reliable scientific tool to identify and characterize different sources of pollution in the River environment. The concentration

factors (Kd factors) for Ra-226, in the River sediment, was in the range of 1×10^3 to 5×10^3. The concentration factors for trace metals showed individual variation over wider range, from 10^2 to 10^4.

Various modes of uptake, for radium and trace elements, have been identified in the fresh water environment. Prominent among these are foliar adsorption, intake (systemic & non-systemic) and food chain. The pathways identified in human exposure were generally direct ingestion, the grass-milk route and fish consumption. Unlike in the marine environment, no significant bio-magnification was observed in the fresh water eco-system.

2.1.5.2.11 Concluding remarks

The visionary outlook and scientific zeal of Dr. Ganguly enabled a comprehensive and systematic study of pollution of several conventional industrial plants, including IRE, situated on the banks of River Periyar in Kerala. The study was hailed as the first ever, undertaken in the country and received wide national and International scientific acclaim.

2.1.6 Dr. Ganguly and the evolution of Marine science research in AEET. K V K Nair

2.1.6.1 Oceanographic research in Health Physics Division

In 1958, Dr. Ganguly had initiated with KC Pillai work on physiochemical and radiological aspects of Bombay harbor bay which included tidal movements, water renewal rates and distribution of natural and fallout radionuclides in sea water, sediments and biological organisms. These are described in other sections of this volume. The significance of oceanographic studies in evaluating the discharge of radioactive effluents in the sea was amply demonstrated by these studies. As a consequence of this, Dr. Ganguly realizing the importance of oceanography and biological studies in environmental sciences formed a group in 1960 with recruits having previous experience and academic qualifications. This was headed by Dr. R. Viswanathan who was formerly from CMFRI (Central Marine Fisheries Research Institute) and a chemical oceanographer by profession. He had his PhD degree from Russia, writing his thesis and defending it in Russian. Subsequently, many others were inducted into this group as observed by Dr. K V K Nair, one of the members of the group who grew up with the group. The other members of the group were Dr. J S Sastry, a physical oceanographer, Dr. Bhupendra Patel, his wife Dr. Shakuntala Patel, a couple who had their training in UK, Dr. Yogesh Bhat and Dr. T P Sarma who had been working in TIFR. This strong academic group was strengthened by fresh recruits of SS Gogate, VN Sastry C. Sreekumaran, TM Krishnamoorthy, MC Balani, Vincent D' Souza and K V K Nair. All these members made

their imprint in the program and later many of them graduated as leaders in various disciplines in BARC, IGCAR and National Institute of Oceanography. KVK Nair reminiscences that the group was twenty strong and easily the best marine science group anywhere in India. This is a clear example of the vision of Dr. Ganguly which led to such strong technical groups within the framework of Health Physics in AEET. The group's activities encompassed study of aquatic systems, both marine and inland throughout the country. The group can be even seen as the forerunner of many activities in the National Institute of Oceanography in Goa.

2.1.6.2 IAEA aided Project Marina, the first IAEA project in AEET

One of the earliest IAEA project known as Project Marina was initiated by Dr. Ganguly and the marine science group carried out pioneering studies of radioactivity in the marine environment by measuring fallout nuclides like Cs-137, Sr-90, etc., in marine ecosystems including water plankton, benthos and sediments in the Bay of Bengal and the Arabian Sea. The group was the outcome of the initiative of Dr. Ganguly in studying the aquatic environment in view of the coastal power stations being planned in India. The IAEA gave equipment and support worth over USD 80,000 during the course of the 3 year project. This was the biggest project awarded by IAEA till then. The project resulted in large number of publications many of them carried out for the first time in the region and enabled one of the well-equipped laboratories for environmental studies.

Dr. Ganguly had planned to secure a research vessel for this group and asked. T. Subbaratnam to draw out a proposal for a research vessel to meet the needs of Project Marina in 1965. The proposal put up with all details and drawings was submitted to the AEC. At the AEC meeting Dr. Bhabha opined that Dr. Devendra Lal who was in TIFR and who was a visiting professor in Scripps Institute of Oceanography (SCI) should be approached whether we can get a research vessel on lease from SCI. Dr. Lal was also doing work on Be-10 and Si-32 having applications in marine geochemistry. Due to various reasons, both due to the crunch of resources in the aftermath of the 1965 Indo Pak war and other internal issues, the proposal for a research vessel could not be carried through, remembers KVK Nair. He feels if the project materialized the BARC group would have been the first in the country to use such a research vessel and could have contributed significantly to the ocean sciences much ahead of the program that was being shaped in Goa in the form of NIO. The planning however led to several Indian Ocean Expeditions including one to Angria Bank of Ratnagiri led by AEET and NIO in later years. Dr. Sastry and Dr. Sen Gupta later joined the NIO and became deputy directors. One can

gauge the depth of the vision and planning which Dr. Ganguly had from this development. But when he found the people whom he nurtured could benefit the national scientific activities he had no hesitation in allowing them to take roots elsewhere. This is a rare quality which many others had observed in AKG.

2.1.6.3 Study of environmental impact of Project Plowshare in Australia

Dr. KVK Nair reminiscences that in 1966 a proposal was made from USAEC to Australian Government to make use of nuclear detonators to make a harbor at Cape Keraudren on the west coast of Australia. On the suggestion of A M Thomas who was Indian High Commissioner in Australia, a study was initiated on the consequences and impact of such a step to India due to the ocean connects with Australia. Dr. Ganguly was the evident choice to undertake this evaluation and he constituted a working group consisting of K V K Nair and a few members of his oceanography group to study the possible impact of the Project Plowshare in Australia. K V K Nair and his group prepared a detailed report and submitted to the Chairman AEC (BARC-I-5). It was a comprehensive report covering physical chemical and biological aspects of such a Plowshare program. It was much later that India undertook a PNE test for investigating the use of underground nuclear explosion for peaceful uses of Atomic energy. This is an instance of how the vision of Dr. Ganguly helped in carrying out investigations when India was called upon to do so and how the infrastructure he had generated came in handy.

2.1.6.4 Research on algae photosynthesis ponds for pollution control and sewage treatment

On instructions from Dr. Ganguly, KVK Nair visited NEERI Nagpur to study microbiology and virology of sewage treatment in general. Dr. Ganguly clearly foresaw the importance of this activity to India. He enabled this to be realized since Dr. Majumdar who was the Director of NEERI was a close friend of Dr. Ganguly. Many years later NEERI approached the editor for help in instrumentation in setting up a nuclear laboratory in their Centre in Worli in Mumbai.

After Nair's return from NEERI, Dr. Ganguly suggested him to move to Kalpakkam where flexibility existed to facilitate the work since RRC (later named IGCAR) was an upcoming institution. Dr. Nair organized necessary facilities at Kalpakkam attached to the ESL there and built a high rate photosynthesis pond, mini ponds and a fish pond. The water has to be kept in circulation and Mr. Seshadri helped him in engineering the auxiliaries. The group was augmented with a microbiologist Swathi Sebastian and V Kannan from ESL also joined.

Work picked up at Kalpakkam and the facility attracted the attention of many such as S. Venkataraman of IARI Pusa, Delhi and C. V. Seshadri, a former professor from IIT Kanpur and founder Director of Murugappa Chettiar Research Institute. They visited the facilities set up by K V K Nair in Kalpakkam and gave useful suggestions. Dr. Nair used to bring the township sewage after activated sludge treatment to the algae pond for field studies. He studied natural growth, nutrient removal and pathogen removal in batch systems, intermittent flow systems and in continuous flow systems. He found E. coli could be removed in 2 to 4 days respectively in intermittent flow and batch systems. A maximum solar energy conversion of 3.58% was achieved in algal-sewage mass culture system. The Photosynthesis pond was shown to be a plausible solution of the wide spread source of water pollution in the county. Thus, Dr. Ganguly was farsighted enough to look at the most formidable problem of today and provide experimental proof that it can be tackled. Dr. Nair notes that it was a unique effort working on photosynthesis ponds for sewage treatment.

Successful demonstration of comprehensive sewage treatment nutrient removal and pathogen removal for the first time was demonstrated. The river pollution problem is a big health hazard facing the country today and it is worth mentioning that Dr. Ganguly foresaw it almost five decades back and tried to demonstrate a way out. The seeds sown by Dr. Ganguly in this stream of activities gave training to many including Dr. Venugopal, a colleague of Dr. Nair in those days, who is presently working on bio-remediation in this context. Dr. Venugopal is now heading the Nuclear Agriculture and Biotechnology Division of BARC specializing in the development of granular biomass for bioremediation applications.

2.1.6.5 Dr. Ganguly a man without pretensions

KVK Nair had fond memories of Dr. Ganguly when he used to call for him remarking "let us call the pundit" for discussing certain points related to oceanography in his research on humic acid with T N V Pillai and Elizabeth. Nair says Dr. Ganguly had no inhibitions in readily recognizing the expertise of his students and seeking their opinion on matters related to their area of expertise, a very rare quality in science managers. Nair also acknowledges the rare quality of personal training he received during 1960-62 under Prof. C C John, the doyen of marine biology who started marine research activities in the erstwhile state of Travancore in 1936. He formalized the first institute in India to give specialized training in Marine sciences in Kerala University in 1957. This enabled Nair to earn such recognition from one of the greatest environmental scientists of our time Dr. AK Ganguly. The anecdote narrated

by Nair, reminds the editor that this quality of Dr. Ganguly was also underlined by Krishnamony in his memoirs in this volume: *"he was a man without any pretensions and would consult anyone on the spot to learn about the facts and even seek their opinion if he notices similar problems elsewhere"*.

2.2 Evolution of Operational Health Physics

Introduction

M R Iyer & L V Krishnan

2.2.1 M R Iyer, K K Narayanan

2.2.2 S Somasundaram, M R Iyer

2.2.3 P Abraham

2.2.4 V K Gupta

2.2.5 M S R Sarma

2.2.6 P Kotrappa, A R Sunderarajan

2.2.7 S Krishnamony

2.2.8 A C Paul

2.2.9 M R Iyer, A H Khan, M Raghavayya

2.2.10 K N Kirthi

INTRODUCTORY REMARKS TO SECTION 2.2

M R Iyer and L V Krishnan

Just as in the case of ESLs, Dr. Ganguly believed in having an organizational set up for the Operational Health Physics program independent of the operations of the units. He was championing this cause and insisted on continuing with this program under the independent control of Health Physics division of BARC. That is how operational health physics for all nuclear facilities of DAE were administrated by HPD of BARC. Besides it also facilitated early adoption in the various plants of the results of related R&D studies carried out in Health Physics Division. He had resisted the shifting of the operational responsibilities to the operational management of the power plants and the editor is aware of many such occasions but he had his last say on this during his tenure. However there has been a shift in the setup during the post Ganguly era. Today the NPCIL oversees the health physics operations. With the expansion of the power program the question of viability of handling this by a unit of DAE, the BARC, would have been a consideration in the shift in policies, but the sanguine spirit in ensuring independence of health physics operations which Dr. Ganguly had in mind had its own merit.

The memoirs of evolution of health physics in various plants in the nuclear fuel cycle that follows in this section will illustrate how such an independent

management sustained a healthy growth of operational health physics program which produced tangible results.

2.2.1 Role of Subbaratnam on evolution of Operational Health Physics in AEET

Narration by M R Iyer and K K Narayanan

2.2.1.1 Initial activities on waste management in AEET

When I (MRI) joined AEET one of the faces I clearly remember to have seen at first in the Hot Labs sheds in TIFR premises was that of T Subbaratnam who was busy going through some drawings and reports. As narrated in the INSA memoirs by Dr. Jagdish Shankar, Dr. Ganguly was inducted into AEET on his potential also for organizing the waste management activities of AEET. And when Dr. Ganguly started his career these activities under him were centered around Subbaratnam who was a chemical engineer recruited in 1957 to meet these responsibilities. There was even a team of chemical engineers in those days working with Dr. Ganguly, among them were Chinoy and Victor Amalraj. I have seen S Hathwar, an associate of Subbaratnam going around for collecting low level radioactive wastes from various laboratories and stored in a shed in the TIFR precincts. Thus the waste management activities in AEET started under Dr. Ganguly.

However, with the planning of the reprocessing and other plants and laboratories in Trombay and the proliferation of radioactive wastes, these activities were transferred to the Chemical Engineering Division under H N Sethna. I have heard stories how Sethna had approached Subbaratnam to get himself transferred to Chemical Engineering Division to organize the work on waste management. But TS seems to have been not quite agreeable and preferred to continue with A S Rao and Dr. Ganguly to the discomfiture of Sethna. Subbaratnam would have perhaps headed the Waste Management Division had be accepted that offer. As an afterthought that decision turned out to be greatly beneficial to the evolution of Health Physics activities of DAE. The chemical engineering associates of Subbaratnam, Amalraj, a first batch training school product shifted his operational area to Chemical Engineering Division and headed the operations later. Subsequently Subbaratnam was given the responsibility of organizing a radioactive waste laundry in the south site under the Health Physics division. This project was known as project "White Wash"! This plant was for washing and decontaminating all contaminated safety apparels such as boiler suits and lab coats worn by radiation workers in AEET. And Subbaratnam went about quite earnestly and made the plant operative. And the Health Physics Division and Electronics Division also built some radioactive laundry monitors to monitor the boiler suits and lab coats

after washing. Subbaratnam also set up limits of contamination in the safety apparels after washing. The plant was in operation in the HPD but later shifted to Chemical Engineering Division.

2.2.1.2 Transition of Subbaratnam - Chemical Engineer to Health Physicist

Subbaratnam who preferred to stay on to HPD then started gravitating to work in operational health physics. One of his early assignments was his involvement in the evaluation of tenders for the Tarapur reactor. He was a meticulous worker getting down to every detail in his assignment. I have seen him working on the assignment at the draughtsman's table himself abstracting the complex drawings provided by the various tenders on the designs for the proposed reactor. Few engineers would organize their work from such grass root level! Professional background as a chemical engineer helped Subbaratnam to discern and understand the various designs submitted by International General Electric (IGE), General Dynamics Corporation (GD), etc., and analyze them. Dr. Ganguly had constituted a team with T Subbaratnam, DV Gopinath, LV Krishnan and K Santhanam for evaluating the safety aspects of the reactor designs. Gradually Subbaratnam initiated health physics operations in power reactors. Many persons like P. Abraham, V K Gupta, late B M L Sah S. Venkatesan, late S Parameswaran, Patnaik, KK Narayanan, VK Sharma, late M Sundaram and others have worked with him closely in these assignments. Eventually, he headed the Power Project Safety Section of Health Physics Division whose responsibility was to oversee the health physics operations at all nuclear power plants and he organized these operations starting with the Tarapur Power Station and proceeded with the RAPS and MAPS while AKG groomed Somasundaram to oversee the health physics operations in Trombay facilities in the RHC Section under S. D Soman.

2.2.1.3 Exponent of ICRP Principles

KK Narayanan who in later years worked in the HQ with TS on matters related to health physics assignments in power reactors notes that Subbaratnam's association with Dr. Ganguly was not very observable by others, though he succeeded S. D. Soman as Head, Health Physics Division. TS had great respect for Dr. Ganguly as a scientist. He was a Chemical Engineer by profession and that aspect was evident in all his approaches toward Radiation Safety, especially with respect to Radiation Safety in Nuclear Fuel Cycle facilities. This enabled him to be successful as Head, Power Plant Safety Section. He used his skill in English language, both in writing and in speaking, to teach the Engineers and Scientists of Nuclear Power Plants, the fundamentals of Health Physics and ICRP recommendations. He was one of the few experts in DAE who clearly understood the true philosophy of ICRP recommendations with all its

associated biological, legal and social intricacies. A very important quality of TS was that he wanted to pass on the knowledge on ICRP and radiation protection to all his colleagues irrespective of their grade. His Chemical Engineering background helped him to a great extent to fully grasp the complicated Nuclear Power Reactor System during his training period in USA. He was also a teacher par excellence and gave many lectures on the basic principle of ICRP in many fora. Like Dr. Ganguly, TS was also very compassionate toward their junior colleagues and will listen to their problems. AKG will go to any extent to solve their problems, but TS will stop his efforts if the solution of the problem is beyond his power. Both AKG and TS were keen to use Indian data for developing Radiation Protection Standards in the country. One good example of this is the setting of discharge limits of radioactive effluents from BARC to Trombay Bay developed by Dr. Ganguly and Dr. K. C. Pillai using the tidal variation and dilution factors. TS encouraged the use of site specific data, wherever they are available, to set the effluent release limits from NPPs. He along with K. K. Narayanan was primarily responsible for developing the discharge limits for multi-facility nuclear sites like, Tarapur, Kalpakkam and Rajasthan.

When ICRP Paris statement came out in 1985 wherein the standard for population dose limit was reduced from 5 mSv per year to 1 mSv per year, India was the first among the countries to adopt this new limit and TS with active guidance from Dr. Ganguly (though he was not in service during that time) undertook the task of downward revision of these limits along with K K Narayanan. To start with, the Kalpakkam site with its multi facility characteristic was chosen for this. The term "Dose Apportionment" was coined by Subbaratnam for the revision of the discharge limits. The basic principle was to apportion 1 mSv per year limit to all the existing facilities at site and leave a margin (about 0.15 mSv per year) for future facilities. There was lot of resistance toward this, especially from NPCIL, because all the operating plants had to reduce their emission rate to meet the new criteria of 1 mSv per year. But, finally TS could convince the regulatory board to accept the revised dose limit and this became part of the technical specification for all plants, both operating and planned. Another important area where AKG and TS collaborated was in the drafting of Emergency Preparation Manual for TAPS and later on for other sites.

The development activities related to Personnel Protective Equipment (respirators, Plastic suits, etc.,) were initiated in early 1960 by TS on advices of Dr. Ganguly. Awatramani was in-charge of this group which manufactured and fabricated protective equipment under the direction of S D Soman for

all the plants and laboratories in BARC where radiation works were involved. The design of ventilated plastic suits for work in tritiated areas by this group is worth mentioning in this respect. A portable personal air conditioner based on Peltier cooling was also tried to be innovated for fresh airline plastic suits for the comfort of the operators.

2.2.1.4 Costing of man-rem

During the last phase of his career, Subbaratnam was instructed by Trombay Council to evaluate the cost of a man-rem or person Sievert. For this he along with KK Narayanan collected lot of data on cancer incidence, treatment cost, survival rate, etc., from Tata Memorial Hospital and Central Labour Institute. A model was developed by TS and KKN using ICRP risk coefficients. The salary structure of DAE employees applicable to occupational domain produced an unrealistic value for the cost of man-rem. The exercise was a unique one anywhere in the world. The confidential report submitted to TC was not accepted and this report never saw the light of the day reveals Narayanan. One of the concerns about this study expressed by some was that assigning monetary value to human life would be considered to be sacrilegious and hence the cost of man-rem based on cost of human life will not be acceptable in the Indian society. In this process he also started an exercise to develop a common hazard scale for radioactivity and chemical toxicity of various chemical toxicants and to compare their hazard potential. His aim was to bring both the hazards into the same scale so that they can be compounded for occupational workers who might be exposed to both the hazards such as those in nuclear chemical plants in the front end and back end fuel cycle operations.

2.2.1.5 Chernobyl accident analysis

One of the assignments he took on himself and excelled was in the analysis of the Chernobyl accident in 1986. He analyzed the accident meticulously collecting details and with his background as an engineer and his expertise on interpretation of various complex principles of radiation protection and ICRP recommendations. He had delivered many lectures in various forums including the Nuclear Power Corporation on the analysis the accident. Perhaps he was the only one who for the first time understood the accident so well that it was really educative to listen to his lectures on the topic. As one who was greatly benefited by his exposition of the evolution of the accident I felt time stood still listening to his lectures on this any number of times. He also went further to propound how such accidents would not be possible in Indian reactors and made studies in depth by comparing various systems of reactors. When I showed him a report I had prepared on the gamma spectrometric analysis of Chernobyl debris and surmised the unit which would have undergone accident

much before the Russians had divulged it, he was very appreciative of the analysis more than anybody else in the Division. I had occasion in later years to work under him as the head of the RHC section when he was the Head of the Health Physics Division and understood from him a few nuances of scientific administration.

2.2.1.6 Personality of Subbaratnam

Thus, one can observe that there were a lot of collaborative activities between Dr. Ganguly and Subbaratnam related to operational health physics. But there was not much fanfare or publicity about these between the two. Subbaratnam was modest in his aspirations and worked on principles rather than the end results. In spite of his many personal misfortunes he was very compassionate and balanced in his professional involvement. In this context K K Narayanan remembers that when Subbaratnam touched on his experiences in his personal life and professional career during the farewell function arranged on his retirement, he was emotionally overwhelmed. It is unfortunate that though Subbaratnam is alive today his medical condition did not permit the editor to meet him and share his exciting journey through the "Ganguly saga", though we tried our best to plan a trip to Pune, where he resides, to take an interview with him for inclusion of his memoires in this compendium but was deterred by many! The memoir compilation is to that extent poorer!

2.2.2 Evolution of Operational Health Physics

S Somasundaram

2.2.2.1. Organizing Health Physics operations in AEET reactors

After joining AEET Somasundaram was also involved in organizing operational health physics in various plants in AEET along with his other activities. After the startup of the second research reactor in Trombay, the 40 MW Canada India reactor, S D Soman had personally concentrated his efforts in setting up operational health physics and guided the health physics operations at the reactor. His contribution of putting the health physics operation at CIR (Canada India Reactor later came to be known as CIRUS, acronym for Canada India Reactor and Utility Services) has been noteworthy. Dr. Ganguly seemed to have been grooming Soman as the next in command for the health physics operations in Trombay. He was ably assisted by Somasundaram, P Abraham, K Santhanam and L V Krishnan. N B Prasad was the project director for construction of CIR. Mr. Surya Rao was the first Reactor superintendent of CIR ably assisted by VN Meckoni. Somasundaram as Group Leader and later as Head RHC Section also provided RHC supervision for the CIR reactor for a few years after the reactor started regular operations. Having contributed to laying the foundation for the operational health physics at CIR, Somasundaram

turned his attention to the overall supervision of the operational health physics for the Project phoenix. He was appreciative and supportive of the initiatives of his junior health physicists and projected their accomplishments to the operations. He ensured that they are not asked to undertake decontamination jobs but only to supervise these, as was the practice in the initial days. Many in RHC Section were grateful to him for this.

2.2.2.2 How operational health physics for Plutonium Plant evolved

This was the first major nuclear project taken up by DAE without any foreign technical cooperation. Plutonium chemistry and separation experiments were undertaken even from 1957-58 at the Radiochemistry Division first under the supervision of Dr. Sharma along with Hariharan, Rengan and Namboothiri who were products of the I batch of AEET Training school. They standardized procedures for plutonium separation by irradiation of uranium samples in Apsara reactor. When Sharma left, M V Ramaniah who had a stint of working under stalwarts like Seaborg and Wahl in USA became Head of the Radiochemistry Division. The radiochemical scheme for separation of plutonium standardized by the radio chemists was useful input for the design of the plant. The aluminum clad uranium metal was planned to be transported from CIR in lead transport casks mounted on a special trailer to the receiving bay in the Plutonium plant. After transferring it into a shielded cell the fuel is chopped using a specially designed chopper designed in the central workshop and then dissolved in fuming nitric acid for separating plutonium. All the operations had to be done by master slaves remotely which were designed and manufactured in the central workshop. The operations were viewed through lead glasses. The operating gallery with master slaves and lead glasses was an impressive sight. All the equipment were fabricated locally. All these had to be as per stringent specifications and isolated air-tight from the working atmosphere under differential pressure to avoid any leakage of Pu in operating area air. The required ventilation design was also reviewed by Health Physics division. Whatever assistance available was by virtue of training of some of the scientists in USA. P Kotrappa and S Krishnamony had the benefit of training in health physics operations at reprocessing plants in USA along with the chemical engineers. But all these stopped in the aftermath of the 1974 PNE experiment. Thereafter the other processing plants like PREFRE, refurbishing of the Trombay plant and setting up of the Kalpakkam plant were all indigenous efforts.

Dr. Bhabha appointed H N Sethna as the project director an N Srinivasan as the officer in charge of the project. He appointed a committee to address the health and safety issues in the design and operation of the plant and submit

a report. N Srinivasan was the Co-chairman of this committee along with Dr. Ganguly. Several senior managers of Electronics Division and Central Workshop were also members of this committee. Somasundaram on AKGs recommendations acted as Secretary of this committee.

Besides external hazards from the highly radioactive fission products the highly toxic plutonium posed potential internal hazard to the workers and this called for developing of air sampling paraphernalia. Since the limits for detection were very low, special impactors were developed by the RHC section to separate Pu aerosols from the natural radon daughter product particles using the aerosol size variation. These were being indigenously and innovatively developed by Kotrappa and Kirthi since their work in the radiochemistry labs. Lot of work were also undertaken by the RHC and Air Monitoring Section teams for developing continuous air monitors for Pu which was essential to safeguard the workers in case of ventilation failure or other leakages. Kotrappa proceeded to work on aerosol physics and became an expert in this area. Criticality hazard was another aspect that was required to be considered. Here again the team from RHC section was formed by Dr. Ganguly consisting of L V Krishnan, T N Krishnamoorthy and V Kalyanasundaram and they initiated work on adopting various computer codes for the CDC computer and did excellent work. This turned out to be the one of the pioneering groups that carried out such work in the Centre and for some time they provided consultation to other groups in AEET who were interested in similar work. This group provided guidelines and data by computation on criticality safe geometries for the columns and reaction vessels in the plant. Thus the first adaptation of Monte Carlo and transport codes were initiated in the RHC Section. This also led D V Gopinath to carry out development of analytical codes using solutions for integral coupled equations which was accepted in ORNL code library. Dr. Gopinath maintains that these methods were exact and very suitable for regular geometries but for irregular geometries one had to take recourse to Monte Carlo methods. All these were due to the vision and initiative of Dr. Ganguly. The design guidelines for the bird cages for storing plutonium was also evolved by this team so that stacking these bird cages would not lead to any criticality problem even in the worst case of flooding. The bird cages were also innovatively tested for fire and impact hazards by TS Laxminarayanan the person who set up the chemistry control lab in the plant. He was perhaps the best example of an extremely safety conscious plant operator and took health physics objectives as his responsibility.

Dr. Ganguly used to often inspect the plant and suggest many safety features. Full rapport between Dr. Ganguly and Srinivasan was instrumental in evolving

and implementing radiation and nuclear safety in the plant. Other special instrumentation required were criticality monitors and after lot of discussion with Health Physics divisions personnel, the rate of gamma dose rise concept was adopted and the testing of these again called for innovations. And RHC section evolved a procedure using mechanical shuttling of source to simulate the dose rise in case of a criticality excursion and was implemented by Electrons divisions.

2.2.2.3 SS Memoires on "Indian Reference Man"

In 1958 Dr. Bhabha directed Dr. Ganguly to evolve maximum permissible levels of surface contamination for use in the Indian Atomic Energy Program. Dr. Ganguly assigned the task to S Somasundaram and in turn he associated PV Hariharan. They followed Dunster's papers and modified his model to suit Indian conditions. In the forwarding letter Dr. Ganguly pointed out that difference between the Indian Standard Man (ISM) and the ICRP Standard Man particularly the body structure, food and water intake and eating habits. ICRP had based such parameters for the ICRP Standard Man and evolved the radiation protection standards. Since the Indian Standard Man would be distinctly different, these standards also need to be evolved for Indian conditions. Dr. Ganguly setup a task force to evolve appropriate data on Indian Standard Man. Dr. Bhabha approved the proposal. Somasundaram was named leader of the task force. Under Dr. Ganguly's advice he further requested Dr. V R Shah, Head, Medical Division AEET to participate in the program and they in turn met Dr. K Srinivasan Director, of UN Populations Studies center in Mumbai. During the course of this work Indian eating habits using hands, unlike in western countries was a consideration for arriving at the permissible personal contamination levels, which was addressed to by Somasundaram successfully. Somasundaram used to tell the editor that, south Indian food and style of eating result in larger transfer coefficients of contaminants from hand to man, due to better ion exchange properties of some ingredients!

Dr. Srinivasan suggested resources for the study of various aspects of Indian standards man - Dr. Ramaswamy, CLI Mumbai for air intake data, Dr. C Gopalan National Institute of Nutrition, Tamil Nadu for food and water intake data, and Dr. Bhushan Rao Indian Society of Forensic Medicine Hyderabad. Somasundaram promptly got in touch with all institutions and these were inducted into the program of evolving Indian Standard Man. Each of these experts readily shared data and suggested the way ahead for consolidating data. Dr. Bhushan Rao suggested contacting the director of health services in each state and leading hospitals to collect data on organ size from autopsy cases. Thus within a short time the vision of Dr. Bhabha under the directions of

Dr. Ganguly was transformed into a national venture by Somasundaram. This led to establishing a wide network of source of information and SS started organizing collection of data from these sources.

At the grass root level within AEET, SS enlisted the work force; HSRC Murthy for a laboratory type respirometer, JL Kapoor for respirometer data collection of AEET employees, and VM Raghunath to develop a special of vernier calipers to measure skin thicknesses and for collecting data on dietary and water intake of AEET employees. I remember the employees being supplied a measurement glass to take water and a card to enter the intake data. Dr. Ganguly true to his culture of grass root association with all the work he initiated periodically reviewed the progress and suggested modifications. The services of K Venkataraman who later joined the Health Physics Division in 1962 with a post graduate degree in Statistics from Madras University came in handy for the statistical analysis of the data. Santhanam who joined AEET in 1959 from AEET Training School with flying colors was also involved in analyzing the data.

It was at this stage that Dr. Ganguly mentioned to Somasundaram about Atomic Absorption Spectrometry just then introduced by Dr. Alan Welch in Australia which could be used to analyze major and trace elements in food materials and food stuffs consumed by Indian population. This paved the way for establishing Trace element analysis program in AEET. SS was asked to order for a Perkin Elmer AAS system. In those early days getting allocation of foreign exchange was a difficult task and SS completed all formalities to procure the instrument with the active support of A S Rao. Somasundaram expresses his indebtedness to A S Rao for his career advancement in all his assignments. In the meanwhile, SS left for US for one year training and V K Panday, a product of AEET TS was identified by Dr. Ganguly to handle the instrument and establish a trace element analysis laboratory. Dr Panday organized the Trace element analysis laboratory very well and carried out significant investigations during his entire service and had a stint of research under Prof. Sansoni in Kernforschungsanalage Julich, Germany before he left BARC.

On A S Rao's recommendations Somasundaram was deputed to go to US for training in the areas of work he was associated. It may be recalled Somasundaram along with K S Somayaji, S Vasudeva Murthy, and A Ramamurthy were the initial crop of Health Physics personnel sent to USA for training under the USAID program. SS made use of this opportunity to the full extent and showed initiative to contact many experts and collect very useful information and establish contacts. Somsundaram got training under

Dr. Elda Anderson and Dr. W S Snyder trained him in ICRP methodologies for internal dosimetry. He met Dr. Lisco at ANL and obtained from him detailed protocol used for organ masses data by ICRP, met Dr. Moeller Director RA Taft Sanitary Engineering Research Centre, Cincinnati USA and obtained details of radio analytic procedures used for estimation of radionuclides in food stuffs and water and received detailed training in Health Physics Division ORNL on methodology used by committee II of ICRP for estimation of radiation doses. This contact put the foundation for SS building up the internal dosimetry program in AEET. Dr. KZ Morgan Director of the division at that time was later Chairman of ICRP committee II. Dr. WS Snyder and his colleagues conducted the training program. Thus he established contacts with all leading international authorities connected with his work which enabled him to carry out work on Indian Standard Man when he was back home in September 1960. He communicated the procedures used and found those were similar to that followed by ICRP. Thus one can appreciate the national web he had organized earlier were integrated with international contacts to make the work on ISM fully authentic.

The preliminary data was analyzed and presented at the annual meeting of the health physics society by Somasundaram and Dr. K Z Morgan who was the Editor-in-chief of the Health Physics journal encouraged SS to present the results of, further studies in the Health Physics journal. SS who showed his aptitude for scientific document editing since the early days did not lose anytime in putting the results of his work on Indian standard man in international forum. Thus the paper on evaluation of the radiation protection standards for Indian conditions by K Venkataraman, Somasundaram and S D Soman appeared in Health Physics 9, 1963, 647. Preliminary results of studies on pulmonary physiological norms in Indian adults by K Venkataraman, VM Raghunath and K Santhanam and Somasundaram was published in the Health Physics journal in 1965. The effort to define the Indian Standard Man then centered around collection of organ data from Hospitals around the country after Dr. Ganguly and SS started approaching hospitals around the country on the suggestion of Dr. Bhushan Rao. A S Rao who was the Director of the Heath Physics group wrote several official letters from AEET to various hospitals to request providing the data. A team consisting of Venkataraman and others visited several hospitals to interact with the staff to collect the data. The data of accident victims only were selected as it should be on a healthy Indian adult. Accordingly autopsy data including the observation of the attending surgeon were compiled. SS approached Dr. C. R. Rao of the Indian Statistical Institute which was considered as Mecca for all students who had

done post-graduation in statistics in India in those days. I was one of those who as a statistics post graduate student in 1956-58 had that ambition, but in 1958 after joining the AEET my area was shifted to Physics which was my desire. Dr. C. R. Rao was well known worldwide for his work on multivariate analysis and later was professor at the Pennsylvania State University USA and had earned the gold medal from President George Bush for his outstanding contributions. SS and Venkataraman had their guidance from Dr. Rao for the analysis of data. Venkataraman also visited PRL several times where an IBM main frame computer was available. Dr. S. Raman, Director of Centre for advanced computing studies wrote that the work done by the task force was major application in life sciences in India. Thus, the efforts on arriving at the Indian standard man for radiation protection purposes made a good impact on the life sciences in India. The important findings were:

- Brain size was 50 gm. more than the IAEA standard man
- Spleen was enlarged generally due to infections in childhood
- Intestine in Indian standard man has a leafy structure compared to tubular structure in IARP standard man
- During the course of this work Indian eating habits using hands unlike in western countries was a consideration for arriving at the personal contamination levels, which was addressed to by Somasundaram successfully. Organs of the endocrine system have masses appreciably greater than that in ICRP Man

The results were published in Health physics journal – "Physiological norms in Indian adult –statistical analysis of organ weights in Indian adults" by K Venkataraman, VM Raghunath K Santhanam and Somasundaram.

SS notes that the paper led to some changes in ICRP directives. ICRP changed the norm "ICRP standard man" to "ICRP reference man" implying that the secondary standards given by ICRP may be considered as guidelines by national regulatory authorities and may modify it according to the conditions in their county. Somasundaram feels that the Indian Reference Man should have been taken up as a national project by ICMR and others for inclusion in a national data base for use by researchers as was done in Japan for Hiroshima and Nagasaki bomb victims which was used by UNSCEAR and ICRP for developing models for deterministic and stochastic models.

2.2.2.4 International HP Training course for the IAEA conducted in AEET
S Somasundaram and M R Iyer

Somasundaram proposed and conduced an extended International training

course under the auspicious of IAEA for two months in AEET during 1984 which was a unique one completely architectured by him. He drew inspiration and lessons from the famous Stewart lectures which Dr. Ganguly conducted in 1961 or so in Trombay which benefited the Health physics division staff members to get trained in the nuances of the health physics subject perhaps the first of its kind. The notes of Stewart lectures which the editor (MRI) remember was a bible for all of us in the formative years of our nuclear program. The 1984 IAEA course was evolved on the model of this and further innovated to give hands on training for the trainees. The participants were drawn from several countries in Eastern Europe, Africa and Asia apart from AEET. The trainees had not only class room lectures and practical classes but also each one of them was required to take up a project and work under various co coordinators in the Health Physics Division. The editor had the good fortune of being associated in the organization of the course which Somasundaram remembered in his memoirs. We had a trainee from Slovenia Mr. Bogdon who carried out a project on characterization of decay products from U-233 and U-232. Dr. Ganguly had obtained a few milligram of U-233 from the first batch produced in Trombay from CIRUS J rods which he gave to the editor was used in this. This led to publications in the American Physical Review which according to Somasundaram benefited Bogdon in his professional career in his country. Somasundaram says Mr. Rosen of IAEA visited AEET and was all praise for the way in which this unique interactive course was conducted. The notes on lectures delivered by several AEET staff members and on the seminars and research work conducted by the trainees as part of this course was supplied to IAEA in a volume and it also contained the candid comments made by the trainees. An interactive question and answer test was organized by Abani, Sharma and Suri and developed along with the editor. The hardwired logic unit could be loaded with 5 different sets of questions and the participants after answering the question got their evaluation displayed. The unit later was an integral part of all the exhibitions held in India by Publicity Division DAE for popularizing atomic energy and was appreciated by many including director of German research center during his visit. The course had also social impact on some of the participants from India in that in at least in one case a participant found his, life mate during this course.

2.2.3. Glimpses of Dr. Ganguly

P Abraham

2.2.3.1 Introduction

P Abraham under Dr. Ganguly was involved with developing of operational health physics, first at the CIR reactor, later as the Health Physicist at the Tarapur Atomic Power Station (TAPS) and finally as the Secretary of DAE Safety Review

Committee DAE-SRC, which was the nursery for the regulatory activities and the forerunner of the Atomic Energy Regularity Board (AERB). Though he joined AEET Training School in 1957 and started his career as a health physicist at the newly commissioned CIR reactor, his direct association with Dr. Ganguly started in 1967 when he was posted at Tarapur as the Health Physicist in charge of TAPS. Abraham notes that prior to launching Health Physics activities at TAPS, major efforts of Dr. Ganguly in this area were preparation of the Radiation Protection Manual for the Atomic Energy Establishment Trombay (AEET), as BARC was then known, CIR Hazard Evaluation Report, and Plutonium Plant Hazard Evaluation Report. A S Rao, who was the Director in charge of the Health Physics operations in BARC, states in his Foreword of Radiation Protection Manual AEET, quoting Dr. Homi Bhabha from one of his Office Orders*: "What is done in DAE should not only be right and safe, but also be such that the rest of the country can be asked to emulate."* Strict adherence to such principles by AKG contributed to the high standards of safety in the DAE installations throughout the country and made these to be emulated in other industries in the country.

2.2.3.2 Health Physicist at TAPS

Since the Tarapur reactors had not attained criticality when Abraham commenced work there, he was asked to familiarize himself with the different systems in the Station. He was sent to the US for training in the operational aspects of Boiling Water Reactors along with TAPS personnel and got on-the-job training at the Big Rock Point Station and Vallecitos (General Electric) facilities which enabled him to deal with the different aspects of TAPS systems. It was observed that the Government contract with General Electric Co. (GE) had laid down that the safety provisions at TAPS should be in accordance with those in similar facilities in the US. This provision enabled him to contact US Nuclear Regulatory Commission (NRC) directly to find out the then current requirements in the US. For example, he obtained a copy of the Technical Specifications for a Power Station then being licensed in the US. It was observed that the Technical Specifications prepared by GE for the operation of TAPS, were very lenient and did not match the rigorous requirements of USNRC. This matter was discussed with Dr. Ganguly and he brought this to the attention of TAPS and GE representatives at Tarapur. As a result of this, GE agreed to many of the requirements, though reluctantly.

Dr. Ganguly was the Chairman of the Committee set up by DAE to authorize the operation of TAPS reactors. This Committee had long sessions and heated discussions at Tarapur, often lasting till late hours in the night. Authorizations were given in stages. It may be noted that *this was the first major step in the country to regulate nuclear facilities and many procedures laid by him are the corner stones of the regulatory*

process being followed in India today. Similar procedures were then implemented later for RAPS, MAPS and FBTR. Dr. Ganguly thus laid the foundation for regulating nuclear operations in the country. Discussions on the creation of Atomic Energy Regulatory Board were in progress and it was Dr. Ganguly who prepared several drafts for this purpose and were submitted to DAE.

Notes on matters related to safety of TAPS were routinely sent to Dayal, the Chief Superintendent, with copies to Dr. Ganguly. He was regularly sending them to Homi Sethna, who was then Director, BARC. Violation of Technical Specifications is serious business in the US and when such violations in TAPS were brought to the attention of Station management, obviously this created tension. But it is a matter of great personal satisfaction that this modus operandi followed by Dr. Ganguly could be handled routinely without upsetting personal relationships, in spite of differences of opinion on technical matters. The involvement of AKG on a routine basis was very helpful in this operation.

The role of Health Physics was redefined by Dr. Ganguly to include the safety of the Station, the personnel, the public and the environment, instead of limiting it to radiation hazards control for the personnel in the Station, unlike what was followed in US. This was mainly due to his concern for the environment and his involvement with controlling the environment in setting up the Centre, AEET, earlier.

When the Tarapur reactors commenced operation in 1964, it was observed that the radiation levels in the Station and radioactive releases were much higher than normally expected. When this was pointed out, the response was that, unlike research reactors, power stations have to generate power on a regular basis and so, cannot be shut down. But soon the problem became very acute. Waste management team from BARC was brought in to augment the facilities in the Station. BARC personnel were inducted to maintain personnel exposures within limits. The concept of collective exposure was used as a way out by using contractor personnel and this helped to keep the average exposure low. It was pointed out that extension of waste management facilities was not a panacea for the problems faced by the Station. All these could be undertaken only because of the constant support provided by Dr. Ganguly. He was available on phone all the time and could be visited any time at his residence, for consultation. Visits to AKG had to be frequent for Abraham, leaving Tarapur by train in the evening after office hours, holding discussion with AKG at night at his residence, and returning early morning to Tarapur by Saurashtra Express to be in the office on time. Thus the personal involvement of Dr. Ganguly went a long way to sort out and solve the teething problems of radiation safety at TAPS.

2.2.3.3 TAPS safety review

In 1971, a few weeks prior to his sudden demise, Chairman, AEC, Vikram Sarabhai, convened a meeting in his office at Old Yacht Club to discuss all matters related to safety of TAPS. The numerous notes that were sent by Abraham to Dayal and Dr. Ganguly formed the background for the discussion. Sethna, A S Rao, Brahm Prakash, Gopal-Ayengar, and Dayal were present. Since Dr. Ganguly was out of station, Abraham was asked to be present in the meeting. Very hot discussions took place between Sarabhai and Sethna, who insisted that the reactors should be shut down for safety reasons. After the meeting, Abraham was asked by Sethna to prepare the minutes of the meeting. He was taken by surprise as he was not aware that this responsibility will fall on him and so he had not scribbled notes of the proceedings. However, as instructed, the minutes were circulated two days later. Dr. Ganguly later appreciated the drafting of the minutes. This was one of several instances Dr. Ganguly used to project his junior colleagues to the higher ups and train his personnel in the management responsibilities.

There were several instances when the Tarapur Station complained to AKG about the notes sent by the Health Physicist. AKG visited the Station on such occasions to discuss the matters in detail and provided the necessary support. During his visits to Tarapur, on arrival at Boisar railway station, Dr. Ganguly along with Abraham used to visit a nearby restaurant for coffee. Always his order for snacks was "one-one, each-each, ek-ek." The bearer understood the prescription of AKG correctly and would serve both of us one item each from his stock of snacks, each time! The personal touch of his involvement with his staff was a hallmark of the greatness of Dr. Ganguly about which almost everyone who worked under him would vouchsafe.

The Three Mile Island (TMI) accident occurred on March 28, 1979. Detailed daily updates on the accident were being sent by USNRC as telex messages of several pages to Abraham; copies of these messages were circulated to all concerned in the country for information. DAE constituted a Committee, with AKG as Chairman, to study the accident in detail and recommend measures to be incorporated in the Indian reactors to prevent recurrence of similar accidents. NRC also used to give a brief summary of the events at TMI as news releases daily. A few months after the accident, Abraham's office started receiving envelopes marked 'Secret' from DAE. The envelopes contained only newspaper cuttings regarding the TMI accident. The different Indian Embassies sent these newspaper cuttings to the Ministry of External Affairs in Delhi by Diplomatic Bag. They were routed to DAE and then to Abraham.

Of course, it took some months to reach us, after we had received the details on a daily basis, directly from NRC. So much about our secrecy!

2.2.3.4 Dr. Ganguly, national figure as an environmentalist

Because of his pioneering efforts in the field of environmental sciences by setting up environmental survey laboratories, meteorology stations, and the other steps he had implemented in atomic energy installations in the country, he was soon recognized as an expert in the field nationally. *He was a member of the Committee constituted by Prime Minister Indira Gandhi soon after the Stockholm Conference, under the chairmanship of ND Tiwari, for defining the terms to create the Ministry of Environment*. At that time, environmental matters were dealt with by a section of the Department of Science and Technology. When the Ministry was formed, he continued to serve in several expert committees set up by the Ministry. He served as the Chairman of the Task Force to find a suitable site for the location of an additional fertilizer plant for Rashtriya Chemicals and Fertilizers (RCF). As desired by AKG, Abraham joined the Task Force which visited several sites in Maharashtra and then selected Thal Vaishet, near Alibaug, for the plant. His experience in the site selection of nuclear plant sites earlier stood him in good stead in this. Thus the experience gained in the nascent atomic energy program was a forerunner for the procedures which were retrofitted to the environmental protection at large in the country, thanks to the vision of Dr. Ganguly.

Abraham was appointed as Director in the newly formed Ministry of Environment, though he had not applied for any such assignment. Dr. Ganguly, whose recommendation of the COST conference was partly responsible for the formation of Department of Environment, was silently behind this. However, when for personal reasons Abraham could not accept the offer, Dr. Ganguly quietly accepted his decision.

AKG had the last word in all matters related to safety in all the units of DAE. In addition, he was the recognized authority on all environmental matters in the city of Mumbai, as well as nationally and internationally. AKG was firmly convinced that anyone choosing to release pollutants to the public has no authority to withhold information on the quantum of release from the public. Similarly, his firm opinion was that a person exposed to radiation has the right to know the amount of exposure. This became a bone of contention later between the workers' association and BARC safety authorities later.

(Late) Mr. Shyam Chainani, the ever active leader of the Bombay Environmental Action Group (BEAG), used to frequently visit AKG for consultations on

technical issues. Even after AKG retired, AKG and Abraham together were members of the Environmental Safety Group constituted by Godrej Foundation to protect the mangroves in and around Mumbai. The other members of this Group were Sethna, Soli Godrej and Shyam Chainani. Dr. Ganguly always made sure to personally inspect and understand the environment beforehand and its recipient capacity before making recommendations about how to protect it. Abraham vividly recalls the boat rides, arranged by Godrej Foundation for the group, through the mangroves in Vikhroli, near the Godrej factory campus. They had so much respect for Dr. Ganguly that they were among the mourners when he passed away in 1988. One of the unique things which can be noted in Dr. Ganguly is what made him acceptable and respected by activists, as recorded elsewhere in this volume. We can say definitely that he was the only institutional safety expert till today who commanded respect among the activists due to his bold and genuine concern for environment. Dr. Ganguly was requested to study the potential environmental impact of the Sewri-Nhava Trans-harbour link, which is hanging fire since many decades. Results of his joint study with Abraham were published in the journal of Nehru Science Centre. The inspections he made in such missions were invariably occasions to discuss the concerned problems and to suggest remedial measures, remarks K C Pillai. Reminiscing about his association with Dr. Ganguly, Abraham states it was always enjoyable, educative and pleasant. He was a great man with a treasure house of knowledge on various branches of science, but always humble and humane.

2.2.3.5 Ganguly the regulator

As a member of the Senior Advisory Group (SAG), constituted by IAEA, to coordinate the Nuclear Safety Standards (NUSS) program for preparing the safety codes and guides for nuclear power plants, AKG was involved with five different Technical Review Committees (Governmental Organization, Siting, Design, Operation and Quality Assurance), with members from many different nations. As a member of the TRC - Governmental Organization, Abraham could witness at first-hand the respect AKG had earned in the international arena. AKG chaired the Committee on Safety Codes and Guides, set up by DAE to coordinate the Indian contribution for the NUSS program. Abraham was the Member-Secretary of this Committee. In these efforts Dr. Ganguly inducted several reactor engineers and chemical engineers from reprocessing plants into the regulatory ambit of DAE.

2.2.4 Dr. A K Ganguly through the eyes of his last PhD student
V K Gupta

2.2.4.1 V K Gupta inducted into operational health physics at CIR

V K Gupta joined the Radiation Hazards Control Section, Health Physics Division of Atomic Energy Establishment Trombay (AEET) on August 16,

1960, soon after acquiring his M Sc degree in Physics from Agra University. A few more recruits joined at that time. They were inducted into the profession of health physics by undergoing an orientation lecture course for a few weeks. Gupta was posted as Health Physicist in ZERLINA, an indigenous Zero energy reactor for lattice investigations assembled in Engineering Hall No. 1 of AEET. Gupta's first interactions with Doctor (as Dr. Ganguly was addressed by people close to him) was when he asked Gupta to report to S D Soman to work as a health physics at the 40 MW heavy water moderated, light water cooled, natural uranium fuelled Canada India Reactor CIR (subsequently re named as CIRUS). During this period Gupta did not have much interaction with Doctor. However, opening for interaction with doctor was in the annual picnics of staff of the Division which he insisted on being organized. He used these social occasions to get familiar with the members of his Division. This was the time when CIR started operating round the clock and health physics man power had to be augmented. Gupta was among the second group of health physicists to be posted in CIR along with BML Sah, Patnaik, Dhabadkar, Venkatesan, Phalke, P P Chakraborty and J L Kapoor. A D Sharma, P Abraham, K. Santhanam and L V Krishnan, were inducted to organize the health physics activities and evolve procedures in the new 40 MW CIR research reactor during its commissioning and initial test operations under the supervision of Soman in 1959-60. Soman was identified by Dr. Ganguly to lead this group for the health physics operations at the CIR reactor in 1959-60. Dr. Ganguly had spent some time in the NRX reactor, Chalk River in Canada for familiarizing with organizing the health physics activities in the reactor. NRX was the blue print for the CIR reactor. Soman who had spent 6 months at the NRX reactor in 1957 to get familiarized with organizing health physics operations for CIR, thus became the group leader for CIR health physics operations. Later he was elevated to be the Head, Radiation Hazards Control Section for overseeing the radiation protection activities in AEET. Once the health physics operational procedures were frozen, K. Santhanam and L V Krishnan were transferred to Mod lab in 1962 for multifarious assignments particularly for participating in the Tender evaluation for the first nuclear power station at Tarapur. Thus, V K Gupta had his first hands-on experience in operational health physics for heavy water reactors during his CIR assignment.

2.2.4.2 Central Emergency Post at AEET organized

In 1965 the India Pakistan war erupted and Trombay being at a short aerial distance from the border was considered as a possible target for Pakistani bombers and with the sensitive oil refineries in the neighborhood was a very sensitive area. There were rumors that a fighter bomber aircraft indeed was on its way to the area when it was knocked down by the IAF. Dr. Ganguly

realized the need to strengthen the health physics and radiation protection vigilance in AEET in case something unforeseen happened and wanted to augment the health physicist work force with the availability of senior health physics personnel present on the site at all times and particularly in the silent night hours. Thus he created a Central Emergency Post (CEP) in AEET equipped with monitoring instruments, vehicle and protective equipment in case they were needed for any eventualities. Thus CEP in AEET was created in the aftermath of the 1965 Indo Pak war for round the clock health physics vigilance in AEET. Gupta was asked to organize CEP along with Kirthi. All senior personnel of the HPD were asked to come in shifts in CEP and carry out vigilance surveys during all the shifts in BARC and environment. CEP continued to function for several years. The editor notes CEP was instrumental in all the health physics personnel getting familiarized with the different health physics surveillance procedures in various other plants in AEET. The diverse plants such as uranium metal plant, uranium fuel fabrication plant, research reactors, fuel reprocessing plant, radiological laboratories, and waste management facilities, all called for differing strategies for health physics surveillance. The institution of CEP enabled all the health physicists to be aware and familiar with procedures in dealing with emergencies in all type of plants.

The editor adds: As an aside it may be interesting to note that those who were coming in shifts in CEP had the unique experience of visiting the top of Trombay Hills once a week for extensive radiation monitoring of the entire BARC site. The top of the hill known as Bhabha point at that time was the highest point on the site commanding a beautiful view of the entire site on one side and the refineries on the other side along with the entry to the Bombay port with elephant Cave island on the side. Dr. Bhabha had plans to develop the hill as a botanical garden. The trees were watered using water tankers and BARC garden superintendent Vaidya had meticulously planted trees. A cashew garden was also set up on the side of the hill which proliferated the monkey populations on the hills and the neighborhood. We had later set up a radiation monitoring point with remote data transmission on the hill top.

2.2.4.3 Training at Douglas Point in Canada and induction into operational Health Physics at RAPS

After organizing CEP for a couple of years, one day in 1966 Gupta was called to Dr. Ganguly's office and informed that he has been selected for deputation to Canada to be trained in operational health physics for PHWRs planned in Rajasthan. Training in Canada was at the 20 MWe Nuclear Power

Demonstration NPD reactor and at Douglas point 200 MWe reactor (both PHWRs) under Colombo plan for a period of one year. Doctor had then mentioned that no one should ask for extension of deputation. After his return, Gupta was posted in Mod Lab till 1971 for carrying out multifarious assignments given by Subbaratnam who was by then Head of the PPS section in HPD responsible for all health physics work in nuclear power reactors. Soman then had become Head, Health Physics Division.

There was a document under preparation for an IAEA working group on reactor safety. Dr. Ganguly said it was very important and gave it to Gupta for review, when Gupta was planning to visit his parents after his return from Canada. Doctor said that his home visit can wait. But while Gupta was leaving perhaps brooding how to visit his parents, Doctor called him back and told him that "you can go for a week but no more" and review the document and get back to me. This shows the humane nature of Dr. Ganguly. Gupta reminiscences that the document did not contain anything about PHWRs and he added a section related to PHWRs and covered some aspects of LWRs fresh in his mind from his Canadian training. When Gupta submitted the document of about 50 pages to Dr. Ganguly, he seemed to have remarked "What do you think, I have to read all these". It was for a presentation to an IAEA group meeting and when Dr. Ganguly came back from the meeting, he called BML Sah, colleague of Gupta and told him that he has done a fantastic job! BML Sah was taken aback and told him it was Gupta who prepared the report! The PHWR portion in the document was added by Gupta. PHWR was not popular in those days and western stress was for LWRs.

In 1970 Gupta was posted in RAPS as the health physicist there along with BML Sah. Gupta informed doctor his inability to move immediately as his wife was in the family way and advised rest. Doctor conceded to this request and asked him to move to RAPP as soon as Gupta's wife become mobile. Gupta recollects that this was great humanitarian gesture from Doctor. Finally, Gupta went to RAPS in April 1971 and joined his colleague BML Sah.

On return from Canada, the engineers who had gone to Canada for training in operation were keen to adopt the Ontario Hydro radiation protection system as practiced in NPD and Douglas point. The system there was based on the concept of self-protection. The radiation protection was spilt into surveillance and services. This was not acceptable to Dr. Ganguly and he held to his ground. The health physics coverage was thus organized by HPD, BARC independent from the operation, as planned by Dr. Ganguly. Later on the stand taken by Doctor was vindicated and the very same persons who were advocating the

Canadian system appreciated the stand taken by Doctor when they realized how that would not have worked in the Indian conditions.

RAPP was not operational for the first year after commissioning due to turbine bearing problems and had prolonged shut down. This was much before Canadians finally left the project in 1974 following the Indian PNE. Gupta made use of this time preparing a document on ease of accessibility and maintenance of various equipment in the reactor building from radiological safety point of view and conducted some real time simulation deploying persons dressed in protective equipment such as ventilated plastic suits and tritium respirators, etc. Tritium was a special radiological hazard problem in RAPS but Gupta notes not only tritium but external radiation was also a problem during the initial days of operation.

Gupta made a report containing photographs to illustrate these activities and sent it to Dr. Ganguly. And Dr. Ganguly did a unique action of making 100 cyclostyled copies of the report and sent to Secretary DAE and senior persons in PPED and BARC. Gupta remarks that this is how Doctor used to project all his people. He used to put up the persons working with him and expose them to seniors. This was his way of training the staff for managerial positions. Others like KC Pillai have also underlined their experiences with Dr. Ganguly in this respect.

2.2.4.4 Career as a regulator at DAE SRC

V K Gupta was transferred to BARC from RAPS in 1974 and was inducted as Secretary of Atomic Energy Regulatory cell by an order of the Secretary DAE. Doctor had by then become the Director of the Health Physics Group in BARC. Doctor instructed Gupta to move to Mumbai only when residential accommodation is allotted to him, as he knew that Gupta's parents stayed with him. A noble gesture indeed says Gupta. The Cell was created to evolve a regulatory system on matters connected with atomic energy and radiation safety for the country. This presented Gupta the opportunity to be closely associated with Dr. Ganguly. During discussions on the issue, Dr. Ganguly was keenly looking forward to having a regulatory body which in his opinion could be sustained only if it has comprehensive access to research and development on nuclear technology and on all aspects associated with radiation safety for occupational workers and for the public.

Another aspect he stressed was the need to have a specialized Legal cell in the regulatory body, which was one aspect which was never taken care of even after the formation of AERB for many years. Gupta feels that there must be

some communications from Dr. Ganguly on this aspect, but unfortunately no documents on these remarks were available either in AERB or BARC. The editor points out that unaware of these remarks by Doctor, he had discussed this aspect in his later articles in 2005 or so. The editor feels that to this day this is one of the areas in AERB which needs attention. One shot legal opinions from professional governmental lawyers will be lacking the special relevance and implication of the requirement in atomic energy. The Editor notes that of late there are efforts to rectify this by getting a few technical personnel of AERB to get formal law degrees.

In seventies a Committee was constituted for review of Atomic Energy Act consisting of senior members of the Trombay Council with RP Garg as chairman and M/s. Bhatnagar, G Subramaniam, Dr. Ramaniah and others as members. Dr. Ganguly nominated V K Gupta as a member of this Committee. Gupta expressed his apprehensions in sitting in a committee of seniors and Dr. Ganguly retorted "you are the best person for the job and don't buckle down". That was how AKG used to build up confidence in his people and prepare them for greater responsibilities and indicates the confidence he reposed in his people and enabled them doing the assignments boldly. The editor notes that this was a characteristic of Dr. Ganguly underlined by many contributors to this volume. Dr. Ganguly was later identified to lead the regulatory cell in AEET known as the DAE-SRC which was constituted by an office order of Chairman AEC to provide regulatory control for all DAE projects.

Documentation was prepared in DAE-SRC on safety review of operating and proposed plants by having several review committees. Safety review meetings were held regularly on the operation of the nuclear power plants, reprocessing plants and front end fuel cycle facilities. Dhruva reactor was under construction and project safety review was also carried out in DAE-SRC. Dr. Ganguly inducted many people from reactor operation and reprocessing into the regulatory work. Notable among them were MSR Sarma and Vasant Kumar. MSR Sarma notes in his memoires that it was only because of Dr. Ganguly he came out of the operations. Afterwards, engineers started flooding the regulatory cell with the enhanced scope for international interactions. V K Gupta along with Abraham was closely associated with Dr. Ganguly in the working of the DAE-SRC secretariat and he would always attend DAE-SRC meetings. Once during prolonged deputation of Abraham, Gupta was asked to take the responsibility of Secretary DAE-SRC also. This gave him exposure to the safety aspects of nuclear fuel cycle facilities.

Gupta remembers that when Fariduddin was Additional Director, BARC, once he came to Dr. Ganguly's chamber for something. Dr. Ganguly stood up and humbly told him "why you should come to me, you could have given me a ring and I would have come to you!" Such was the respect he used to give the chairs of Director BARC. However he never addresses anybody above him as Sir. He always addresses Sethna as Mr. Sethna or Ramanna as Dr. Ramanna.

2.2.4.5 Regulatory stipulation for containment for Dhruva

Dr. Ganguly was the group director for several groups at one time - Health and Safety, Chemical groups and Reactor operation. During this time he became the Chairman of the R5 implementation committee. V K Gupta had an interesting anecdote about Dr. Ganguly's remarks on containment for the Dhruva reactor. When Dhruva was being commissioned, the containment was required to be tested as per the regulatory norms. Kakodkar along with Seshadri approached Dr. Ganguly with this problem asking for a value to be prescribed for leakage. "We have designed this containment and there should be some number on that. What to do?" AKG looked back at them and asked them to conduct a comprehensive leak test at whatever pressure possible and that will become the standard for future. Gupta remembers Kakodkar remarking that it was a fantastic proposal which did not occur to him and that "we never thought that way". These are the type of remarks which created respect for AKG in the minds of experts.

Gupta used to visit Doctor at his Saras Baug residence after he had completed his tenure of DST National fellowship. He would normally carry with him a couple of Calcutta paan and Doctor used to be delighted. Whenever Gupta visited him, Doctor would request for some refreshment and tea to his wife or daughter in-law and make a comment that he would like to get one more installment. Gupta mentions his work on Forest Fuel and Desert along with MVM Desai started in the post-retirement period of Dr. Ganguly. Dr. Ganguly was brooding if a green belt (rows of trees) could be used to contain the spread of radioactive dispersion of radioactive materials in case of a nuclear accident. Incidentally Gupta was the last student of Dr. Ganguly in 1980 working on green belt cover of trees around nuclear power plants. Gupta remembers his frequent visits to Dr. Ganguly's residence during this period to get directions for his work.

2.2.4.6 Reminiscences of Dr. Ganguly

Gupta had fond reminiscences of how doctor once conceded his request to visit Gupta's parents when he had presented him with a *rudraskh* bought by his parents during a visit to Rishikesh which was supposed to be a cure for blood pressure for use by Mrs. Ganguly who was suffering from hypertension. Gupta

noted a unique kind of happiness on Doctor's face for having remembered his problems and procured the rudraksh for Mrs. Ganguly.

Doctor in one of the meetings of DAE SRC on Beryllium Pilot Plant at Vashi had suggested a green belt around the plant to reduce the ambient dust load which could affect the purity of the products. Subsequently Gupta asked if there is a quantification of the dust load reduction. He looked at Gupta and smiled and told that this is what he should undertake. Later Gupta and Kapoor developed a model for the quantification of the reduction in dust load by green belt and published a paper in Atmospheric Environment. Gupta mentioned that when he passed on a copy of the reprint of this paper to Dr. Ganguly, the happiness in his face was greatly satisfying to Gupta. Gupta continued to work on this and did register for PhD under Dr. Ganguly as his last student but regret for not having completed it. After completing the paper on Forest Fuel and Desert, Gupta and Desai completed the assignment.

Gupta remembers doctor's unique way of appreciating good work. He sometime called Gupta as *"buddhiman Buddhu"*. Once when Gupta went to doctor's house to inform him about his daughter securing a rank in her SSC examination, Dr. Ganguly remarked in his characteristic style "this is Healthy Physics".

2.2.4.7 Monumental contributions of Dr. Ganguly

Gupta summarizes the monumental contributions of Dr. Ganguly:

- Establishing a comprehensive environmental surveillance program touching on all the aspects of the nuclear fuel cycle. This became the backbone of DAE in dealing with issues on public perception regarding the country's nuclear program. The institution of ESLs conceived and implemented by Dr. Ganguly in the India nuclear program is not only unique but even today serves well to answer the public questions whenever they are raised.
- Doctor was very keen on research and development to support the Health Physics program. Large number of students completed their M Sc and Ph D degrees in varied topics as this memoir volume will reveal. His fascination for soil chemistry was astounding. Gupta mentions that if the Head Health Physics Division (Dr. Ganguly) was not found in his office, he would be invariably be in the separate chemistry lab he had set up near to his office in Mod Labs with TNV Pillai and MVM Desai, himself doing experiments. Gupta has seen Doctor once taking a gamma spectrum using a single channel analyzer.

2.2.5 Regulatory Activities

Late M. S. R. Sarma (prepared in 2008)

The concern for safety was mandated by Dr. H. J. Bhabha in the early days which reads "Practices should be such that they don't cause harm to any worker or anyone else, but in an exemplary manner, such that other organizations in the country are asked to emulate these practices". The directive was, when we have not even started handling radioactive materials. He wanted DAE to be a role model and to a large extent it had been.

Only in the case of Apsara, while there was no formal committee to authorize various operations: all those who matter including Dr. Bhabha used to be present more or less on every occasion in the initial days of Apsara operation. In the case of Apsara, Dr. Bhabha directed that one fuel element from the core to be removed and put aside in the pool as abundant caution when the reactor is shutdown overnight. This is how the safety culture in the department started.

When it came to CIR, a committee was constituted headed by A. S. Rao to authorize the commissioning, operations and also review "Hazard's Evaluation Report". When it came to Tarapur, a start-up committee to review and authorize various start up tests/operations in the initial days was constituted. For RAPS, a safety committee was constituted headed by S. L. Kati to recommend to Chairman, AEC for permission during various stages of commissioning. At this juncture, DAE-SRC was constituted, headed by Dr. A. K. Ganguly and DAE-SRC was mandated to supervise the safety in all the activities of the department including industrial safety.

I had the privilege of interacting with Dr. A. K. Ganguly right from the initial days of my joining the department. We were in Canada together and hence had closer interaction with him on personal issues as well. My experience with him was that he was a real teacher – Guru. He knew how to defuse the situation. During the framing of Technical Specification for RAPS, I used to have heated discussion and Dr. Ganguly used to defuse the situation without any rancor. When he was heading DAE-SRC, I also had the privilege of facing him from the utility side. He had strong conviction on safety and had not compromised them at any time during his tenure.

He was the head of site selection committee which has prescribed limits for exclusion zone and sterilized zone as well as population limit within 16 km radius. In the case of Narora, the exclusion zone was to be reduced and recommendations from NPC was made but Dr. Ganguly didn't relent and when the file was put up to Dr. H. N. Sethna, he returned the same with a remark "both of you agree on

a number and come to me for approval" and hence the exclusion zone stands at 1.6 km till date. These distances were prescribed based on the evaluation of releases and the effect on the surrounding areas/population for control.

The establishment of Environmental Survey Laboratory at each one of our installations is a unique feature and Dr. Ganguly was the pioneer in this field. These were established before the units went into the production, to collect the base line data and subsequently to monitor the changes due to the operation of the unit. These laboratories were subsequently recognized by the Ministry of Environment & Forest. This has been a unique feature to win the confidence of the public.

On several occassions, I visited him on various issues while he may not have agreed with my proposals for consent but he never left any bitter taste in my mouth while leaving his room. It is this experience of mine that make me feel he is really "The Guru". The concept of Technical Specification has come from Tarapur, which is US-NRC practice. The Canadians had "Operating Policies and Principles" to govern the operations. At this juncture for RAPS, Dr. Ganguly suggested, we should formulate Technical Specification and we went for whole exercise for RAPS and this has become standard document for authorizing subsequent units in the country.

Being the first Chairman of DAE-SRC, Dr. Ganguly set the standards and guidelines in relation to authorization for various units at various stages. This was a trend setter and a great help to the successors who occupied the chair. I was privileged in that position and had the courage of conviction to carry forward not necessarily pleasant decisions always and the safety culture in the department is such that these decisions were never over-ruled. To that extent the department is grateful to Dr. Ganguly and even today convincingly carries out safety mandates in all its activities without grudge or grumble.

2.2.6 Evolution of operational health physics in back end nuclear fuel cycle

P Kotrappa and A R Sunderarajan

2.2.6.1 Dr. A. K Ganguly -as my Guru

Payasada Kotrappa

Dr. P Kotrappa joined the RHC Section from the I Batch of Training School in 1958 and started his career under Dr. Ganguly. Dr. Ganguly had selected him to lead the health physics team in the Project Phoenix (later named Trombay PP). Kotrappa had a flair for R&D work and he started integrating R&D along with routine health physics operations from the beginning. Kotrappa was first posted in the Radiochemistry Division labs as health physicist to join

K N Kirthi. Kirthi had already been working on developing an impactor for estimation of low level of Pu in air by differentiating it from the natural radon daughter product activity and is described in his memoirs. Kotrappa joined in these efforts which was a prelude to his work in the plutonium plant. He and Kirthi started further developing methods for Pu air monitoring based on particle size separation from radon daughter products which was a hindrance factor in detecting the very low level of Pu required for safety of operating personnel in Pu operations. He experimented with depositing aerosols on a moving belt of photographic films to allow the short lived radon daughter products to decay and then automatically count the Pu activity in the air. He then started working on centrpeter air spot samplers using high volume staplex pumps. The PP labs were ready by this time and he shifted to the PP labs and started organizing the health physics operations there. He was joined by P P Joshi and GS Jauhri. The project manager was H N Sethna and he was ably assisted by N Srinivasan. The Plutonium lab team consisted of Nadkarni, T S Laxminarayanan, A N Singal and others complemented by the radiochemistry team. Later on A N Prasad, G R Balasubramaniam, Shankar Singh, S V Kumar and others joined from training school batches. Krishnamony joined the HP team in 1963 followed by A R Sunderarajan.

Kotrappa had developed aerosol physics research in AEET and guided many students for their Ph.D. degrees. He used his experience with aerosols to develop aerosol generators for other applications including one for lung scintigraphy. This was further developed later and was distributed to many countries through IAEA for screening the lung condition in smokers. He developed a Ca-DTPA aerosol inhaler for enhancing the Pu excretion from internally deposited Pu aerosols in the lung from suspected Pu exposures. He studied the aerosol size distribution in case of Pu fires by using controlled simulation experiments. Electrets were innovatively developed by him for dosimetric application. He developed a radon dosimeter using electrets and also started looking into using electrets for many other applications. He used his innovative work in establishing himself in USA after he left BARC in 1987 and floated a firm known as Elprem which marketed electret radon dosimeters extensively in US for which he took a patent. These dosimeters were more rugged and easy to operate than the existing radon measurement methods using pumps and samplers. His product of Elctret radon dosimeters were accepted by EPA for use in clearing residential buildings for radon concentration which was mandatory in USA. These devices became even popular in Europe. Here was a rare instance of an innovative idea developed in India being extensively used in abroad.

This is what Kotrappa has to say on his involvement with developing HP operations in the Plutonium plant:

"Based on my work in BARC (1958-1987), I consider Dr. Ganguly as his Guru". And he gives the reason why he considered him as his Guru. "I was on leave of absence on an USAEC fellowship program to USA (Atomic energy project University of Rochester, NY, USA) for a period of 5 years (1967-1972) which allowed me to come to USA with family, obtain a Ph.D degree and complete post-doctoral work in leading USAEC laboratories". Kotrappa mentions that Dr. Ganguly was partly responsible for this USAEC fellowship. Kotrappa states that his work and training at BARC helped him to complete the work very successfully. After the end of the postdoctoral period when Kotrappa told the director of the laboratory that "I will be leaving the laboratory", he was surprised since he knew that Kotrappa was with family and fairly well settled in USA. The director asked him why PK want to leave. He also told that "he can make such sweet offers that will make it very difficult for me to leave, both in terms of money and immigration facility (arranging for green card). He was very particular that I should continue. When he realized my decision was firm, he asked why I need to leave. One reason I gave was the Director with whom I intend to work in BARC India wants me to return and work in India. I just cannot refuse. He is like a magnet to me."

Few more reasons that made me call Dr. Ganguly as a magnet or guru.

While in India, he trusted me so much, deputed me to USA for one year training in the field of fuel reprocessing. He made me responsible for the most difficult problem "the radiation protection control problems of plutonium plant".

While in USA for nearly 5 years:

- He was continuously in touch with me.
- He wanted me to attend all annual meetings of Health Physics Society on behalf of BARC.
- He wanted me to report to him important new developments in the field.
- He wanted me write to him on the progress of my postdoctoral research work and keep sending him the publications.
- After my return from USA, he spent lot of time with debriefing my work, especially those related to plutonium. His final comment was the appreciation of US system that molded me to contribute so much in the needed fields of research.

He enthused me to look for problems in the field of radiation protection, so that our scientists do not have to go for other divisions for the fields of research. Later, I did satisfy him almost fully, most of my students obtained degrees (MS and Ph.D.) in the fields related to aerosols and radiation protection.

His sad demise probably contributed to some extent for my return to USA after taking early retirement at the age of 50. I am sure that many of my other associates feel the same way as me. Only other person who shares status of my Guru was my director for Ph.D. program at University of Rochester, NY, USA, Professor Thomas Mercer. He continued what Dr. Ganguly did for me during my next career in USA.

2.2.6.2 Operational HP group at PP
Reminiscences by A R Sunderarajan

Dr. Bhabha was such a great visionary that he realized at the very inception of our department that closing the fuel cycle through spent fuel reprocessing and recycling the recovered plutonium is essential to maximize the utilization of our resources. It was in December, 1958, Dr. Bhabha issued the order saying that we would build a Plutonium Plant. It was to process 20 ton of fuel per year to recover about ten kg of plutonium. When the project started there was hardly any open literature about Plutonium. The only source of some information was a volume of the proceedings of a symposium on Reprocessing of irradiated fuels held in May 1957, at Brussels brought out by ORNL. The project was completed sometime in 1964 just in 6 years Most of the process parameters had to be developed through laboratory and pilot plant studies. There were no written design criteria or codes at that time. Many were developed in-house and adopted. Most of the things being done for the first time, the plant had its woes. There were several hot spots in the plant with spills of radioactive liquid with great potential for significant exposures to workers. It was indeed a huge challenge to provide effective radiological protection to the workers. All these problems were resolved with great professional approach which often required innovative techniques. The Health Physics team was ably led by Dr. P. Kotrappa who graduated from the first batch of AEET training school.

Some of the major problems faced by the health physics group included the following

1. Unlike in the reactor facilities, one encountered often open unshielded spills of fission product solutions. Ratio of beta to gamma radiation levels from these radiation sources having many beta emitting radionuclides was very high some time as high as hundred. There were no survey instruments capable measuring high beta radiation levels. The personnel monitoring

film badges too did not provide accurate beta exposures received by the personnel.

2. For the first time large quantities of plutonium were being handled. The maximum permissible concentration of plutonium in the air is very low and one has to detect this long lived activity in air in the heavy presence of short-lived natural activity. Sensitive alpha spectrometry based monitors were not available then.
3. As efficient detection of internally deposited plutonium by lung counting was not available one has to depend on personal and static air monitors for assessment of intakes. For proper assessment one had to characterize aerosol parameters like activity median aerodynamic diameter, solubility characteristics, etc.
4. PP was the first plant in Trombay to discharge significant quantities of effluents both through air and water route. There was a need to develop an appropriate effluent monitoring system.
5. Yet another challenging task was installation and testing of criticality monitoring system.

As a result, the HP group in Plutonium Plant in addition to providing the routine radiation protection services to the plant was deeply engaged in applied research activities. Due to the paucity of foreign exchange import of radiation protection instruments was not possible. This necessitated development of indigenous techniques and instruments. In parallel some basic research work was also undertaken in allied areas.

Following are the highlights of the development that were carried out by the group

1) Radiation Protection Techniques and Instrumentation
   - i) Stack monitoring technique
   - ii) Development of Kr-85 and I-131 monitors
   - iii) Development of centrpeter type impactors for plutonium
   - iv) Design and fabrication of extrapolation chamber for beta measurements
   - v) Assessment of beta response of radiation survey instruments and pen dosimeters.
   - vi) Study of beta attenuation characteristics of various personal protective wears
   - vii) New techniques for Performance Testing of criticality monitoring systems
   - viii) Development of high volume air samplers
2) Aerosol Studies

i) Development of different types of aerosol generators for filter testing, calibration of aerosol spectrometers, lung imaging, air movement and ventilation studies
ii) Particle size distribution studies in nuclear fuel cycle facilities including in U and Th mining, fabrication and fuel reprocessing plants.
iii) Autoradiographic studies of plutonium aerosols
iv) Dynamic shape factors of plutonium aerosols
v) Re-suspension of aerosols in ventilation ducts and active areas
vi) Development of aerosol charge spectrometer
vii) Development of cyclone method for field aerosol size parameters
viii) Determination of solubility of different radioactive aerosols in lung stimulant
ix) Several basic studies on diffusion characteristics of radon and thoron

3) Electret studies
   i) Development of electret for x and gamma dosimetry
   ii) Radon and thoron dosimetry using electrets
   iii) Electret dosimeter for radon measurements in dwellings

When the HP development work at PP gathered momentum AKG used to visit PP and review the work in progress. He would be so involved in the proceedings, he would often forget the passage of time until a phone call comes from his office in Modular laboratory reminding him of his engagements. What was started as a monthly meeting could not be sustained for long as he was assigned several responsibilities. Later as and when significant progress was made group members would meet him in his office invariably late in the evenings. When the plant management raised concern about the distraction of the R&D work from routine surveillance work, he would assert that the quality of surveillance work would only get enhanced by the research work. Plutonium Plant provided immense opportunities for research work and large number of operational health physicists of PP group got their M.Sc and Ph.D degrees. This was unique at that point of time.

Though PP was commissioned in 1964, a formal safety committee under Dr. Ganguly was constituted only in 1966. Both PP and PREFRE came under formal review of SARCOP only in 1987. Until then AKG was the ultimate regulatory authority for the plant and the management had great respect for his decisions as they were always backed by comprehensive understanding of the issues, sound analysis and patient explanation of his perception.

2.2.7 Reminiscences of evolution of operational Health Physics in the back end of fuel

S Krishnamony

2.2.7.1 Early days

Shri. S Krishnamony was one of the successful products of the BARC training school and joined the Health Physics Division in 1961. He had a brilliant educational career to equip him for this task. Soon after joining he learnt the preliminaries of health physics monitoring methods at the Apsara reactor for a short time before landing himself in his earmarked assignment. We had a short stint working together at Apsara before we departed ways earmarked by Dr. Ganguly. I (MRI) was asked to concentrate on basic R&D. Dr. Ganguly had already earmarked Krishnamony to become an operational health physicist at the back end of the fuel cycle and groomed him for this task. Krishnamony has fond memories of how the two outstanding personalities of the Indian atomic energy program, Dr. Ganguly who laid the foundation for a robust radiation protection program and Mr. N Srinivasan who pioneered spent fuel reprocessing technology indigenously became his mentors. He mentions that Srinivasan was an excellent operational manager and Dr. Ganguly was a "gentle intellectual giant" endowed with sharp wit and sense of humor which he effectively used to disarm those who opposed his logic in a pleasant manner. At the same time he did not mince words to express his disapproval on safety issues even to the pillars of power carrying conviction, a rare virtue. He commanded respect on account of his stature.

Recalling his initial days as the health physicist at Apsara reactor, SK mentions an incident that showed how Dr. Ganguly made the Health Physics Division as the independent custodian of radiation safety in AEET, which Dr. Bhabha had in mind when he created the Division. SK correctly concludes that "one is as independent as one wants to be". The editor feels that, notwithstanding the spirit of independence, not all are "Gangulys" nor could stand on principles, uncompromising, to the authorities. The editor who had a stint in the management of health and safety mostly in post Ganguly era has also experienced numerous instances of this facet of his personality described elsewhere. Though an independent regulatory body was formed later, personalities concerned only can make it independent.

SK has numerous instances for illustrating the independent mind of Dr. Ganguly. During his stint as the health physicist at Apsara once Krishnamony wrote a note to the Reactor Superintendent Nadkarani on the need to have better housekeeping in the isotope room in Apsara, and marked a copy to Dr. Ganguly after personal discussions failed to elicit a positive response. This was frowned upon by the Reactor Superintendent,

though there was nothing offensive in the note. This led the RS to direct that all health physics personnel in Apsara should report to him and forced it on Somasundaram who was the group leader and a circular was issued. SK reported the matter to Dr. Ganguly. Later he was surprised to see the copy of the minutes with remarks of Dr. Ganguly strongly contesting the contents of the circular remarking "who is he?" and "I do not agree". Finally Dr. Ganguly went further to arrange a meeting with Mr. Suryarao the Head of Reactor Operations, Kothari, SD Soman and Somasundaram along with Nadkarni and Krishnamony, showing that he had taken the matter very seriously. In the meeting Dr. Ganguly bluntly asked Suryarao "since when, have you decided to take over the health physics division?". Doctor did not yield any ground and understandably the meeting ended in a cordial note and the purpose of the note viz. cleaning up of the isotope room in Apsara was achieved.

Later on Dr. Ganguly as Head, Health Physics Division and Director of the Health and Safety Group demonstrated this spirit of independence in abundance and no wonder, he was selected as the first Chairman of the DAE-SRC which was formed to initiate regulatory activities in DAE. He had showed astonishing independence on matters of safety and all were compelled to listen and respect him on account of his stature and lack of bitterness in his style of functioning. He focused on issues and not on personalities no matter who were involved.

SK mentions another anecdote when the stainless steel lining of the underground vault which provides secondary containment to the waste tank farm at PREFRE plant in Tarapur cracked on account of ground water pressure despite the thick concrete slab. The decision in the safety committee that the operations can start without the benefit of secondary containment (since the primary containment integrity was tested) was signed by S D Soman and A N Prasad and communicated to Dr. Ganguly. This was sternly turned down by Dr. Ganguly who wrote that "no waste shall be taken to waste tank farm unless the defect is rectified". He further stipulated that the rectification need to be certified by an independent expert and chose Ranganatha Rao of ROD, for this purpose. This led to a decision to rip open the lining and build a thicker lining. Even after the certification after the repairs, Dr. Ganguly checked with SK before according his approval. This is an example that Dr. Ganguly never compromised in matters of safety even under pressing circumstances.

2.2.7.2 Dr. Ganguly a man with a sense of humor

Krishnamony quotes a few anecdotes how Dr. Ganguly disarmed his opponents at safety committee meetings with his deep sense of humor.

Once the problem due to stray cattle inside the PP complex came up for discussion. A N Singal, the plant superintendent, to belittle the problem asked Dr. Ganguly "how many cows, do you think there are in BARC" and prompt came the reply "5000 plus". Everybody laughed but the joke went over the head of the questioner. He persisted that it is not easy to stop them. AKG responded "do not tell me that the cows are smarter than you" and that settled the discussion.

Dr. T. S. Iyengar had a problem with the pumps he borrowed from NPD for his tritium work and they refused to take it back telling it might be contaminated. On being approached, Dr. Ganguly advised "tell them there is no tritium in the pumps and if they can detect it, they have solved your problem!"

Mrs. Kamala Rudran who carried out bioassay analysis of urine samples, once noted that some of the urine samples from PP were being diluted with water by the workers. The concerned people could have done this to avoid collecting the void samples in early mornings. Singal, the operations superintendent, was uncooperative saying that it was health physics staff who were indulging in this mischief. The matter came to the notice of Dr. Ganguly and he abruptly told Singal during a safety committee meeting: "It looks lots of your people are passing water in their urine and they need to be hospitalized" and that settled the matter.

Once when the matter of a doctor unable to use rustication equipment to render first aid to a couple of firemen was brought to the notice of Dr. Sundaram, Head of Medical Division and he was unwilling to accept this in the meeting, Dr. Ganguly intervened and told: "Dr. Sundaram, if there are good engineers and bad engineers there would be good doctors and bad doctors" and with this the discussion ended.

Krishnamony mentions another aspect of Dr. Ganguly, viz. he was a man without any pretensions and would consult anyone on the spot to learn about the facts and even seek their opinion if he notices similar problems elsewhere. SK has several instances of his experience in which Dr. Ganguly called for him and consulted him regarding problems related to the back end fuel cycle facilities. One of them related to the issue of giving clearance for the Radio Metallurgy Lab. Yet another was when the operations in PP reached a stage when it could not be continued. SD Soman asked SK to prepare a note which was sent to Doctor. SK was called and Dr. Ganguly told him that he has sought an interview with Mr. Sethna on the matter and asked SK to be prepared to present the problem. SK was nervous about an unpleasant encounter with

Sethna but Dr. Ganguly took care of that and talked to the Director and saw to it that the plant was shut down after exploring the possibility of CIRUS metal fuel being reprocessed at PREFRE. The Trombay PP plant was subsequently taken up for revamping. When the issue of using MOX fuel in TAPS following the stoppage of fuel supplied by USA for TAPS, in the aftermath of 1974 PNE experiment by India, a committee was constituted. SK was nominated to the committee by Dr. Ganguly to look into the safety aspects. However, alternate source of enriched fuel was found subsequently but the exercise resulted in the setting up of an advanced MOX fuel fabrication facility which today meets the fuel requirement for the PFBR program.

Dr. Ganguly did not lose any opportunity to acknowledge the achievements of his students. SK met him after return from deputation to the Idaho facilities, where he got a certificate of merit given by Idaho operations which was sent directly to Dr. Ganguly. On seeing Krishnamony, Dr. Ganguly stood up ceremoniously and asked "where is the gown?" as if it was convocation and advised SK to conduct himself in profession, as well as in life in a manner worthy of that recognition. Dr. Ganguly was an integrator of disciplines as everyone who has worked with him would testify and SK also noted this aspect. The dimensions to his vast field of activities showed no limit and SK, much after his retirement was surprised to see the name of Dr. Ganguly as the chairman of a committee under the auspicious of Sri Sathya Sai Organisation on "Science and Spirituality".

2.2.7.3 Evolution of operational health physics in back end of fuel cycle

The radiation hazards associated with irradiated fuel processing are much different from those encountered in reactor operation and in other parts of the fuel cycle. Large amounts of radioactivity are handled in dispersive and corrosive form remotely in shielded cells in these chemical operations and transferred in stainless pipelines from cell to cell using steam jets, airlifts or vacuum transfer and sometimes using isolated pumps located in cells. The sampling required for quality control and safety monitoring are to be done using elaborate system of sampling to ensure effective isolation of working atmosphere from the process atmosphere behind heavily shielded cells.

The presence of highly dispersive and toxic plutonium in solution form poses challenges in radiation protection from the standpoint of accidental criticality. And the rather classified nature of operations forces the methods and equipment to be developed indigenously. Safety philosophies and methodologies for these were developed for the Indian fuel reprocessing program under the guidance of Dr. Ganguly by the team consisting of

Kotrappa, Krishnamony and others. Krishnamony has several interesting anecdotes in these activities which bring out clearly the vision of Dr. Ganguly

Krishnamony remembers a presentation given by N. Srinivasan after return from visiting reprocessing plants in France and UK in which he began by saying that in late fifties when we "rushed in where angels fear to tread" to elaborate how potentially risky these operations were. This was a bold challenge thrown to our scientists and engineers by Dr. Homi Bhabha. It is a matter of satisfaction that today Dr. Bhabha's dream stands vindicated in India being perhaps the only country in the world offering a nursery of development of intricate technologies of the complete nuclear fuel cycle, all grown indigenously, of which the country can be proud of. Krishnamony admits in retrospect, though we had an understanding of the potential problems involved, it is fair to say that there was insufficient appreciation of the complexity of the various dimensions of the "monster" we were trying to tame! The epithet is taken from a dialogue SK had with Dr. Ganguly while reviewing the various safety problems in the prototype 30 Te per annum Trombay PP. Dr. Ganguly seems to have remarked that "if this is the case here, what about the monster they are setting up at Tarapur, the PREFRE plant?" By today's standards even that monster of yesteryears, a 100 Te plant is a "Pygmy". Our program needs to graduate reprocessing operations to industrial levels of hundreds of tons of throughput per annum if one has to tackle fully the fast reactor technology, the path to overcome the limited uranium resources in the country that India has adopted almost single handedly.

Krishnamony joined the health physics team of Kotrappa, Joshi and Jauhri at the Project Phoenix, the name for Trombay PP, in its construction stage. The commissioning of the plant was in full swing at that time. This team attended to commissioning of PP under close direction of Dr. Ganguly. N Srinivasan had close liaison and respect for Dr. Ganguly and used to take advice from him in safety matters. Much later when PP established a pilot plant for separation of U-233 from the thorium J rods in CIR and first batch of material was produced by a team led by G. R. Balasubramaniam, the first thing Srinivasan did was to dash to Mod Labs to show a sample of the material in a sealed vial to Dr. Ganguly! I was a spectator of the childlike enthusiasm of these two stalwarts. Doctor called for me and asked me to carry out spectrometry studies on U-233. N Srinivasan remarked to me that "the sample is yours now". This led to several investigations and publications on U-233 and U-232 and the sample was in my custody till I left for IAEA in 1994! The reprocessing technology for separation of U-233 from Thorium which calls for chemical procedures different from that for Pu separation from Uranium required for

a successful thorium breeder reactor program was thus tackled for the first time in the laboratory.

It was at this time the AEET radiation protection manual which Somasundaram had carefully put together was published. This has propounded the zoning philosophy for controlling the radiation exposures in radiation plants and air changes required to control the radioactivity concentrations in air in working areas. Dr. Ganguly had taken personal interest in evolving this idea. Krishnamony remembers that PP was the first plant to enforce a dress code for workers, white coats with yellow collars, meticulously selected red shoes and gum boots. This code ensured that contaminated protective wears were not taken out into the uncontrolled areas and greatly helped in contamination control. Suppliers had to be prevailed upon to manufacture these specially designed protective wears - respirators, airline masks self-contained breathing apparatus and special plastic suits for entry into highly contaminated areas for maintenance as these had to be specially manufactured. Under Soman's directive HPD set up a unit for manufacture of these items at PP and Awatramani was identified to design and supervise the production and he and his staff had to do overtime to meet the plant's requirements. Eventually private manufacturers were identified to pass on the knowhow for production of these in large numbers. An innovative respirator testing unit was also designed to ensure that no leakages existed when worn. System for testing the HEPA filters for efficiency was another requirement met by HPD. Kotrappa devised a Na 24 tracer aerosol generation unit for in situ testing of the HEPA filters. Ventilation is an important factor in controlling spread of Pu into the working atmospheres and this was tested and expert guidance was provided by the Industrial Hygiene Section of HPD. The requirements for special radiation monitoring instruments particularly continuous alpha monitors to monitor the working environment was essential to control internal radiation exposure of workers to plutonium which has stringent safety limits and called for detection in the presence of a larger natural radon daughter product concentration in the air. Plutonium in air monitors using alpha spectrometry was developed indigenously by A N Singh of Air Monitoring Section. Surface barrier detectors which were initially used were found to deteriorate with time and were replaced by more sturdy diffusion junction detectors. The impactor samplers for spot sampling of plutonium which makes use of discriminating the natural radiation activity by particle size were developed. As a matter of fact work on this had started much earlier in the radiochemistry division by Kirthi and Kotrappa under instructions from Dr. Ganguly which came in handy and the techniques were further fine-tuned to distinguish the natural activity by virtue

of their sub-micron size. Use of calcium DTPA inhalers using nebulizers to chelate the deposited Pu in the lungs by workers was developed and used for internal exposure cases. The exercise to monitor Kr-85 from the standpoint of emissions from the stack led to it being used as tracer to study the details of dissolution and found use in the operations. I-129 a long-term burden on the environment from releases in reprocessing plants was quantified by the work carried out by Dr. P M Ravi. Very elegant analytical procedures were developed by Ravi in which he made use of the very sensitive ratio of I-129/1-127 is worth mentioning. I have the satisfaction of being associated with Ravi in this work. In addition to I-129, tritium which is another radioactive product with long term implications likely to be released from reprocessing plants was quantified at the PREFRE plant.

One of the noteworthy investigations carried out by SK and his team was on the investigation of the nature of iodine aerosols. Sampling methods were innovated to distinguish between molecular iodine and iodine in various forms especially methyl iodate, CH_3I using a bank of multiple filters. AKG recommended these methods to be used in testing the efficiency of filters for iodine in the exhaust system of PHWR reactors. G S Jauhri made significant contributions in this area.

Emergency preparedness was looked into in the Plutonium Plant. Plant emergency preparedness was organized and emergency annunciations using audio visual methods were carefully planned and installed and assembly areas were identified for personnel to assemble and get monitored in case of such eventualities. Emergency preparedness was planned and classified as stay-in, evacuation ,etc. and installation of audio siren signals and the subsequent all clear signals. All these called for a separate type of R&D and Dr. Ganguly commended the efforts of Krishnamony for such investigations of practical importance away from the wide spectrum of basic and applied research which was organized by him.

Criticality safety was an area in which AKG had concentrated from initial days. The significant contributions of LV Krishnan, V Kalyanasundaram and TN Krishnamoorthy are recorded elsewhere in this Compendium in other sections. It may be noted Kalyanasundaram was the one who commissioned several transport and criticality computation codes in AEET for the first time and was offering these to all who were managing safety. This team formed an expert group to which all such problems anywhere in AEET were referred to in those days. The implementation of criticality safety requirements called for developing criticality monitors and criticality dosimeters for surveillance.

Criticality monitors based on rate of rise of gamma dose and criticality dosimeters based on threshold detectors were also developed by various groups in BARC. The testing of criticality monitors was another area in which large teamwork was involved and innovative methods were developed. These monitors had the function discriminating high gamma background common in such plants from those originating from criticality excursions. The rate of rise of gamma radiation would be significantly different in such events and this was exploited in testing the systems.

Since the plant was carrying out the reprocessing of short cooled, low burn up metal fuel from CIR, iodine plate out in the ducts was investigated and a value of 50 per cent plate out was arrived, experimentally.

Workers often had the potential for exposure to high beta dose in reprocessing plants in case of spills and during maintenance. Dosimetric procedures were developed to assess beta dose and used in the field AKG commended SK on carrying out research on this type of work that was of practical value. S K Dua had contributed significantly in this work by fabricating an extrapolation chamber for measuring absolute beta dose rates.

The need for discrimination between Pu aerosols and natural radioactivity led to special branch of Aerosol Physics. Kotrappa and Dua became specialists in these areas. Numerous spin offs from these investigations can be seen as the outcome from the activities of this group. One of these in which I was involved in later years was the development of an aerosol generator for lung scintigraphy to assess the damage to the lungs of smokers. This was widely supplied to several countries through IAEA. The dependence of lung dose in case of inhalation depends on particle size and this was investigated by SK and A. R Sunderarajan and presented in an IAEA meeting and was commended by Dr. H J Dunster. When the autoradiograph of the filter samples were shown to AKG he remarked "so these are the particles which were not breathed in by the workers" echoing the observations of Krishnamony in his paper that the random nature of the distribution of the small number of plutonium particles led to erroneous interpretation of air sampling data as an indicator of internal exposure.

2.2.7.4 PP Safety committee

Krishnamony mentions that when PP was commissioned there were no written documents. Only after few months of operation N Srinivasan prepared a design manual and another for operation. Within months Dr. Bhabha constituted a hazard evaluation committee to prepare a report with Dr. Ganguly as chairman. It might be recalled that he was earlier called upon to prepare a

hazard evaluation report of CIR reactor by Dr. Bhabha. SK attended most of these meetings as a co-opted member till he went abroad on deputation. Somasundaram acted as Secretary of this committee. A S Rao who addressed the meeting raised the question of impact of the operation of the plant on the neighboring Anushakti Nagar. The committee later considered this and came to the conclusion that offsite emergency was not probable in this plant. Subsequently a PP Safety Committee was also constituted. Dr. Ganguly suggested SK to prepare a radiation protection manual for the plant.

SK notes that the meetings of PP safety committee offered great opportunities to observe first hand the deep insight of Dr. Ganguly into various problems and his approach to various issues. SK mentions that the transactions of the committee often witnessed lively exchanges between Srinivasan and Ganguly both of whom had respect for each other. AKG had the gift of focusing on the issue and even after heated exchanges there was no trace of bitterness. This aspect has been underlined by many others as well.

What was more important and unique was that the HP group at fuel reprocessing plants was considered part and parcel of the operations and was consulted every day for planning the operations. SK and his team contributed significantly to the preparation of the hazard evaluation report. AKG took personal interest in the transactions of the safety committee of which he himself was the chairman. The rapport he had with Srinivasan and his ability to focus on safety issue and his natural gift to defuse any serious situation went a long way to solve thorny issues.

SK enumerates several abnormal occurrences in the plant which were discussed in the safety committee. This led AKG to remark "purely analytical approaches potentially unsafe situation have their limitations". He said this while discussing an unusual occurrence when a fuel rod being charged into the dissolver broke and called for urgent measures to rectify the situation. One of the incidents involved the transport flask which was used to transport irradiated fuel from CIRUS to PP when it tilted and partly landed on the road. Fortunately no fuel was inside but only spilled contaminated water on the road. The head of the Reactor Operation Division S M Sundaram defended the design of the cask which prompted Dr. Ganguly to remark "your allegiance to the flask prevents you from seeing the weakness in design". He stated if this is the case he will insist on recording that the flask is unfit for transport of irradiated fuel. This resulted in modification to the flask and safer designs of flask for transport of RAPS fuel to PREFRE through public domain based on international standards evolved.

SK mentions how the specification of fission products in the uranium product that emerged after the process was fixed. Finished plutonium product and the extent of decontamination of fission products limits were based on MPC in air for mixtures. Dr. Ganguly recommended that the fission product and Pu should not exceed the equivalent of the specific activity of natural uranium. Later when SK was under deputation to USA, AKG specifically called for practices in USA and the information provided by SK was useful.

2.2.7.5 Radioactive effluent control

Radioactive effluent control and their impact on the environment was an area close to Dr. Ganguly's heart, notes Krishnamony. Dr. Ganguly, as enumerated elsewhere in this volume, had done pioneering work on establishing limits of effluent release into the Trombay bay, Tarapur environment and Rana Pratapsagar lakes. SK remembers on the basis of his longstanding work, Dr. Ganguly had prescribed the limit of discharge from PP as 1curie of Sr 90 equivalent on the basis of radio toxicity of all radionuclides in the effluent relative to Sr-90 based on their MPC values in sea water. SK mentions that Sethna who was in charge of PP operations at that time was not very happy with the assumptions and at the same time Dr. Ganguly was not happy that effluents were to be discharged near the mud flats near shore of Trombay bay through a pipe line. Sethna asserted that his effluents will be so clean that one can drink it, notes SK. Dr. Ganguly stood his ground and added that "you stick to your view and I will stick to mine". SK notes that when the plant went into operations the concentrations in the effluent were higher than anticipated and it was not even possible to meet the specified discharge limit. Parts of the effluents having higher levels of activity were shipped in shielded containers to the Effluent Treatment Plant of the Waste Management Division for treatment. These ultimately led to HNS admitting that "we have goofed and let us face it" and AKG was proved right. Better design for the PREFRE plant in Tarapur was evolved. SK narrates how AKG asked I S Bhat to carry out dispersion and dilution studies in the Tarapur coast which showed that a pipe line of 3 km was required to ensure that discharged effluents do not return to the shore and achieve the limit of discharge. An acceptable solution was arrived at by constructing a waste treatment plant that would give a decontamination factor of 100 and a 1 km discharge line which met the stipulation was laid. And the specification by AKG of 25 mCi of discharge per day could be achieved. The liquid effluent treatment facility provided by GE for the TAPS reactor was found to be inadequate. The hold-up tanks at PREFRE were found useful in handling these wastes from TAPS. All waste management operations at the Tarapur site were integrated and brought under

the waste management division. This led to the construction of a full-fledged back-end waste management facility for all the plants on the site such as WIP, TWMF, TRAP PEST Project, S3F and AF3.

As a follow up, a Health Physics laboratory was commissioned to consolidate all the health physics R&D operations for the site. Though in the initial stages this was planned on the scale of the health and safety laboratory at Kalpakkam site but could not attain such a status but only catered to common day to day health physics support for the site such as TLD Services, Whole body counting facility and other auxiliary facilities for HP operation. It had a full-fledged emergency center. It also became the site for the stipendiary health physics training program launched subsequently.

2.2.7.6 PREFRE safety evaluation

Krishnamony remembers his contribution to the PREFRE plant design safety evaluation based on his experience with PP. He started his tryst with organization of health physics activities at PP and was later on shifted to oversee the activities at the PREFRE plant. A committee was constituted by Ganguly and Srinivasan with SDS as the chairman and SK as member secretary. The deliberations of the committee took over 3 years before the report could be prepared. The various groups involved with design and construction of various systems were requested to prepare reports which were discussed and safety aspects analyzed in the safety committee and implementation was the responsibility of the group concerned. On completion a report was presented to Ganguly and Srinivasan. Dr. Ganguly suggested to S D Soman to forward a copy to Director BARC, Dr. Ramanna. This became a model for the preparation of safety reports of other back-end facilities subsequently.

Krishnamony remembers how S D Soman's initiative enabled the starting of the one year Health Physics stipendiary training program to meet the growing requirement of the health physics man power to be launched in 1986. SDS was successful in persuading the then director Dr. PK Iyengar for getting the approval for this program. The syllabus including class room lectures, practical hands on training in various plants, periodic evaluations was prepared by a committee consisting of SK, BML Sah, and MSS Murthy. SP Kathuria provided support as member secretary and looked after the day to day administration of the program. This program provided trained man power for the health physics program when the BARC training school was found to be more generalized and did not meet the demand for the special requirement. The venue for the course was shifted to the HP laboratory at Tarapur from Trombay after 2 years, considering that better infra-structure

existed there for the course. This also enabled the trainees to undergo hands on experience in health physics activities in various parts of the nuclear fuel cycle along with class room training as SK points out. And this program even now provides the technical manpower for radiation protection activities of all DAE programs. The program was originally modeled after the various courses successfully conducted by RPA Division in the Health Safety and Environment Group.

2.2.7.7 Health Physics Handbook

Krishnamony in his extensive memoirs also remembers how he happened to compile a health physics handbook which became popular with all health physicists. During his earlier stint at Apsara he used to collect information and data useful for a health physicist and made a file. Once Somasundaram happened to see this and took the file. It seems he showed this to Dr. Ganguly. Dr. Ganguly called Krishnamony and commended his work and asked him to take it up as a project and prepare a comprehensive handbook with ready to use data for the health physicists. I may add that since 1957 we were using a collection of handbooks such as that by Kinsman published by US dept. of public health and Rockwell's shieling manual and were popular with all of us. But the efforts of Krishnamony made all these available in one cover with more additional information. The work continued in later years during his stint in PP. Dr. Ganguly inquired about the book after SK returned from deputation. He was pleased with the compilation but remarked that this looked like register and not a handbook. SK then restructured it and got the whole matter retyped (a laborious job in those days) from Chhabria and along with Raghunath prepared a draft. Dr. Ganguly was pleased and recommended it to be published by Dr. Kamath who headed the library and publication division of BARC. Within few months the handbook (BARC/I-55, 1969) was on the table of all health physicists in Trombay through controlled distribution from the office of Dr. Ganguly who used to respond to any request for a copy with the remark that "this is not meant for use as a pillow!".

2.2.8 Reactor Water Chemistry studies

Activation of Corrosion Products in Reactor Systems"

A. C. Paul

2.2.8.1 Introduction

A. C. Paul was one of the operational Health Physicists who, under Dr. Ganguly, carried out several R&D assignments on radioactivity in reactor coolant and moderator systems for the first time. As his anecdotes will amply testify, the requests for R&D scientific assignments sought from Dr. Ganguly invariably flowered into important streams of activities, many of them proved to be

pioneering works. So was the case with Paul, who carried out investigations on radioactivity in reactor coolant and moderator systems.

A.C. Paul joined the Health Physics Division of Atomic Energy Establishment, under Dr. Ganguly, in November 1960, soon after completing graduation in Chemistry. He was initially assigned work in the environmental laboratory of the Division in Trombay, where he picked up the basics of radio-chemistry. It was the time when the Canada India Reactor (later, CIRUS) was getting commissioned. Soon, Paul was asked to report to the CIR Operational Health Physics Unit. Though he was very elated to work in the reactor, he felt that his dream of becoming a radio-chemist might not get fulfilled. He, therefore 'boldly' approached Dr. Ganguly for a change of work. It was his first informal meeting with him. Doctor looked at him with his eyes piercing through his thick spectacles. Paul mentions that he could instinctively feel the warmth in his heart that emboldened him to blurt out his request "Doctor, I would like to come back and continue to work in the chemistry laboratory". Doctor looked at Paul sympathetically and, for a moment, Paul thought that his request was granted. Dr. Ganguly then asked a few questions to Paul on the reactor coolant chemistry and remarked that a reactor chemist was the need of the hour for the Division and expected him to be molded into one and assured him that his new assignment would enable him to become one. Paul was fully enthused at his advice that he felt ashamed at his request to get back to a small analytical laboratory. This was a trait in Dr. Ganguly that became evident in the memories of many, which produced new avenues and streams of work whenever someone approached him with a feeling of dissatisfaction. The very first interaction with Doctor made Paul realize that the world was wider and its horizons unlimited. Paul recollects that S. D. Soman, who was supervising the Health Physics operations at CIR, was very supportive and provided all facilities and guidance in pursuing the work on radio-chemistry of the reactor coolant and moderator.

Room No. 11 of the CIRUS administrative building thus became the nucleus of a new discipline in the Health Physics Division and produced a unique scientific work, under the visionary zeal of Dr. Ganguly. The main objective of Paul's work was set as operational health physics along with radiochemical analysis of the liquid effluents. The work dealing with radioactivity in coolant and moderator was carried out during 1962 to 1965. Paul did most of his work using a single channel analyzer but the acquisition of a 512 multi-channel analyzer by the Division, under Project Marina, provided an additional impetus to the work. Published literature on the subject, the world over, was scanty when Paul carried out a review of the work on the subject. Dr. Ganguly

specially insisted all his students to carry out a critical review of the earlier works on the subject, before undertaking any research assignments for post-graduation.

Paul had several meetings with Doctor, discussing the work. He always infused positive thoughts on the listener. His enthusiasm for research work was contagious. While talking to him, one gets transported to another world, full of visionary ideas. However, his suggestions are down-to-earth and highly practical. One comes out of his room with a feeling of extraordinary elation. He has the capacity to make everyone feel important in the organization, which smacks rare leadership. He encouraged his students to use their research work to earn a degree which almost created a 'Ganguly School' in AEET and Paul got registered for his Master's degree under Dr. Ganguly.

Dr. Ganguly's eye sight deteriorated during the period and it was physically impossible for him to read text. He would, therefore, ask Paul to sit close to him and read the text slowly and clearly. He would frequently interrupt, asking questions, seek clarifications, giving suggestions and even mildly scolding for any errors. Many of those discussions went on in the mornings, at his Ghatkopar residence. Paul notes that Dr. Ganguly also requested M. R. Iyer, a senior colleague, who had finished his M.Sc degree and carrying out investigations on fission and fission products for his Ph.D. degree to oversee Paul's thesis drafts and provide suggestions for the work. In this context, MRI remembers that a new dimension to his own activities was thus initiated by Dr. Ganguly of giving guidance to fellow students, which was till then confined to his own work on fission products. MRI realized that Dr. Ganguly was gradually grooming him how to guide students that paved the way for him to guide students in the "Ganguly School."

MRI remembers the work on Apsara coolant by D. V. Gopinath and in tracing the origin of Na-24 from the aluminum structural parts, earlier. Paul's work was more focused and incorporated radiochemical analyses as well of the CIR reactor coolant and heavy water moderator. A large number of activation corrosion products, in the reactor, were also covered in Paul's work. The work was completed in 1965 and a thesis entitled "Activation of Corrosion Products in Reactor Systems" was submitted to Bombay University in 1966. Dr. Ganguly enabled the work to be published as a BARC External Report. Paul remembers Dr. Ganguly telling him later that Vikram Sarabhai, the then Chairman, AEC and Dr. Karl Z Morgan, Editor, Health Physics Journal were very much impressed with the work.

2.2.8.2 A brief account of the work and its salient features

The study of the origin, nature and concentration of radio-nuclides in the reactor primary coolant and moderator systems was important for the radiation hazards control in the reactor and environment. Various activation products, both in-core and out-of-core were identified and estimated. Apart from the intrinsic activity, which was short-lived, activation of impurities, contributed by corrosion products, substantially enhanced the radioactivity inventory in the circulating systems. High radiation fields were associated with crud-traps in the system and such hot-spots were mainly contributed by the deposition of activated corrosion products. The investigations also helped in studying crud formation and deposition on fuel element sheaths. Efficiency of the ion-exchange resin was evaluated to improve its role in reducing the build-up of long-lived radio-nuclides in the system. A simplified procedure for rapid estimation of radio-nuclides by gamma spectrometry was developed and usefully employed in the work.

Nearly 20 radio-nuclides were identified in the primary coolant by rapid gamma spectrometry, ranging from Al^{28} (half-life2.27 m) to Co^{60} (half-life 5.27y). While estimation of short-lived radio-nuclides was solely based on gamma spectrometry and decay analysis, radiochemical separation was resorted to for nuclides of longer half-lives. Different nuclear reactions such as (n, γ), (n α), and (n, p) reactions were identified in the production of different radio-nuclides in the primary coolant system. Traces of fission products were also identified in the system due to the "tramp" uranium in the aluminum clad and also from occasional fuel failures.

In order to estimate the scaling and deposition of the radio-nuclides, resulting in the build-up of radioactivity in the system, the activity in the coolant was divided into soluble and insoluble (crud) fractions. The studies showed that the activity build-up in the solution fraction attained an apparent steady state in a short duration; however the activity in insoluble fraction showed steady build-up. The short-lived activities were concentrated in the soluble fraction and the insoluble crud accounted for most of the long-lived activity.

Radiation survey, post shut-down, of the primary coolant system indicated that major quantities of the corrosion products were deposited immediately downstream of the reactor core and crud traps. This observation played an important role in designing appropriate radiation monitoring protocol related to shut-down maintenance. The editor comments that this is an instance of demonstration of the vision of Dr. Ganguly in initiating an all comprehensive health physics program for AEET, not confining to radiation surveillance

alone. It may be recalled that he refused to adopt the practice in Canada and elsewhere for the Indian Health Physics program as stated in other sections of this compendium. The health physics program followed by Dr. Ganguly often proved to be useful for the operations as well.

The chemical and radiochemical purity of the primary coolant, in a circulating system, is mainly dependant on the capacity and efficiency of the demineralizer. Paul's work enabled the quantification and performance of the clean-up system in the reactor. Later investigations revealed that peroxide in the coolant system interfered with performance of the anion resin, which even affected the physical integrity of the resin. The studies also revealed the cation resin also acted as a crud filter.

Data on radioactivity in heavy water moderator, excepting for tritium, were scanty in the literature. Therefore, Dr. Ganguly specially insisted that Paul should take it up as part of the coolant work. He also gave guidance for the work and precautions to be followed in handling the samples and specially requested the Reactor Superintendent for permission to carry out the work.

The focus of the work was to generate maximum data within the shortest possible time. Quick delivery of the sample to the counting unit was the need of the hour. In the absence of a mechanical rapid sample transport system the only option was to take the samples manually and put in the counter with minimum possible delay. Thus the assay time, after sample collection, was 4 minutes initially. By having the gamma spectrometer closer, the time lag could be reduced to 1 minute. Thus, many short-lived nuclides, which could not be detected in the primary coolant, were identified in the heavy water. Prominent among these was Ag^{110} (half-life 2.27 m). MRI nostalgically remembers the thrill in working with Paul when they detected a peak in the gamma spectrum and identified it as a silver isotope. The origin of this radioactivity was under in-depth discussion and when the very low yield of fission product origin could not account, it was finally traced to the welding component of silver. When Paul reported this to Doctor he immediately took the phone and called Shri. V. Surya Rao, the Reactor Superintendent, to ascertain the possibility of silver in the heavy water. When the reply came in the affirmative he stood up from his seat and was visibly agitated on the finding. Such was his burning fire for scientific quest!

Since the primary coolant and the moderator contained radio-nuclides having different chemical and nuclear properties it was necessary to evolve a suitable method for their separation and assay. The short half-lives of some of these

nuclides necessitated simplified separation schemes to save time and judicious selection of the radio-chemical process to isolate nuclides, based on their gamma energies. Thus a general scheme for the separation of Fe^{59}, Mn^{54}, Cr^{51}, Co^{60} and $Zn^{65}$was evolved. The common separation scheme was based on precipitation and solvent extraction, using isotopic and non-isotopic carriers. The method ensured adequate radio-chemical purity and chemical yield ranging from 80 to 90% for all nuclides. Special gamma spectrometric analysis methods were also developed for the assay of individual nuclides.

2.2.8.3 Epilogue

Paul considers himself as very fortunate to receive the first "Dr. A. K. Ganguly Felicitation Price" instituted by the Indian Association for Radiation Protection in 1986, especially when the legendary Guru was alive. He could not attend the function, as he was bed-ridden by then. "I went to his residence and placed the Citation at his feet. As I touched his feet he blessed me. He also sought my forgiveness for not being able to attend the award ceremony. I looked up at his face and could see the same warmth and intensity that motivated me throughout my carrier" - Paul recalls.

2.2.9 Evolution of operational health physics in front end fuel cycle

2.2.9.1 Introduction

MR Iyer

Dr. Bhabha had a clear-cut vision of developing Atomic Energy Establishment Trombay, AEET as a comprehensive center since its very inception touching on all the aspects of a complete nuclear fuel cycle. Even in 1956, he is quoted as saying that the fuel for Canada India Reactor would be fabricated in Trombay using Indian uranium when no such facilities were even started. The blue print for reprocessing activities seems to have been taking root in his mind even when the CIR with Canadian assistance was being erected.

The plan for making available uranium to fuel the CIR was quickly put together in Trombay in the Uranium Extraction Section of the Metallurgy Division under Dr. Brahm Prakash, one of the stalwarts of the atomic energy program under Dr. Bhabha. Dr. T. K. S. Murthy of the Uranium Extraction Section was responsible for some of these activities as noted by L. V. Krishnan, T. S. Iyengar and K. Sundaram in their book on 50 years of Atomic energy.

A Thorium Plant was in operation at Trombay since 1954 under the Indian Rare Earths Limited which was getting monazite concentrates from its Alwaye and Manavalakurichi plants. To process and purify uranium to nuclear grade the Uranium Metal Plant was set up in its vicinity at Trombay in 1958. A fuel

fabrication plant to fabricate the metal fuel element for CIR was also set up. The project was known as Faggots. The first uranium ingot was produced from uranium recovered at the Thorium plant.

The Health Physics Division provided health physics surveillance for all these plants from the very inception. S Vasudeva Murthy who joined HPD in 1956 and obtained training abroad along with Somayaji was organizing the health physics coverage in these plants but toward the end of 1965 he left. PPVJ Nambiar and N Subramaniam from the first batch of Training School and Ramanathan were looking after Health Physics activities under the watchful eyes of Dr. Ganguly and Shri Soman. Shri Subramaniam was reportedly a stickler to health physics discipline and carried out the directives of Dr. Ganguly sternly and dealt even with the higher ups sternly. One of the anecdotes mentioned about him is demanding the security badge of an Assistant Security Officer who was checking the security badges of the occupants of the AEET bus. Evidently the ASO was not wearing his badge. This led to stricter directives for all to display security badges. In all his enforcing health physics norms Dr. Ganguly supported him but sometimes also advised him to be more diplomatic.

Another problem faced in Faggots was the incidence of uranium fire quite often. The uranium metal clipping stored outside used to catch fire even though they were stored in oil. Under the directions of Dr. Ganguly, one Jolad developed ansul powder for fighting uranium fires. This was found very useful in controlling this problem in faggots. S Viswanathan who was looking after HP activities of the Faggots was shifted to NFC as the health physicist in early 1970s and served there till his retirement. Even after retirement he continued as an RSO in one of the commercial accelerators installation in Hyderabad. Recently he passed away in January 2017, his sad demise was known when the editor tried to contact him for getting his memoirs.

P. P. V. J. Nambiar who joined HPD from 1st batch of training school was sent abroad for health physics training in uranium mines and was identified to organize health physics activities at Jaduguda mines. Since he was not willing to shift to Jaduguda, Dr. Ganguly identified M. Raghavayya for developing methodologies and devices to carry out radon monitoring which was the most important radiation hazard for mine workers. It can be said that he is the pioneer in this field though some activities under Dr. K. G. Vohra were carried out in the initial days for environmental radon. However, for developing techniques for the front end of the fuel cycle Raghavayya is considered as the pioneer. He was looking after the health physics activities in the Ore

Extraction Section in Hall no. 6 where he developed the radon monitoring system based on Lucas cell and this lead his selection to organize the health physics activities in Jaduguda.

I am including the saga of innovatively developing the radon cell by Raghavayya all by himself described in his own words in this compendium, since this illustrates the working of an innovative mind. Dr. Ganguly had once testified: "Raghavayya is one of the last of the breed of innovative scientists who built their experimental equipment from rudimentary and common materials available at hand." This rare testimony from the father of Health Physics science in India speak volumes for the innovative skill of Raghavayya. The editor feels perhaps had he chosen to finish his MSc and joined the training school, he could have used his skill in forefront research in any area of science he would have chosen! This reminds me once Dr. Ganguly sharing with me that "we must bring Raghavayya back to Trombay and groom him to greater heights" but due to personal reasons he preferred to take up a routine assignment in Mysore Special Material Plant instead. Raghavayya says his decision to proceed to the "primitive" Jaduguda mines following the demonstration of his innovative skill was a "wise one", I may add his decision not to relocate to BARC as desired by Dr. Ganguly later was an "unfortunate one", denying himself and the institution a chance to further benefit from his innovative skill!. The editor cannot but note the parallel evolution of his career and that of Raghavayya in choosing themselves to take up the post of JSA in preference to their pursing Master degree courses in their respective universities. Both of us were singularly fortunate in ending up as protégés of Dr. Ganguly which retrieved the situation!

The memoirs of A H Khan is included first since it gives a kaleidoscopic view of the evolution the uranium mining and milling industry in India, how the institution of a comprehensive health physics program for the nascent Uranium industry visualized by Dr. Ganguly contributed to its "healthy" growth, how the challenges were met in the initial days and how it contributed to the efforts of DAE in allaying the fears of the public and facing the exaggerated hype of the media.

2.2.9.2 Health physics in the Mining Industry - A tribute to Dr. Ganguly
A H Khan

2.2.9.2.1 HP Work in Front end fuel cycle facilities in AEET

When I joined and reported to the Health Physics Division of AEET on 25th February, 1965 I was asked to wait in the mezzanine floor of the Health Physic Shed at south site where few other colleagues were also waiting as Dr. A. K.

Ganguly, then Head, Health Physics Division was perhaps abroad. When he returned a couple of days later we all were asked to meet him. With some awe we went to his chamber where he asked every one of us the university from which we obtained our degrees and directed us to meet Shri S. D. Soman who directed me, Henry Mathias and S. N. Karekar to meet Shri. S. Vasudeva Murthy in the Health Physics Unit in the nearby IREL dispensary premises. Vasudeva Murthy put me with P. R. Ravindranathan Nair in the Uranium Metal Plant while Mathias was sent to S. Viswanathan in Faggots and Karekar joined Shri R. Dhandayutham in the Thorium Plant.

2.2.9.2.2 Uranium Mining and Ore Processing

For sustaining a large atomic energy program it was considered necessary to develop indigenous resources for uranium. In their search the famous geologists from Geological Survey of India Dunn and De had reported traces of uranium present in the rock samples from the geologically famous Singhbhum Thrust Belt of Chota Nagpur Plateau of Bihar. The search for atomic minerals was undertaken by the 'Rare Minerals Survey Unit' of the GSI which was brought under Atomic Energy Commission on July 29, 1949 and renamed as 'Raw Materials Division' (RMD), with Headquarters at New Delhi. In 1958 the RMD was renamed as Atomic Minerals Division under the Department of Atomic Energy. The first mine-able deposit of uranium was discovered at Jaduguda by Prabhakar Rao of the RMD in 1951. The first bore hole was drilled by Associated Drilling Company of London. Subsequently from 1955 onward AMD acquired its own drilling machines. Intensive drilling at Jaduguda led to discovery of uranium along an East–West strike length of about 800 m, initially up to a depth about 300 meters which was found to extend up to 600 meters and 900 meters, respectively, in the second and third stages of exploration.

Exploratory mining was taken up at Jaduguda in mid-1950s by the RMD, and the ore processing studies were undertaken in the Ore Dressing Section of BARC. The encouraging results led to the setting up of a Pilot Plant at Ghatshila about 22 km from the mining site where a copper smelting and refining plant of the Indian Copper Complex were already in operation for a few decades. T. K. S. Murthy, D. V. Bhatnagar and several other scientists from BARC and AMD played important role in these studies which finally led to the establishment of Uranium Mill to process 1000 tons of ore per day to produce uranium concentrate in the form of Magnesium Di-uranate (MDU).

To augment the uranium resources, exploratory drilling began at Bhatin about 3 km from Jaduguda in 1962 and at Narwapahar, about 12 km from Jaduguda in 1963. Thus, Singhbhum Trust Belt emerged as a major uranium mining

province with currently 5 underground and one opencast mine operating in the region.

2.2.9.2.3 Evolution of Health Physics at Jaduguda Mines

In keeping with the importance given to the radiological, industrial hygiene and environmental safety in all phases of the atomic energy program, Dr. A. K. Ganguly, was keen to initiate the health physics operations in uranium mining and milling industry. To begin with, S. Vasudeva Murthy and K. S. Somayaji occasionally visited Jaduguda for radiation survey and collection of water and effluent samples from the site for analysis at Trombay.

Dr. A. K. Ganguly decided to provide on-site surveillance and establish a Health Physics Unit at Jaduguda and posted M. Raghavayya and S. C. Saha who established the Health Physics Unit at Jaduguda in the Aluminum huts near the mine shaft on 16th May 1965. Raghavayya established a good working laboratory almost from scratch in a hostile location and mixed well with the local social fabric which was essential for life at remote a location.

Later, when the Jaduguda Uranium Mill Project (JUMP) was in advanced stages of completion the HP manpower was augmented and activities broadened by posting M. A. R. Iyengar, A. H. Khan (myself), M. C. Barve and G. Jha to look after the HP activities of Jaduguda Uranium Mill Project in October 1966. The importance given to these activities can be gauged from the fact that Shri Soman also came to Jaduguda on this occasion. We were allotted 2 rooms for the radiation protection and industrial hygiene and 2 rooms for the environmental surveillance in the Control, Research and Development Laboratory of the mill. P. M. Markose, D. K. Ghosh, G. K. Srivastava and K. P. Eappen joined between 1969 and 1971. N. Padmanabhan, S. Venkataraman joined the Unit in subsequent years. Now all of those have retired and second generation of the health physicists are continuing the legacy.

Dr. Ganguly took keen interest in the development and expansion of health physics activities and visited Jaduguda almost at an interval of 6 months and in a relaxed atmosphere met every one of us and encouraged each of us to take up research and development work in addition to the routine monitoring activities which were evolving as per emerging needs of a developing industry in the country for the first time. S. D. Soman, P. R. Kamath also visited the site frequently gave support. K. S. Somayaji provided guidelines for ventilation which is the mainstay for radon exposure control and on industrial hygiene aspects.

Besides being a scientist of eminence and a tough administrator, Dr. Ganguly was a nice human being and mixed with all of us, in a patronizing atmosphere. In one of his very first instructions to us he warned us to make any recommendation only after a thorough study of the problem; but once a recommendation has been made we must standby it. This served Khan in good stead when he was made officer-in-charge of the unit in 1987 and he could make several tough recommendations on mine ventilation, effluent treatment and tailings rehabilitation and had to defend them before very senior executives and regulatory authorities. This helped UCIL to counter the onslaught of the print and electronic media in later years.

2.2.9.2.4 Dr. Ganguly' patronizing qualities

In spite of his very busy schedule Dr. Ganguly freely mixed with all of us in Jaduguda. He had also a great sense of humor. Once he asked Saha as to 'where he can get paan'. Saha told in Bengali of language 'Morey paabe' (will get at the road turning), to our amusement Dr. A KG exclaimed '*Oh God, 'moray paabe'?* (will get after death, not before ?).

Dr. Ganguly accompanied by Raghavayya, Khan and others were on the their way to Narwapahar mines from Jaduguda. The vehicle which went ahead with the survey party stopped at a wayside tea shack and one of the party was sipping tea. Noticing that Dr. Ganguly also asked his vehicle to stop and got down and sat on a ramshackle bench in spite of Khan protesting that such places are not suitable for a person like Dr. Ganguly. He retorted: "if you can take tea here I too can take" and ordered for a second helping too! He also ordered some rasgullas, which were his favorites. Noticing that the stuff was perhaps several days old, Dr. Ganguly asked the shopkeeper '*kab banaaya*", he replied *ratri*. AKG responded *kon ratri!!* The editor felt envious and remarks that such intimate interactions with the guru were a privilege of the outstation health physicists!

Much later, in 1986, Khan was deputed as a trainee to an 'IAEA Inter-regional Training Program on Radiation Protection in Mining and Milling of Radioactive Ores' at Pocos de Caldas, Brazil. Khan was asked to serve as a faculty. Dr. Dan Beninson, then Chairman of the ICRP was also present. After my lectures he asked me who was your teacher. When I proudly said I learnt it under Dr. Ganguly and Mr. Soman, he embraced me and proclaimed "Dr. Ganguly was my Guru too". He spoke high of Dr. Ganguly and during the entire training program he and the course director as well as all the forty two trainees became very friendly with me. The respect I got at such a faraway place must be attributed to Dr. Ganguly.

2.2.9.2.5 Environmental Survey Laboratory

In view of the increasing workload the shortage of space available to the Health Physics Unit was a great impediment. But thanks to the keen interest of Dr. A K Ganguly and relentless persuasion by Shri P R Kamath, construction of a separate self-contained large building was approved by the authorities in BARC and DAE. The foundation laying ceremony for new Environmental Survey Laboratory was organized at site with plantation of a Bakul tree by Dr. Ganguly in November 1976. Shri Kamath was keen that the building should be completed soon so that it can be commissioned on 1st November 1977, the 59th birth day of Dr. Ganguly. All agencies involved acted fast and the building and installation of necessary instruments was completed in time. It was finally commissioned and inaugurated by Dr. A. K. Ganguly on his 59th birthday on November 1, 1977. Among the dignitaries present on this occasion were Mr. M. K. Batra, M.D., Shri. D. V. Bhatnagar, Shri. S. D. Khanwalkar and all senior executives of UCIL were present. S. D. Soman, P. R. Kamath were also present. All the staff of the Health Physics Unit and their families also attended the ceremony and turned out to be a great social occasion. A large garden with varieties of flowers including a beautiful rose garden has been an attractive feature of the ESL.

The HPU/ESL carried out the radiological, industrial hygiene and environmental safety surveillance and collected the data so well that it became a show piece at UCIL. It became a must see landmark for any dignitary from DAE, DRDO, State or Central Government visiting Jaduguda. Among the most important visitors I must mention were Dr. P. K. Iyengar, Dr. R. Chidambaram, Dr. A. N. Prasad, Dr. Anil Kakodkar from AEC and Dr. V. S. Arunachalam, Dr. A. Nagaratnam from DRDO and Dr. Ramarao and others from AERB. Several Ministers from the state and central government also visited at different times.

The silver Jubilee of the Health Physics Unit was celebrated in a grand manner on 21st November 1991 in the presence of Dr. R. Chidambaram, then Director, BARC. Dr. D. V. Gopinath, Dr. K. C. Pillai and Dr. I. S. Bhatt besides Dr. M. A. R. Iyengar, Shri M. Raghavayya and Dr. S. C. Saha also attended the function. The one day scientific seminar held on the occasion was also attended by senior executives from Tata Steel and nearby Copper industry. Lunch was hosted by Shri J. L. Bhasin, the C&MD, UCIL for nearly 400 participants.

Similarly, in 1991 Shri S. D. Soman, the then Chairman AERB advised me to organize a Seminar on Radon Exposure in Non-uranium mines, with

the local support from UCIL. It was organized in a befitting manner and senior executives from Directorate General of Mines safety (Dhanbad), Central Mining Research Institute (Dhanbad), and those from many copper, coal and zinc mines from eastern part of the country attended. This led to the intensification of radon survey in non-uranium mines by N. B. Nair and T. V. Ramachandran on request from coal, copper and zinc mines.

When the personal dosimetry of mine workers was taken up for all the workers of Jaduguda, Narwapahar and Bhatin mines the new Dosimetry Wing of the ESL was constructed. It was inaugurated by Dr. Anil Kakodkar in early 2001.

The Unit has always strived to fulfill the vision of Dr. Ganguly.

2.2.9.2.6 The multifaceted activities HPU/ESL, Jaduguda

A variety of work from monitoring of radiation and radon in mines and the mill, silica bearing ore dust, sulfur dioxide, analysis of soil, vegetation and water sample, safety training of workers, safety exhibition and many more were undertaken by the members the group.

Raghavayya had developed Lucas Cell type radon monitors with conical Corning glass beaker coated inside with ZnS (Ag) with the help of silicone grease, which was in regular use, he continued to improve upon it and after several versions he perfected it to the present shape of cylindrical aluminum chamber made from solid Al rods with a transparent glass window to be coupled to the photomultiplier tube of an alpha counting system. Swagelok connector ensured vacuum better and many such cells could be taken to the mine for sampling. During his yearlong deputation to USA and Canada Raghavayya had developed a wire screen method for estimation of unattached daughter products of radon which was an important aspect of lung dosimetry.

I was closely associated with Raghavayya in radiation and radon monitoring of mine areas. I extensively used his Scintillation Cell system to estimate radon emanation from the ore body by sealing the drill holes in the rock after flushing with air and collecting sample after pre-determined build up period. Ore pieces of different sizes were also enclosed in glass jar and radon sample taken after a known build up time. Radon emanation rate from ore body, tailings backfill material in mines and from surface of the tailings pond were also estimated and the work was presented in the form of papers in many international conferences. Radon emanation potential of the large tailings surface compared to the nearby natural soil was also studied.

Raghavayya also developed the SSNTD & TLD based radon dosimeter which are being extensively used for personal dosimetry of mine workers. G. Jha and G K Srivastava were also actively associated with it. They obtained their Ph.D. degree for the work on personal radon dosimetry using this dosimeter. Results of these dosimeters also indicated that radon levels needed to be brought down. It also showed that the internal dose by mine workers is significant in terms of man-rem consumption in the whole of the nuclear fuel cycle.

Exhaustive surveys of radon and its daughters in the different work areas of the mine by the HP Group indicated that ventilation in many of the working areas required significant improvement as the mining activities extended to deeper haulage levels. And the necessary modifications were implemented.

I brought the urgency of the problem to attention of the authorities concerned. After extensive review by expert committee of the AERB headed by Dr. P. Kotrappa of which I was also a member and along with ventilation experts from BARC and UCIL it was decided to grossly improve the ventilation. Thus the matter was referred to the Central Mining Research Institute (Dhanbad) to study the present system and recommend ventilation which will take care of the future development of the mine to deeper levels. It was finally decided to widen the mine galleries and increase the fan capacity to provide a total of 150 m^3/s, with a distribution network such that each or at least every alternate haulage level gets fresh air supply and return air joins the return air stream at each level without mixing with the air at higher haulage.

It was an extensive work involving widening of mine galleries and sealing of worked out areas and installation of large capacity fans. The work was finally completed in 2002 and the new ventilation system was inaugurated by Dr. Anil Kakodkar, Chairman AEC in 2002. As I was shifted to BARC in late August 1999, UCIL management invited me for the occasion. At an air supply rate of 120 m^3/s, the system was still short of the required ventilation rate of 150 m^3/s. But even this has resulted in a reduction of average dose by 30%.

Raghavayya also developed a glass bubbler technique for radon estimation in water and also used it for estimation of radium in environmental samples. While Iyengar, Markose, Eappen and Venkataraman used it for radium estimation in environmental samples, I used it to evaluate radon dissolved in mine water and ground samples from different parts of the country. Later I could extend the work with the help of Shri S. K. Basu to study radioactivity in the wells, tube-wells and geological bore holes at different distances from the tailings pond. Analysis of the results of these and previous surveys established that the seepage from

tailings pond did not affect the ground water quality beyond the periphery of the Complex. Analysis of radionuclides and heavy metals in the Subarnarekha River also established that these pollutants were well within the regulatory limit. Apart from treated effluents from uranium industry, the river has also been a recipient of discharges from the steel and copper industry for several decades.

Dr. Ganguly and Shri Soman were instrumental in the installation of a Shadow Shield Whole Body Counter with the help of D. S. Katoch and R. K. Hukkoo. Due to paucity of space it was first set up in an abandoned bungalow on the hillock near the mine. D J. Mehta and later G. K. Srivastava monitored the Ra-226 in the body of mine and mill workers. Due to the higher radiation background in the vicinity of the mine and mill, a low background room was built in the new Environmental Survey Laboratory but the matter could not be solved. Hence the whole body counter was replaced by a radon in breath measurement system developed by Srivastava using a low level radon measurement system developed by Dr. Kotrappa in association with Raghavayya, Srivastava and Khan. Using this setup, very low level of radium in the body of workers (>2% of the then used MPBB or 74 Bq) could be estimated. The system was extensively used for monitoring large number of mine workers. Srivastava obtained his master's and doctorate degree using this system. The editor was associated with the thesis work of Srivastava as his guide.

Industrial hygiene and safety was also important as silica bearing ore dust was always present in the mine and mill operations. Drilling and other mining and milling operations were constant source of noise. The sulfuric acid plant released SO_2 and SO_3. Saha and Ghosh looked after the industrial hygiene and safety aspects. Sampling of airborne dust with Midget's impinger was later replaced by personal air samplers attached with a small cyclone to collect the respirable size dust. Collection of accident statistics, noise monitoring and safety training of workers was also attended to. While S C Saha obtained his doctoral degree on studies of siliceous and radioactive ore dust, D K Ghosh used lung function monitoring of mine and mill workers and exposure to silica dust for his doctoral degree.

I conducted hourly measurement of radon and its daughters in the mine exhaust to evaluate the radon output from the mine and attached and unattached Radon daughters were found to have correlation with underground operations.

As funds were not available in those days to procure costly imported equipment I developed a continuous radon monitor and an instant Rn-daughter Working

Level Meter in collaboration with Dr. D. N. Sharma and Dr. M. R. Iyer. This instrument was used for continuous monitoring of environmental radon and Rn-daughter in the workplace. This was modified to monitor thoron daughter WL in Thorium plant at Trombay.

With the expansion of mining and setting up of large uranium mills at Turamdih (Jharkhand) and Tumalapalle (Andhra) local health physics/and environmental laboratories are established at these sites.

2.2.9.2.7 Vegetation of the tailings management facility

Tailings pond is the depository of the nearly 50 % of the solid waste arising from the milling operations. The coarse fraction of the waste is backfilled in to the mine cavities. The tailings slurry neutralized with lime is pumped to the tailings pond. Through a system of decantation wells the liquid is led to an Effluent Treatment Plant and solid slimes remain in tailings pond which may dry and lead to generation of dust at the end of the operations. There are two used up tailings depositories and the third one is in use at Jaduguda. Hence covering of the used up tailings surface with soil and growing of shallow root vegetation is an essential part of the decommissioning of the tailings facility. Experiments were carried out on a small portion of the 2nd stage tailings facility to provide a soil layer and plant vegetation on it. Expertise of the Forest Research Institute, Dehradun, was utilized to suggest the suitable vegetation. Vetiver grass from NABTD, BARC is a good candidate as the roots are shallow with good soil binding properties.

2.2.9.2.8 Media and Public Relations

From the mid-1980's there was an onslaught of adverse report and false allegations about the health impact of the uranium industry on its surroundings. It was started by local a Hindi paper and the same allegations were repeated by a number of national newspapers and journals. This was subsequently picked up the electronic media in the name of investigative journalism. The monitoring data collected meticulously over the years came handy in countering the allegations.

To facilitate the progress of uranium projects in Meghalaya uranium sites, Shri M. M. Jacob, the hon'ble governor of Meghalaya was taken round the uranium deposit sites and proposed millings and tailings management project. As a representative of the Health Physics/ESL I also made necessary presentation. Along with UCIL and DAE officials I also participated in discussions with the NGOs in Meghalaya to allay their unfounded fears.

Many research programs in consultations with the people associated with the work and through BRNS a large number of research projects were awarded to

educational research institutions in different areas where mining is undertaken or likely to be undertaken. These collaborative baselines studies have been helpful in generating the essential data base and use the same to ally the unfounded concerns of the people at large in the uranium mining areas. These baseline studies proved very helpful in convincing the regulatory authorities, legislative members and the NEAA.

2.2.9.2.9 Dealing with Regulatory Bodies

While dealing with AERB is a regular affair, the HPU/ESL is called upon to deal with the State and Central pollution control boards and MoEF for obtaining clearance for the new projects expansion of the existing projects.

The HPU/ESL provided necessary inputs for many PIL cases and this led the HC to dismiss the cases. The concerned NGO went in an appeal before the National Environmental Appellate Authority in Delhi. This case was also pursued with adequate inputs from the HPU/ESL and I attended 12 hearings and finally the appeal was dismissed.

2.2.9.2.10 IAEA Meetings

The work culture and an aptitude of research infused by Dr. A. K. Ganguly in the staff even at remote locations like Jaduguda generated confidence of the authorities that many of us were deputed to important meetings of the Agency in Vienna. While Raghavayya attended several meetings in Vienna, Dr. G. Jha attended meetings in China and Australia while Dr. G. K. Srivastava attended meetings in Vienna. I had the good fortune of attending an inter-regional training program in Brazil and later participated in many Technical Committee Meetings, Advisory Group Meetings and Consultancy Meetings at Vienna. In these meetings, several IAEA Safety documents related to mining and processing of uranium were produced. An important document of control of radon in homes and workplaces other than mines was also prepared. I also participated in an IAEA Expert Mission on 'Evaluation of safety of the decommissioning of uranium mine, mill and the tailings management facility Slovenia'.

The encouragement and guidance received from a stalwart like Dr. A. K. Ganguly in our formative years has been helpful in taking up several challenges in our scientific work. The health physics fraternity knows it well as to how difficult it is to study and the implement the ever changing radiation protection standards in mining and milling industry. That we were successful is largely due to inspiration from a person like Dr. Ganguly. I must pay homage to the memory of Dr. Ganguly on behalf of all the health physics professionals from the front-end fuel cycle and on my own behalf.

2.2.9.3 The Boss who was not a "Boss"
Muliya Raghavayya

Yes, Dr. Anil Kumar Ganguly, nationally and internationally acclaimed scientist, environmentalist, radiation protection professional and above all a humanist par excellence, was my boss. I am proud and was privileged to have worked under him for nearly two decades. He was not a 'boss' in the sense that he never threw his weight around or bossed over. In so saying, I am putting the cart before horse. So let me begin at the beginning.

2.2.9.3.1 How it all began

The year was 1956. I had just joined the Pre-University class in Madras Christian College, Madras with Physics as my optional subject. One day in August of the year, Dr. M. A. Thangaraj, Professor and Head of the department of Physics announced in our class that the first atomic reactor of India had attained criticality at a place called Trombay in Bombay. We the freshers had no idea that time what an atomic reactor was nor did we know what "attaining criticality" meant. When about thirty or forty blank faces gazed at him from the class room gallery, the professor patiently went on to explain what an atomic reactor was and what was meant by 'criticality', etc. We were unable to understand fully what he was saying because the technical terms he was using such as protons, neutrons, fission and moderators were all Greek and Latin to us. I decided then and there that I would very much like to work in the Department of Atomic Energy after completing college education. It was only when we started to learn Modern Physics a couple of years later in our graduate class that I could appreciate what he told us then. In due course I completed the Pre-University course and opted for Physics as my major subject in the B.Sc. class. We learnt more about nuclear physics and nuclear reactors and my resolve to work in the Department of Atomic Energy became stronger. In B.Sc. I secured the first rank in our class and was entitled to get a seat automatically for M.Sc. class if I so desired and also an annual scholarship of three hundred rupees in addition to a prize. I made a formal application for M.Sc. class and also applied for the 4th batch of Training School of Atomic Energy Establishment Trombay (AEET) as Bhabha Atomic Research Centre was known then. I was called for an interview, that was held sometime in June 1960. The venue was the Express Building close the Church Gate railway station. I appeared for the interview, with clothes soaking wet because of the monsoon downpour! After the interview I was sent for medical examination to AEET dispensary in the Old Yacht Club premises. I was asked to wait for further communication about the final result of the interview. I returned home and was eagerly waiting for the result. In the meantime, the M.Sc. admissions in the College was over and the classes were about to begin. The college authorities wanted to know if I

was planning to join the college or not. Since the result of the Training School interview was still awaited, I was in a dilemma whether to join the college or not. When I explained my position to the college authorities, they told that either I have to join immediately or forfeit my seat and also that if I joined, I could not leave the college in the middle of the academic year. They were also sympathetic and appreciated my predicament and told me that in case I failed to secure admission in the Training School, the college was prepared to give me admission to the M.Sc. class in the following academic year, without my having to apply afresh. I decided to take a chance and wait for the Training School interview result. In the meantime I learnt through a friend of mine in Mumbai that my name was in the first waiting list for admission. I had to wait for some more time before my fate was known. In the last week of October of 1960, I received a communication from AEET, offering me a post of Junior Scientific Assistant on the basis of the interview already held and if I were to accept the offer, I had to join within two weeks. I decided to accept and set forth to Mumbai.

On the morning of November 7, 1960, I reported to the Establishment Section of AEET then housed in the Old Yacht Club (OYC) premises. After the formalities of joining, I was asked to proceed to the Trombay Atomic Energy Establishment in the departmental bus leaving OYC at 1:30 p.m. and report to the Health Physics Division (HPD). As there was time, I strolled around and when it was time to return to OYC I realized to my dismay that I had lost my way! The watch was ticking and the time of departure of the bus from OYC to Trombay was nearing. I was in panic and somehow reached OYC just in time to catch the bus. Once inside the bus I heaved a sigh of relief and thanked my stars!

Once inside the Trombay establishment, I was directed to the Electronics Shed that housed the HPD then. I was directed to report to Dr. A. K. Ganguly who was the Head of the Radiation Hazards Control Section (RHCS). But since he was on leave I presented myself to P. R. Kamath who was then the Group Leader of the Chemistry Laboratory. He in turn took me to another group led by D. V. Gopinath pending permanent placement. I spent about a week with his group. I simply did what Gopinath asked me to do some calculations. At the end of a week I was one day summoned to Dr. Ganguly's room. I went to his room nervously and found that there were two other gentlemen there with him. One was S. Vasudeva Murthy and the other was K. S. Somayaji who led the Industrial Hygiene and Safety Group. Dr. Ganguly was very courteous and I lost some of my nervousness. After some discussion, he assigned me to work with Vasudeva Murthy in one of the Operational Health Physics Group.

Vasudeva Murthy was the Group Leader of the operational Health Physics Group attached to the Uranium Metal Plant, Thorium Plant and Fuel Fabrication Facility. For the next one month or so, I spent time with the Health Physicists posted at these three facilities by turn. At the end of this breaking in period I was asked to work with N. Ramanathan who was the Health Physicist in Uranium Metal Plant. For the next one year I spent considerable amount of time in the library, reading about the basics of Health Physics and attending orientation lectures about radiation hazards and control measures in general. I was also assisting Ramanathan in the routine work of radiation monitoring. Around January 1962 I was posted to work as the Health Physicist at Engineering Halls No. 4, 5 and 6, situated in the North Site. Hall No. 4 housed the Ore Dressing and Ceramic Sections of Metallurgy Division, Hall 5 housed the Waste Management Division and Hall 6 housed the Ore Extraction Section of the Chemical Engineering Division. Hall 6 also housed a solvent extraction prototype set-up that was intended for the Fuel Reprocessing Division. I was the lone Health Physicist for all the three Engineering Halls and so my responsibilities increased and so did my association with Dr. Ganguly.

Until about 1963 I was mostly engaged in carrying out routine monitoring only. The work load in Hall 4 and Hall 5 was light. The basement in Hall No. 6 was filled with about 100 tons of pulverized beneficiated uranium ore (uranium content of the ore raised by physical means such as tabling) brought from exploratory mining operation in Umrah, Rajasthan. I am not exaggerating when I say that this stockpile played a significant role in shaping my career in the department. Periodically I used to collect airborne dust samples from the basement for air monitoring although worker-occupancy there was virtually zero. The dust sample collected on the filter paper was alpha counted according to a protocol suggested in a departmental publication for computing the air concentrations of radon, thoron and long lived alpha activity. This generally involved counting the sample thrice the first being within 10 minutes of sampling (C1), the second counting after a delay of about 4 hours (C2) and the third after a lapse of a minimum of three days (C3). While the delayed alpha counts (C3) represented the long lived alpha activity, the difference between the second counting and the third (C2-C3) represented the activity due to thoron progeny and the difference between the first and second countings (C2-C1) represented the short-lived activity due to radon progeny. The air concentrations were then calculated following an algorithm suggested in the above publication assuming secular equilibrium between radon and thoron and their respective progeny. The atmosphere in the basement was so rich in radon that the alpha counter scalers that had only three Dekatron tubes for

display and electromechanical counters for spillover counts were unable to count the activity collected on a filter paper for 5 minutes. The basement was virtually a high grade uranium mine!

The aim was to equate the three counts to three theoretically derived equations involving the decay constants of the radon decay products namely RaA (^{218}Po), RaB (^{214}Pb) and [RaC (^{214}Bi) = RaC' (^{214}Po)] and arrive at their activities. I did not know at the time that E. C. Tsivoglou, H. L. Kusnetz, A. W. Thomas and some others had done the same exercise in U.S.A. Several years later, in 1972, I met A. W. Thomas in New York in his laboratory, and exchanged views. Being a very junior member of the staff, no calculator was available to me. Since the logarithm tables were of no use for calculating the required coefficients, I was using the classical long multiplication and division methods! For speedy work I had to devise my own short-cuts.

2.2.9.3.2 Radon and I

Sometime toward the end of 1963, Vasudeva Murthy went to Vienna to attend a conference held at the International Atomic Energy Agency (IAEA). On his return, one day he called me and told me to work on the development of a direct and more accurate method for measuring radon concentration in air. He also gave me a book written by Duncan A. Holaday (Control of radon daughters in uranium mines and calculations on biological effects. Publication No. 494, United States Public Health Service) for reference. As far as I could gather from available literature nobody in India had till then devised an equipment for measuring radon directly, because the short lived nature of its progeny and the four of them always existing in varying concentration ratios, it was really difficult to measure radon concentrations alone. Even available published literature did not give details of how one could go about devising a system. Whatever methods earlier workers had devised were quite elaborate needing complicated collection and measuring techniques. So I had to begin from scratch.

I split the task into two main parts. The first was sample collection and the second was to devise a measuring set-up. The sampling devise had to be a closed container to prevent the collected radon from escaping. It also had to be the detector unit because the alpha radiation from radon cannot penetrate the wall of the sample holder if the detector were to be kept outside the sample holder Radon being an alpha emitter the obvious detector of choice was silver activated zinc sulfide phosphor ZnS (Ag) which was conventionally used in alpha counting systems. The available system had to be modified to accommodate air samples that were collected in a closed container. Being

a novice at the game, I was not even aware how to go about getting the necessary sampling equipment. At that time I did not even know the process of procurement of materials. So I opted the short cut methods of borrowing. That was where the colleagues I had befriended in the Health Physics Division and in places where I was posted came to my help. For collecting the samples, I borrowed small conical flasks of 100 ml capacity, rubber stoppers, high vacuum stopcocks and so on. For evacuating the flasks, initially I used oil-free air sampling pumps already available with me. Since such pumps were incapable of creating high vacuum in the flasks, I later got an Edward's High Vacuum Pump the next step was to devise a method of coating the interior wall of the flask with ZnS (Ag) phosphor powder.

The alpha detector in the standard drawer assembly alpha counters was a 50 mm dia., 3 mm thick Perspex disc with one side coated with the phosphor powder, stuck to the face of a photomultiplier and the whole assembly contained in a light proof housing provided with a drawer cum sample holder. This method could not be used within the flask because it had a very narrow neck Then I found that silicone grease could be dissolved in carbon tetrachloride solvent. So I got hold of some of the solvent and tried to dissolve the grease in it. The grease did dissolve but very slowly. Once when I was leaving after work the grease had not dissolved completely. So I just closed the test tube and let it stand. Next morning when I reached my work place I found that the grease had nicely dissolved in the solvent! So after that all I had to do was to allow the solvent and grease mixture to stand overnight and let the natural process take its course. I poured the solution into the flask, twirled it around for a short while and then poured it out. This left a thin layer of the solution on the interior surface of the flask. The solvent in the layer quickly evaporated leaving a very thin and uniform layer of grease on the inner surface. The next step was giving a coating of zinc sulfide to the interior surface. The meager supply of the phosphor available in my stock was too precious to be wasted on initial trials. So I decided to use a cheaper substitute. We had fine talc powder in adequate quantities as it was in regular use for preserving rubber hand gloves. I used this talc powder instead of zinc sulfide phosphor for optimizing the process. I poured an excess of talc powder into the grease coated flask, shook the flask vigorously and left it to stand for a short time. After that the excess powder was poured out. This left a layer of talc powder adhering to the grease surface. A few trials soon yielded a solution that gave a layer of adequate thickness. I was at last ready for using the real phosphor powder. But before doing that I wanted my group leader Vasudeva Murthy and Dr. Ganguly to give their approval. So at my request they came and saw the whole exercise and I am

glad to say that they were impressed with my work. AKG was very pleased and asked me to proceed and arranged for half kg of imported zinc sulfide powder soon. Next I used the zinc sulfide phosphor powder in place of the talc powder and the radon flask (scintillation cell or scint-cell) was ready for field testing. Samples of air could now be collected from the radon rich air in the basement. Sampling simply consisted of evacuating the scint-cell using a high vacuum pump and opening it in the place from where a sample had to be collected. To prevent the airborne radon progeny and active dust from entering the scint-cell, a high efficiency glass fiber or cellulose filter paper in a suitable holder used for air sampling was attached to the inlet of the cell while sampling. The next challenge was making a suitable lightproof enclosure for the photomultiplier counting set up. The scintillation cells needed a much larger light-proof housing than the conventional alpha counters. The light proof housing of a conventional alpha counting set up was modified with a large enough chamber with cardboard and black paper. Unlike in the case of an alpha counting set up, for radon scintillation cell the PM tube is upturned and the cell placed directly on the face of the PM Tube. When a sample had to be counted, the EHT applied to the photomultiplier was switched off (to protect it), the cover removed, sample cell placed on the face of the upturned PM tube, cover closed, EHT switched on and counting started. Initially I calibrated the scint-cell by comparing it with the two filter method which was more elaborate but gave a fairly accurate concentration of radon in air. I tried to improve the performance of the scint-cell by further modifications by removing the zinc sulfide coating from the bottom of the cell so that the scintillations produced could reach the photomultiplier without being partially absorbed. I devised a simple procedure to accomplish this. After giving the interior (including the bottom) of the flask a uniform coating of silicone grease as described earlier, I carefully introduced 10 ml of carbon tetrachloride directly into the bottom of the flask using a pipette, closed the mouth of the flask tightly with a rubber stopper. I left the CCl4 in the flask bottom undisturbed overnight. The CCl4 dissolved the grease layer from the bottom only. Next morning the solvent along with the dissolved grease was sucked out of the flask bottom again using a pipette so that the remaining part of the interior was not affected in any way. The resulting solution was carefully pipetted out. Next when the phosphor powder was dropped into the flask, only the lateral surface got coated with it leaving a clear window at the bottom. Another improvement I tried next was to wrap the outer lateral surface of the flask with black paper one side had thin shining aluminum layer adhering to it. The shining mirror-like surface reflected some of the scintillation produced back into the flask and hence onto the photomultiplier tube. Still later I replaced the paper with silver coating.

Once the scintillation cell and the counting set-up were ready I developed an algorithm for calculating the concentration of airborne radon on the lines of the Bateman's equation to account for the post sampling build up and decay of radon progeny in the flask. Dr. A. K. Ganguly who had become Head of the Division by then, S D Soman and Vasudeva Murthy were impressed with the innovations that I carried out during the course of the developmental efforts.

2.2.9.3.3 Over to Jaduguda with the scinti-cell

The successful development of the direct method for estimation of radon in air was I believe directly instrumental in my later career in the department. One morning in early 1965, as soon as I reached office, group leader Vasudeva Murthy summoned me to Dr. Ganguly's room in the Electronics Shed. I was a little apprehensive. Hesitantly I knocked and entered the room. Dr. Ganguly complimented me on the work I had carried out on radon measurement and then dropped a bombshell! He asked if I was willing to go to Jaduguda in Bihar (now Jharkhand) and set up a Health Physics group for radiation survey work in the uranium mine being operated by the Jaduguda Mines Project of the Department of Atomic Energy there. An ore processing mill was also under construction there. I was at a loss for words because I had no inkling how a mine would be like. I was given a few days to think about the proposal. Within a week I gave my consent for the transfer. The fact that I had no family links in Mumbai and that I would be allotted an independent house there in the colony tipped the scale in favor of accepting the transfer. Later years proved that my agreeing to the transfer was wisely made.

With me was also transferred Sri S. C. Saha of the Industrial Hygiene & Safety Group. Soon the day for our leaving for Jaduguda was at hand and on May 24th 1965 I and Sri Saha along with Sri Vasudeva Murthy and Sri. K. S. Somayaji left for Jaduguda by the Bombay – Howrah Express. We reached our destination Tatanagar. A station wagon belonging to the Jaduguda Mines Project (JMP) took us to Jaduguda from Tatanagar. We also had taken with us some basic Health Physics instruments such as GM surveymeter, alpha and beta counting set ups and of course the radon measuring devices I had developed, a few scint-cells, the makeshift counting assembly that I had made with cardboard, a high vacuum pump, etc. From the Industrial Hygiene group we had brought dust sampling equipment such as hand operated impinger device, microscope for counting, etc. It was the middle of summer and to say the weather was swelteringly hot is an under-statement! On arrival at Jaduguda Sri Saha and I were each given adjoining one room & kitchen flats in a four unit tenement. We settled down and next day reported for duty at the Mine office. We were introduced to the Deputy Mining Engineer, Sri. M. K. Batra and other staff

of the Mine. For our laboratory we were also given a couple of rooms in the adjoining uranium mill and a room in the Mine area. Many of the surface buildings in the mine area were of a temporary nature, built of prefabricated corrugated aluminum sheets. The interiors of these structures were hotter than the open area outside! The uranium mill was under construction and yet to be commissioned. The responsibility of setting up and commissioning was given to the Indian Rare Earths (Indian Rare Earths Ltd.) The mill project was mostly staffed by engineers of the Chemical Engineering Division of the Trombay Establishment and IRE. I was at home there since many of the engineers were known to me from Trombay.

Sri Vasudeva Murthy and Sri Somayaji returned to Bombay a couple of days later. I and Saha set up the lab with the equipment brought from Trombay and started our activities. I being the senior of the two, had to shoulder the administrative responsibilities in addition to radiation monitoring in the mine. I gave the name 'Health Physics Unit' (HPU) to our two-member group. Being the first of the outstation units, of HPD, the name stuck and all the later groups attached to outstation establishments came to be known as 'Health Physics Unit's.

2.2.9.3.4 "Raghavayya radon cell" at service at Jaduguda Uranium Mine

The uranium deposit at Jaduguda is aligned in an east – west direction, nearly a kilometer in length, about 2 to 10 m in width and about 900 m in vertical depth. The lode was actually inclined at an angle of about 30^0 and partly split in two, separated by about 100 meters of barren rocks. It was a part of the 'Singhbhum Thrust Belt (STB)' which was the name given to a mineralized zone nearly 60 km in length extending from Chaibasa to Musabani in the Singhbhum district of the Jharkhand State (The present Jharkhand was then a part of Bihar). The STB is a richly mineralized zone home to many minerals of iron, nickel, copper, mica, molybdenum, gold, uranium, etc.

The mining scenario was new to us, who were till then used to surface based factory building, and laboratories. Even the mining terminologies such as 'drift' or 'drive' or 'level' (horizontal underground tunnel), 'audit' (a horizontal tunnel driven into a hillside to gain access to the ore body or for any other purpose), 'winze' (a tunnel driven from an upper level to a lower level in the mine), 'raise' (a tunnel driven from a lower level to an upper level in the mine), 'cross-cut' (an underground tunnel driven usually at a right angle to an existing drive), 'face' (advancing end of a tunnel or where current mining activities are being carried out), 'stope', 'stopping' (place where actual ore winning operations viz. 'stopping' is carried out), 'logging' (delineating the uranium mineralized region

using radiometric equipment like a GM probe, 'shaft' (a vertical opening usually used for housing the 'cage' or 'lift' used for transport of men and 'skip' used for hoisting ore or waste from underground to the surface, etc., were new for us and had to be familiarized with.

Then we had to enter the mine through an audit at ground level. Later on, the main entry point would be a vertical shaft, concrete lined and 5 meter in diameter. At that time the shaft was being sunk and being equipped with a double-decked 'cage' for movement of men and materials and a high speed 'skip' for hoisting of ore and 'waste' rock. Soon we got used to the new surroundings and with the limited equipment we had at hand at that time started health physics monitoring operations in the mine. In fact I used the makeshift hand-made radon counting equipment for two years before I could get a 'pucca' set-up fabricated to my specifications. By and by I improved the scintillation cell by using an aluminum body instead of glass. The cell could be dismantled for cleaning, etc., if required and reassembled. The zinc sulfide phosphor powder coating was replaced by factory coated ZnS phosphor sheets. This resulted in improved reproducibility of the cell and also its efficiency. While the initial scint-cell had an average efficiency of about 38%, the present day metallic cells have an average efficiency of about 70%. The metal body also eliminated the need for a separate light-proof enclosure. Moreover the photomultiplier housing was provided with a micro switch through which the EHT was supplied to the PM tube. The body of the scint-cell was provided with a device to activate the micro switch when it was coupled to the PM tube housing and deactivate the micro switch when decoupled. Thus the PM tube was protected all the time. These radon measuring set-ups are now used not only in establishments of the Department of Atomic Energy but also elsewhere like University of Mangalore, University of Mysore, etc.

The radiological monitoring in the mine mostly consisted of mapping the external radiation levels (gamma) and measurement of airborne radioactivity. Soon we established that the airborne long-lived activity in the mine was relatively low compared to the short-lived activity due to radon and its progeny. Over a period I realized that in the mining context at Jaduguda, attention had to be focused on radon rather than other aspects of radiation protection. Mine development and ore winning operations were dynamic in nature because they continuously exposed new faces of operation and the concentration of airborne radon and progeny tended to vary considerably from place to place as also from time to time. We encountered many surprises or unexpected results during radiological monitoring. One instance was when unexpectedly high radon concentration was found in the cross-cut connecting

the shaft landing in the 100 meter level to the main drive. The cross-cut was driven in a barren region. Yet the radon concentration was several-fold higher than in the active regions. When I reported the finding to the mine authorities initially they were not ready to accept it and asked me to repeat the measurement. I did so many times, but every time the results were the same. I remembered reading that although solubility of radon is very poor, underground water can dissolve large quantity of radon from the mineralized zones due to the enormous pressure exerted by the overburden and release the gas when the water seeps into the mine volume. In fact copious amount of water was gushing out of defunct drill holes into the cross-cut in question. But how to measure the dissolved radon was the problem because we had no equipment or methodology to do it. That was the first problem that I had to tackle during my tenure in Jaduguda. Without going into the details of my efforts, suffice it to say that I devised a methodology to collect samples of the mine water with minimal escape of dissolved radon and quantitative transfer of the dissolved radon into the scint-cell for estimation of radon. I was thus able to convince the mine authorities that the high radon values were the result of release of the gas from the outpouring mine water and recommend to them that the defunct drill holes be sealed off. The radon levels reduced considerably when the drill holes in question were sealed off. Later on I refined this methodology and extended it to estimation of radium in environmental and other matrices by emanometry.

2.2.9.3.5 Design and induction of more Radon monitoring systems

That was the first of the many challenges we had to face over the years in the mine as well as the mill (that soon became operational) and the environment. I would like to mention some of the problems we tackled over the next twenty odd years. Development of a low level radon measuring system (LLRDS), radon estimation using solid state nuclear track detectors (SSNTD), development and refinement of the Spark Counter, development of an integrated radon personal dosimeter (TLD plus SSNTD) for use by miners, radium body burden measurement using breath analysis and LLRDS, immobilization of radium and manganese from tailings (uranium) pond effluents using barites and pyrolusite, development of a simple self-regulating equipment for collecting representative environmental water samples from streams carrying factory effluents, etc. Needless to say that my colleagues were actively involved with these development works. It is very satisfying to note that some of these developments that originated in the Health physics Unit Jaduguda such as the direct radon measurement system using scintillation cells, integrated radon dosimeters have found country wide acceptance and application.

In 1966 the mining and milling projects were merged into the Uranium Corporation of India Limited (UCIL), Jaduguda. During the next several years as the mining and milling operations expanded and stabilized, the Health Physics operations also expanded and included environmental survey around the uranium complex. The HP Unit also expanded with additional staff, equipment and facilities. The laboratory space originally allotted was no longer sufficient for the enhanced responsibilities of the Unit. Therefore an exclusive, spacious and independent laboratory was planned. P. R. Kamath, Head of the Environmental Survey Section was mainly instrumental in getting a separate building for the HPU built at Jaduguda. The foundation for the HPU laboratory was laid by Dr. Ganguly in 1977. He planted a 'Bakul' tree (*Mimusops elengi)* in token of the foundation laying. The laboratory was completed and inaugurated again by Dr. Ganguly in 1978. I spent eleven more years in Jaduguda and finally handed over the reins of HPU to my colleague in1989 to take up my similar assignment in the Rare materials Project in Mysuru.

2.2.9.3.6 Dr. Ganguly - the 'Man'

During the years of my sojourn in Jaduguda I had more frequent interaction with Dr. Ganguly. Whatever work I did in the field of radon monitoring was possible because of the support I got from him in all my endeavors. He encouraged us to work on any scientific problem whether it was directly connected with our immediate requirements or not. He used to visit our Jaduguda unit as often as his busy schedule would permit. Whenever he visited us he would show very keen interest in all the work we were engaged in and encourage and guide us to give our best. Under his advice and guidance, I registered for M.Sc. in Bombay University and secured the degree in 1976. The subject of the thesis was 'A Study on the Distribution of Radioactivity in Uranium Mines'. Although I had registered for M.Sc. in 1970, preparation of the thesis got delayed because I was away in USA and Canada for training during 1971-72. After returning, I could spare little time for further work and preparation of thesis because of official commitments on account of my heading the Health Physics Unit. Ultimately I doggedly pursued the thesis preparation during 1975 and could submit the thesis by the end of 1975. Dr. Ganguly asked me to show the first draft to Sri. K. S. Somayaji for scrutiny and correction. I had several sittings with Somayaji who meticulously went through the thesis, scrutinizing every sentence with an eagle's eye in the 180 page document and made valuable suggestions for polishing the write-up. I was not only greatly benefited by the exercise, but also learnt a lot about reviewing of such documents. It came in handy when my turn came to do the same with the theses that my colleagues in HP Unit prepared for their M.Sc. and Ph.D.

theses. The viva voce examination was conducted at Dr. Ganguly's house in Saras Baug, Trombay. Dr. A. Nagarathnam, the soft spoken Director of Defence Research Laboratory, Jodhpur was the external examiner. I was thrilled by the way Dr. Ganguly introduced me to him when he said - "Raghavayya is one of the last of the breed of innovative scientists who built their experimental equipment from rudimentary and common materials available at hand." At the end of the examination, Dr. Nagarathnam congratulated me and said that I deserved a doctorate for the work I had done and presented in my thesis and that had the rules permitted, he would have recommended me for award of a Ph.D. degree. I felt as though I had really got a doctorate!

I must share an interesting anecdote when I was working in Jaduguda. As I said earlier in this article, although we had to carry out intricate and involved calculations during the course of our work we had no access to an advanced calculator. In fact, there was no good calculator at all in the Jaduguda complex except a primitive sort of manually operated device in the mine's geology section that could carry out only addition and subtraction operations. Even that simple machine was not available for our use. Whenever I had occasion to meet Dr. Ganguly in Mumbai or in Jaduguda, I invariably remind him of the difficulties we were facing because of the lack of a good calculator and used to persistently request him to get us a calculator of the type (Frieden make) that was in the Health Physics Division in Mumbai. There were two such machines there, one in use in the R&D group and the other with Dr. Ganguly. But every time he would turn my request down asking me how I could get it serviced in such a remote place if the necessity were to arise. At last, once when I had gone to Mumbai on leave for personal work, I happened to go to Trombay and meet Dr. Ganguly in his chamber in Mod. Labs. As was my wont, I again asked him for a calculator covertly eyeing the Frieden calculator that was sitting on the filing cabinet in his room. And again he raised the question of servicing the machine for which I had no answer. So I remained silent. Then he relented and said pointing to the calculator "O. K. Raghavayya, take it before I change my mind. But, mind you, don't come to me if it gives any trouble and needs servicing". Next moment I was out of his room and headed to the workshop in the basement grabbing the machine to get it packed. Ramesh who was the workshop foreman also lost no time in having it packed in a strong wooden box. Then and there I arranged to take the package to my room in the guest house in Training School Hostel building. Because of its weight, I had to pay Rs. 45/- as excess luggage charge while travelling back to Jaduguda by train. And since I was on leave of absence during the time, I could not claim reimbursement of the extra freight paid!

At Jaduguda the calculator immediately became a show-piece since no one there had seen such a calculator until then! For the next few days I had a constant stream of curious visitors to see the calculator at work. It could perform many of the arithmetic operation including extraction of square root (by iteration) of any number. Being an electro-mechanical device, while operating it used to make a loud click-clack sound that one could hear even from a distance! However one had to be careful never to divide zero by zero using the calculator since it is a forbidden operation and has no definite answer! If at all such task was given to the machine, it would respond by starting and merrily clicking & clacking which would never stop. Even switching it off was not helpful since it would start clicking & clacking as soon as it was switched on again. Only option to stop the machine in such predicament was to punch a random denominator number while it was operating. As my ill luck would have it my euphoria was short-lived. One day, within a week of bringing the calculator to Jaduguda, I had gone out of my room to attend to some work. I was away for about 30 minutes, and on my return I found that the machine was clicking & clacking indicating that some calculation was going on. I knew immediately that someone must have pressed the 'division' buttons with 'zero' input. I tried to stop the operation by pressing a random number as was being done but the operation would not stop. I was in a panic and remembered Dr. Ganguly's warning about servicing of the machine. I was desperate and realized that desperate situations demanded desperate measures. I decided to open the machine and see what was happening. When I opened it I found to my dismay hundreds of levers and wires inside whirring away endlessly. With my heart in my mouth, and a thin screw driver in hand, I started gently poking and pressing the lever/wire one by one. As I pressed one particular wire the 'division' buttons popped up and the calculator stopped. I was saved! Just to be sure of myself, I deliberately performed the forbidden operation again and repeated my earlier action. The machine obediently stopped! I let out a sigh of relief. Well, in due course I was able to get an annual maintenance contract placed on a service provider from Kolkata. After a few years the machine was no more serviceable and was duly scrapped by following official procedures.

Dr. Ganguly used to mix freely with all his subordinate staff, be a senior officer or a mere helper. He had a very subtle sense of humor. There were several occasions when we got a glimpse of it. Once when I had been to his house in Ghatkopar to show him the draft copy of M.Sc. thesis. I spent nearly three hours with him then. His house was very close to the Mumbai Santa Cruz airport. Whenever an aircraft landed or took off from the airport, it would fly very low above his house, obviously making a very loud booming noise. It was

so unnerving that I asked Dr. Ganguly how does the loud noise the aircrafts made during landing of takeoff affect his sleep at night. With a poker face and voice he said "Yes, I cannot sleep at night without that noise!"

During one of his visits to Jaduguda, we had planned to take him to the Narwapahar uranium mine that was being operated on exploratory basis by the then Atomic Minerals Division. Narwapahar is at a distance of about 10 km from Jaduguda by the shortest route. It was rainy season and the 'Gara Nala' river that had to be crossed on the way was in spate and the low level causeway meant for crossing it was well under water. So we had to take the considerably longer Jaduguda – Jamshedpur road. Approximately midway between Jaduguda and Jamshedpur is a place called 'Hata' where we normally used to break our journey. There were no regular tea shops at Hata but only not so very hygienic country shacks that were an apology for hotels. But this time in deference to the presence Dr. Ganguly we had decided to drive through without halting at Hata. We also had decided to carry out our periodic radiological monitoring of the mine in Narwapahar. So we sent the monitoring equipment and some of our colleagues ahead in the first jeep. Dr. Ganguly, myself and some others were to follow a little later in a second jeep. When we neared Hata, we saw the first jeep standing near our usual breaking spot, by the road side. One of our colleagues was standing next to the jeep sipping tea. On seeing our jeep, he hurriedly entered the shop, placed the glass on the table and returned with a sheepish grin at being caught. Since we were already behind schedule, we tried to make some excuse to Dr. Ganguly. But he brushed aside our remarks and said that if they (those in the first jeep) could have tea, we too could have tea there. He got out of the jeep and sat on the rickety bench outside and called the waiter boy and ordered a second cup of tea for all. He also ordered some rasgulla which was perhaps several days old and very hard. Dr. Ganguly asked the shopkeeper 'kab banaaya, he replied ratri. Dr. AKG asked kon ratri!

Dr. Ganguly was very much fond of sweets. As I said earlier, he used to visit our lab in Jaduguda at least once or twice in an year. Sometimes more often. He would fly from Mumbai to Kolkata and travel by train from Howrah to Tatanagar. The train was scheduled to arrive at Tatanagar around 9:30 p.m. in the night. I or one of my colleagues would go to Tatanagar to receive him and bring him to Jaduguda. During one such trips, the train arrived late by more than an hour. When we got into the jeep he said "Let us go somewhere and have some idlies". I was doubtful if we could get idlies so late at night in any of the hotels. Luckily 'Bombay Sweet Mart', a popular restaurant of Bistupur was just closing and we were lucky to be served. Unfortunately idly was not available just as I expected. Undaunted by this setback, Dr. Ganguly asked if

they had 'Falooda' instead. Luckily Falooda was available and he was delighted to have it. Not only did he relish the dish, but also held us spellbound with a vivid description of how Falooda had to be prepared!

During the nearly twenty years of my association with Dr. Ganguly, I do not ever remember him shouting at me in anger or scolding me except on one occasion. When I was working as the health physicist in Engineering Halls in Trombay, once there was a fire accident in the chemical laboratory in Hall No. 5. I happened to be with Dr. Ganguly in his south site office, when the information reached him. We immediately rushed to Hall No. 5 Just as the car reached Hall 5, I opened the door of the car before it actually stopped. Dr. Ganguly who was occupying the front seat turned back and angrily shouted at me and said "Don't open the door until the car stops". This only shows his concern for observing safety rules at all times. For the same reason he was also reluctant to approve sanction of advance to the staff for purchase of two wheelers. That is because of his strong belief that the two-wheeler is an intrinsically unsafe vehicle.

So now I can say what I said in the beginning. I am proud and was privileged to have worked under him for nearly two decades. He was not a 'boss' in the sense that he never threw his weight around or bossed over his subordinates. So he was a boss who was not a 'boss'.

2.2.10 Operational Health Physics in accelerators
K N Kirthi

K N Kirthi was one of the earliest health physicists who joined AEET in June 1957. Dr. Ganguly was abroad and so he reported to K G Vohra. Vohra told him that he will work in radiochemistry lab which was getting ready in Trombay. First Kirthi started work in one of the sheds in Colaba since lab was not yet ready.

When eventually Dr. Ganguly joined, Kirthi met him. Even in his first meeting with Dr. Ganguly Kirthi formed high respect about him. Dr. Ganguly asked Kirthi to study about Plutonium since this toxic substance will be handled in radiochemistry lab. After a few days he called Kirthi and asked how far he has progressed. When Kirthi mentioned about working on methods for air monitoring of Pu, Dr. Ganguly asked him to think of methods of measuring Pu in low levels in air samples in the presence of natural radon daughter product activity, Kirthi initiated studies on this. When the lab was ready Kirthi was shifted there. Hall, an English man was in charge of the Radiochemistry labs. Kirthi says he was a good planner. Maybe, Dr. Bhabha had requisitioned his

services to set up the lab. Ghosh Mazumdar was the next person in charge of the setting up of the lab. The other wing was shared by the Isotope Division which was also headed by another Englishman Taylor, who was an adept in handling radioactive sources. Later, H D Sarma who was a student of Seaborg became in charge of the lab under Hall.

Glove boxes were being set up in the lab to handle radioactive materials. One lab was for alpha active materials and another was for beta active ones. Kirthi came across a journal that carried an article on separation of Pu aerosols by particle size for air monitoring and thus Kirthi started working on fabricating an impactor. For the impactor, he used a vacuum cleaner pump since it required high volume of suction, of about 600 m^3 per minute and normal air sampling pumps did not provide high rates. Dr. Welsh came in the place of Hall and Kirthi says he was knowledgeable in radiochemistry and gave useful directions to Kirthi. Having made an impactor, Kirthi wanted to test it inside a glove box containing Pu and discussed this with Welsh. The idea was to put the impactor inside a glove box containing Pu solution and test it. Kirthi prepared a procedure for this in consultation with Welsh. To be additionally careful a Sunday was selected for the testing since no one would be around in the lab. This was tested in a simulated alpha activity atmosphere inside the glove box. The pump was run and the sample collected on the impactor disc. On analysis it showed 5 percent of Radon daughter product activity and 95 percent of Pu activity and it was a success. That was the beginning of indigenously developing Pu air sampling technique. Kotrappa then joined Kirthi in developing various particle size based air sampling devices. Pu required for research work was imported from Harwell.

Kirthi mentioned that there was the only once incidence of Pu leak in the lab. That was when a chemist took out an open Pu solution sample from one glove box to transfer to another. Air activity of 100 dpm per m^3 was detected instantly in in the air using Kirthi's impactor. This was first actual incidence to be tested with the impactor. On the basis of this, Welsh issued a strong circular that no Pu sample should be removed from a glove box unless it is sealed in a container.

Whenever the glove box filter was to be changed Kirthi provided health physics coverage. The procedure was successfully modified and no activity leaked outside during this procedure. The editor remembers that Kirthi was the first to use the term Radiological Safety Officer in AEET.

End of 1959 Kirthi was asked to work at the CIR reactor and SK Mehta came to radiochemistry as health physicist. Welsh asked Ganguly to get Kirthi back

to radiochemistry. But Ganguly planned to expose all the people to all part of the fuel cycle. KC Pillai started analysis of effluents in the radiochemistry lab. For analyzing the effluents Kirthi provided support. After K C Pillai, A L Mohan was working on this and he was later transferred to waste management division. A M Bhagawat then joined radiochemistry.

In CIR Kirthi worked for 4 years. SD Soman was overseeing the health physics operations in CIR. In the initial days he was assisted by A D Sharma and M G Kolhatkar. Kirthi was then transferred to Zerlina zero energy reactor, since he could not come in shifts due to illness. There he worked on neutron dosimetry. Somasundaram became group leader in 1965 on Soman becoming RHC Section Head. Tritium lab was started in Zerlina by T S Iyengar.

By this time Kirthi got an IAEA fellowship for training in USA. He worked at the National Defense Academy, in ANL and also at Idaho falls in the fast reactor. While he was in Idaho falls he started attending evening part time classes in nuclear engineering and successfully completed the course in reactor physics. PP Joshi was getting trained on nuclear track detectors there. Kirthi after return worked as health physicist at the Purnima critical facility. During this assignment, once a physicist was locked inside the Purnima hall before start up. This led Kirthi to insist on a search and secure system for Purnima before start up. Kirthi says P K Iyengar who was in charge for the facility appreciated the work

After this Kirthi was asked to look after all health physics operations in accelerators in AEET. It was at this time PK Sarkar started his work with Kirthi. Kirthi carried out evaluation of the shielding for the electron accelerator of the Chemistry Division in Mod lab basement. He also provided the shield design for the TIFR Pellatron accelerator. Since the shielding on the top slab was compromised it resulted in unacceptable dose at the Navy area outside the boundary wall due to sky shine. Kirthi did the shielding calculation along with the editor for the 700 MeV and 2.5 GeV Indore SRS rings which called for in depth discussion for the source term as to whether the beam will get lost at one point or would be lost distributive. Kirthi insisted that whatever value the designer may prescribe for beam loss it should be taken as a single point loss and that became the basis for the shield design for the rings.

The editor had interviewed Kirthi in November 2016 for recording his memoirs about Dr. Ganguly for this volume and the above extract is prepared on the basis of that interview. While preparing these memoirs, news came that Kirthi is no more in July 2017. This was the fifth case of a member of the Ganguly

School whose memoirs are recorded in this volume passing away during the preparation of the compendium.

2.3 Radiation Transport, Computer code development, Fast Reactor Safety and Organizational Health and Safety activities in DAE
2.3.1 D V Gopinath and M R Iyer
2.3.2 LV Krishnan and M R Iyer

2.4 Hybrid MCNP code development, Neutron spectrometry and Accelerator Health Physics
2.4.1 V Kalyanasundaram
2.4.2 P K Sarkar

2.5 Health Physics in research reactors, Fission Product & Fission studies, Safeguard NDA Techniques, Radiation Safety systems
M R Iyer

2.6 Dr. Ganguly and laser method of enrichment of U-235
Ramakoteswara Rao

Preamble to the Sections 2.3, 2.4, 2.5, 2.6.
M R Iyer

The next four Sections, 2.3, 2.4, 2.5, and 2.6, deal with contributions made as part of multifarious activities initiated by Dr. Ganguly, and which later on branched off to several other streams. This truly demonstrates the multi-disciplinary nature of the activities started and nurtured by him. For Doctor, there were no borders and boundaries for scientific investigations. The R&D Group put together initially by Dr. Ganguly, of which D V Gopinath was the informal leader, and in which each member followed his own stream of research set by Doctor, was the genesis of the activities described in these four sections. They give the flair and description of how those grew in numerous directions, and in the final analysis all of them contributed to the robust growth of the Health Physics operations. The only common factor of genesis of all these growth was the source being the same R&D group, and it thus represents a unique experience in scientific endeavor. An obvious corollary was that many, from this group ended up as leaders and pioneers of the national atomic energy program. Their impact and/or far-off ripples can be felt even today, in that the second generation of "Ganguly school" alumni continues to achieve and excel. This also reflects the then prevalent ideal atmosphere for science to grow, which was unique in AEET/BARC. These memoirs also truly represents the

irrepressible urge and zeal of Doctor for scientific research. As can be seen, the persons concerned followed unbridled growth of various streams and branched off to newer avenues, so much so, these cannot be grouped under any singular stream of activity. Due to this, I felt the need for this Preamble as introduction to these sections to underscore the spirit of those early days. As the memoirs will illustrate, one can find the influence of these activities on practically every branch described elsewhere in the compendium and even beyond those within DAE. Much of these can be truly attributed as seminal / pioneering contributions of Dr. Ganguly.

2.3 Radiation Transport, Computer Code Development, Fast Reactor Safety and Organizational Health and Safety activities in DAE

2.3.1 Contributions of D V Gopinath under Dr. Ganguly

Narration by M R Iyer

2.3.1.1 Early days in AEET

Dr. D. V Gopinath was one of the greatest finds of Dr. Ganguly. A poetic mind would exult in the rhyming of AKG and DVG! Historically Gopinath's irrepressible mind was not in peace with himself, when joining AEET in December 1954 he was asked to report to P N Krishnamoorthy and allotted the routine drudgery of keeping records of personal radiation monitoring using Kodak film badges. But when Dr. Ganguly joined AEET with his high flying academic accomplishments, Dr. Gopinath at once thought he had found out a way. He seemed to have approached Dr. Ganguly to allow him to work under him. With the concurrence of PN Krishnamoorthy and A S Rao to whom Gopinath was reporting, Dr. Ganguly took him under his wings! And thus started an epic journey through the world of science for both of them! The greatness of Dr. Ganguly was his allowing people under him to grow and nurture their yearnings and ambitions and directing them on the right path and giving them avenues even to become his equals and Gopinath's greatness was his irrepressible urge to grow and both found confluence. That is how many people like Gopinath who had started their career in AEET at the lowest scientific levels grew to great heights! Dr. Ganguly seems to have been running a factory in AEET to generate scientific wizards! And one of the products that came out of this was Doddaballapur Venkatagiri Gopinath and he grew from strength to strength and flew higher and higher. His accomplishments followed a gamut of areas of work starting with innovative research on the activity build up in Apsara coolant water and activity build up in natural radioactive series. He then dabbled for a while in AKG's first mathematical exercise on the temperature distribution in radioactive solids, got attracted toward radiation shielding, got familiar with nuclear reactor design when AKG put him on the work to evaluate the tender for TAPS nuclear power reactor, gravitated to neutron transport theory when the problem

arose for clearing reprocessing plant vessels for criticality safety and when AKG posed the problem of working out critical mass for fissile materials following Dr. Bhabha's directive to the Trombay Advisory Committee members to work on this. DV Gopinath, K Santhanam, V Kalyanasundaram and LV Krishnan took up this challenge and carried and developed the Source Collision Iteration Technique, SCIT as narrated in other memoirs in this volume. This eventually led DVG developing Anisotropic Source Flux Iteration Technique ASFIT working with KS, LVK and D. P. Burte. It is an elegant analytical method for solving the coupled integral equations for determining build-up factors in radiation transport problems. It avoids the need for time consuming and large computer capability to solve such problems by Monte Carlo techniques. The ASFIT, code written in FORTRAN for the CDC 3600 computer which was then perfected by DVG and his team was particularly useful for deep penetration of radiation through thick shields and has been incorporated into the collection of Codes at the Radiation Shielding Information Centre of Oak Ridge National Laboratory in the US. The ASFIT code was subsequently used to generate valuable information for a handbook on shielding published by the American Nuclear Society.

2.3.1.2 An innovative idea for a neutron source

This is narrated as an example of how not only in specialized areas DVG contributed but his innovative mind worked on even other useful applications. "BeBi" source was one of innovations thought over by Gopinath to overcome the scarcity of neutron sources in AEET, in which a mixture of Bismuth (Bi) and Beryllium (Be) is irradiated in a reactor to transmute Bismuth to Polonium, the alphas from which react with Beryllium generating neutrons, much like alphas from Radium do. The neutron source thus configured can be regenerated by repeated irradiation in a reactor since Polonium has a relatively short half-life. In those days RaBe sources with its radiation hazard problems due to leakage of radon was the only neutron source available for calibration and dosimetry/spectrometry research purposes. He later on had a neutron generator set up in Kalpakkam. The editor remembers Gopinath trying his hand on neutron generation using the "exploding wire" technique, though not with success.

2.3.1.3 Health and safety operations at Fast Reactor Research Centre RRC Kalpakkam (present IGCAR)

Noticing his enthusiasm for organizational work Dr. Ganguly introduced DVG to Dr. Sarabhai, Chairman AEC who was planning to set up a fast reactor research Centre, RRC in Kalpakkam. This is an instance of Dr. Ganguly projecting his people to top managers as noted by many of his students and provides them avenues to grow. A great visionary indeed considering most

people would use the work of their co-workers to project themselves! Once in contact with Dr. Sarabhai, Gopinath attracted his attention and impressed Dr. Sarabhai in organizing a fast reactor conferences held in Kalpakkam to launch the new Centre there and the tryst of Gopinath with fast reactors began. The editor had heard a hearsay that Sarabhai once remarked to Ganguly that "in Gopinath you have found a resonating match".

Dr. Ganguly graciously allowed DVG to shift his operational theatre to RRC to organize Safety Research and Health Physics activities independently there. Further AKG allowed him to take his whole retinue to RRC. Thus, DVG and LVK formed the managers of Safety Research and Health Physics in RRC. The editor remembers that when DVG wanted to take him (MRI) also to Kalpakkam AKG retorted "if you take everyone with you what do I do here?"

It is history in itself how DVG extended his domain of work in RRC following AKGs example and as someone said "created another Health Physics Division there". What he created there was a comprehensive group dealing with all possible aspects of fast reactor safety including engineering research, fast reactor safety, sodium safety, aerosol physics, dosimetry, accelerator physics and so on and brought up two laboratories HASL (Health and Safety Laboratory) and SRL (Safety Research Laboratory). DVG thus presided over the empire of health and safety in RRC later named as IGCAR, Kalpakkam for full 20 years. Like his mentor at Trombay, he chaired the Committee set up to review safety aspects of all facilities at RRC. He established a close relationship with the District Authorities and initiated formulation of a detailed Off-site Emergency Preparedness Plan for Kalpakkam and conducted the first Exercise that was pronounced a success by the National observer team. Thus Dr. Gopinath was the originator of Emergency preparedness exercises, which later became a periodical exercise in all NPPs to gear themselves in case of any exigencies.

2.3.1.4 Dr. D V Gopinath in the footsteps of Dr. Ganguly as Director, Health Safety &Environment & Medical Groups, BARC

Then, the call of duty beckoned Gopinath back to BARC to take charge as Director of Health and Safety group in 1990. This was a nostalgic home coming for Dr. Gopinath and he had with him familiar faces like M. R. Iyer, KSV Nambi and others. But he must have missed the benign face of AKG his mentor! Gopinath brought about lot of reorganization in his group giving importance for research and development. The editor remembers how he gave him added responsibility of organizing R&D alongside health physics responsibilities in Trombay installations and formed a new division Radiation Safety Systems Division bifurcating the old Health Physics Division. The editor

has also reminiscences of the many developments he could bring in the area of radiation safety systems under Dr. Gopinath and how it paved the way for his tenure as an Instrument specialist in the Safeguards Department of IAEA. In bringing all these changes Gopinath had the full support of Dr. Chidambaram who was the Chairman AEC. Not only that, Gopinath also gave Chidambaram suggestions for changes in BARC itself. Thus when the post of Director of Bio-medical Group fell vacant Dr. Gopinath was asked to take over the group and streamline its operations. Thus Gopinath like his Guru also was in charge of multiple groups in BARC. It may be recalled that Dr. Ganguly was the Chemical group director for a long time in charge of all chemistry divisions along with the HSE group divisions and even was in charge of the Reactor Engineering group for some time. Gopinath also found a suitable person for the post of Director of Medical Group and on his suggestions Dr. Kesavan was brought in to take the responsibilities. This is one of the rare case of an outsider being appointed for the post of a director of a group. The editor also has fond reminiscences of organizing a National Conference on emergency preparedness for INS as convener in honor of Dr. Gopinath on his retirement from service in 1993. This conference for the first time brought together in one platform all agencies carrying out emergency preparedness in the country and gave an opportunity to learn how each agency carries out the emergency preparedness in their own areas. It was, so to say, a forerunner of the National disaster management outfit of today in which many from the "Ganguly School" have become managers. This is a matter of great satisfaction for the editor to have been a link in this Ganguly school till today.

2.3.1.5 D V Gopinath's memoirs of Dr. Ganguly

The real task of highlighting the contributions of Dr. Gopinath and Dr. Ganguly in this epic journey cannot be confined to my narration, so I am attaching as a separate annexure what Gopinath has written on Dr. Ganguly and on his own work specially for this volume in his own words. I hope this will serve as an inspiration for the younger generation.

2.3.2 Reminiscences of Dr. Ganguly

L V Krishnan

2.3.2.1 Foreword

M R Iyer

L V Krishnan and K Santhanam were inducted into the Health Physics Division after their successful completion of the II batch of AEET Training School in 1959 by Dr. Ganguly. Both of them in their career made significant contributions not only to the programs of the HPD but to the Indian atomic energy program at the national level. The "twins" of Dr. Ganguly's findings

started their assignments together in setting up and streamlining the operational health physics procedures in CIR when the reactor started operation in 1960 and they later contributed significantly to the study of transport theory along with Gopinath. Subsequently LVK was asked by AKG to apply it for criticality safety calculations which were required to ensure safety of the various process vessels in the upcoming Plutonium reprocessing plant at Trombay. He can be called the pioneer in this filed. His contributions in this area are described in other sections of this volume. He was joined by TN Krishnamoorthy and V Kalyanasundaram in these activities prior to his deputation for training in reactor safety at the in Oak Ridge National Laboratory in USA.

The collaboration with TNK and VKS nucleated into a team after his return. The work of this team is also narrated elsewhere in this volume. LV Krishnan and K Santhanam worked on the Sn method for shielding and criticality calculations and implemented the method in a computer code for the TIFR CDC 3600 computer. He participated in the development of the SCIT method along with Dr. Gopinath which eventually led DVG to the development of the ASFIT code. The association, thus started with DVG continued throughout LVK's career, when he along with DVG was selected to head the safety program of the fast Rector Research Centre by Dr. Ganguly. He was a member of the team which spent a year in the fast reactor center at Cadarache for the FBTR program. Dr. Gopinath also had a stint of training in fast reactors at ANL much earlier in 1963. Dr. Ganguly's prophetic actions in assigning work to his people is demonstrated in the memoirs of Gopinath when in 1963 he was selected for a fellowship under USAID program. Dr. Ganguly directed him to get trained in fast reactors when no such program was on the anvil in DAE as against his preference to work with Prof. Fano in NBS on radiation transport. Dr. Ganguly seems to have remarked: 'No, no, fast reactors are the reactors of the future and there are challenging problems in their safety. You better go there!' (see Annexure 1).

When the Cabinet Secretariat was looking for a specialist with nuclear background from Trombay, Dr. Ganguly picked Santhanam. The choice based on his ability to assess his juniors right, proved correct. Santhanam quickly established himself well in the new role and subsequently joined Arunachalam, who headed DRDO to work on nuclear matters. Later on, Santhanam became the leader of the DRDO team under Abdul Kalam for the POKHRAN II nuclear tests conducted in association with DAE under Dr. Chidambaram in 1998.

Prior to his proceeding to Kalpakkam LVK served as the first member-secretary of the DAE, SRC committee for a few months, which was formed

by an office order of the Secretary DAE to initiate the regulatory activities in the country with Dr. Ganguly as Chairman. Dr. Ganguly seems to have selected LVK on a career for developing regulatory frame work for the country, but he was perhaps prevailed upon by DVG to go with him to Kalpakkam to initiate the fast reactor safety operations. Finally LVK, when he chose to go to Kalpakkam, along with Gopinath became an inseparable pair in initiating several safety programs in RRC (later named IGCAR) and made the reactor safety program a robust one. They established two laboratories HASL and SRL the former handling all R & D for the radiation safety and the latter catering to fast reactor safety. L V Krishnan took over the health and safety program of IGCAR as Director when DVG was called upon to take the responsibilities as Director of health and safety in BARC. The following is an account of the reminiscences of LVK in his own words.

2.3.2.2 Reminiscences of Dr. Ganguly
L V Krishnan

Although Dr. Ganguly had specialized in Chemical sciences, after recruitment in DAE and being assigned responsibility for Health Physics Program, he quickly adapted himself to nuclear matters of all hues; as a result he was thoroughly at home in discussing any aspect of safety, physics, chemistry or biology. He had an uncanny sense for safety. He was apparently fascinated by the multi-disciplinary nature of Safety Studies and that suited his interest in diverse fields.

In the early days of the Department, when the focus was on establishing facilities and capabilities and there was no formal body for safety review, it was Dr. Ganguly who was called upon to evaluate the various facilities from the safety angle.

For instance, I recall that when the plutonium plant was coming up at Trombay, N Srinivasan who was the Project Engineer called him over for discussion on various aspects of the plant design with a view to get a prior assessment on them from safety standpoint. The meeting was held in the room of H N Sethna who was away on tour. Dr. Ganguly asked me and some others to go with him. I was fascinated by the interaction between a brilliant Chemical Engineer that Srinivasan was and the redoubtable Chemist in Dr. Ganguly and the respect that Dr. Ganguly earned by his profound observations.

That was also a valuable opportunity for me to acquaint myself better with the plant design and operational features that proved useful in the criticality safety review of the plant. For, I had been asked to undertake an independent exercise in addition to the review carried out by Shankar Singh who was on the rolls of the PP Project specially recruited for the purpose.

Dr. Ganguly was a keen observer of developments in the field of radiation and reactor safety and in related accidents elsewhere in the world. He was constantly looking for ways to understand and avoid accidents in our own program. I believe it was this facet of his that also made him ask for an independent review of the criticality safety of the plutonium plant. He had been following the 1958 criticality accident in the critical facility at the Boris Kidrich Institute in the then Yugoslavia in which five persons died due to acute radiation exposure. When, I was later sent to Oak Ridge National Laboratory for the course on Reactor Hazards Evaluation, he made me write to the scientists in the Laboratory's Criticality Studies Program seeking an opportunity to spend some time in their Laboratory. As that Program was also part of the Defense Studies, I drew a blank. Dr. Ganguly was not unaware of it but believed in knocking at all doors in his quest for ensuring safety. In fact, he even desired that I should contact the Pajarito Group in New Mexico.

In matters of safety, he was acutely aware of the conditions prevailing in India that also had to be taken into account.

By way of illustration, one could cite his approach to development of Siting Criteria for power reactors. Bearing in mind the Indian situation, in these criteria, it was proposed to specify a fixed distance of 1 mile (1.6 km) for the exclusion distance for all power reactors. This was in contrast to the practice in other countries that depended on the type of reactor, the level of release expected in an accident and the degree of containment provided in the design leading to exclusion distances as little as a few hundred meters in some cases. In addition, the "Ganguly criteria" also specified denoting another zone extending up to 5 km beyond as a zone in which only natural growth of population would be allowed and no development of industrial and other activities that contribute to population increases beyond increases in family sizes would be permitted.

When the safety of the Tarapur reactors was being reviewed in late sixties – just about ten years after the Windscale reactor accident in UK in which hot natural uranium fuel caught fire and resulted in environmental release of radioactive materials – he insisted to the GE engineers that the core spray system meant to provide emergency cooling in the event of a LOCA had to have a reliability of 0.9999, to substantially bring down the likelihood of fuel melting due to interruption in cooling. The GE team tried to argue that safety against fuel melting was assured even in the existing design, but eventually Dr. Ganguly prevailed.

Dr. Ganguly had earned the respect of all the colleagues at different levels, lower and higher, due to his knowledge and more particularly in the manner of

presentation of his views. He was quite informal and friendly in interactions with junior colleagues. Despite many demands on his time, he would call them over to his room for discussions on scientific topics and provide tea and biscuits all at his expenditure; this was almost a daily feature; on many occasions the discussions went beyond office hours too. He would also call juniors over to his home for discussion on holidays. Whenever he went for discussion with his senior colleagues he would take some of his junior colleagues along and that provided them a useful exposure that served them well later, even if they were not yet in a position to make significant contribution during the discussions.

Dr. Ganguly never hesitated to hear the views of the juniors on policy matters too. Before the establishment of the AERB, he used to hold evening meetings with T Subbaratnam and some of us, where a possible structure for what was labeled as Atomic Energy Regulatory Authority were discussed.

Whenever Section Heads under him had differences of opinion, he would use his sense of humor to lower the temperature. This facet of this was particularly evident in Safety Review meetings whenever the arguments became heated. He was held in such high regard that even when he addressed one of the senior members in the Review Meeting as a "baldie" due to the scarcity of hair cover on the head, no offense was taken.

He tested the subordinates by giving them assignments and if they did not rise to his expectation, changed the assignment and never took them to task. Whenever someone from his Division assigned to look after radiation protection aspects of a facility pointed to him the need for greater attention to be paid to safety by the management, he would support his staff. On one occasion, when I thought it fit to report to him an informal attempt to start up the Kamini reactor in the absence of one of the three mandatory instrumentation channels, he decided to take it up with the Director, BARC immediately and asked me to go with him. I waited outside while he went in. I could sense the intense argument that was taking place inside by its decibel level. But, apparently Dr. Ganguly had his way.

In 1969-70, a large Indian team was deputed to Cadarache, France for an year-long period for the design of the FBTR. I was part of the team. The team members were provided accommodation in apartments in the town of Manosque not far from the Cadarache site. Around that time, a high level team from Trombay that included Dr. Ganguly was in France for discussions with CEA on the construction aspects of FBTR and associated laboratories. The team visited Cadarache. After the visit all the others stayed in a hotel

arranged for them at Aix-en Provence or returned to Paris. But Dr. Ganguly chose to come and stay with three of us in our apartment and had discussions with me on the general safety issues of fast reactors, in particular on reactivity accidents and sodium fires and sodium water reactions. Subsequently, he also asked me to accompany him by train to Monte Carlo where he had to attend an IAEA Committee meeting. We returned to Manosque and then he left for India. This was another instance of the informal relationship he had with his junior colleagues.

2.4 Computer code development, Hybrid MCNP, Neutron spectrometry and Accelerator Health Physics

2.4.1 Computer code development

V Kalyanasundaram

2.4.1.1 Introduction

After completing the first batch of AEET Training School, V. Kalyanasundaram (VKS) was posted in Health Physics Division along with P Kotrappa, PPVJ Nambiar, N Subramanian, and AD Sharma while MA Prasad, PS Nagarajan, G Venkataraman, Pothukuchi Subramanian, Ramesh Chandra Bhat and others joined the DRP. As there was no room to accommodate all of the new recruits in the stone-walled shed in a corner of new TIFR Complex coming up near Navy Nagar Colaba and Trombay Labs were not yet ready for occupation, they were asked to sit in TIFR Library in Old Yacht Club and to collect literature on Health Physics without any specific assignments, being the formative years of AEET. It so happened that at that time IAEA along with WHO conducted a course on Health Physics Instrumentation & Safety Standards for about three weeks. The faculty included a few from abroad and a few international participants were also there. All of the new recruits in the Health Physics Division and in DRP were sent to attend the course. In the meantime Trombay South Site Electronics shed was functional and they were asked to report there. Initially VKS was asked to report to S Somasundaram. He asked VKS to help him in organizing an HPD Library – indexing & preparing index cards for the books and reports. The editor notes that this was the first divisional library to be organized by a division in AEET much before the BARC Library was set up and can be considered as a pioneering work. Later on VKS was given assignment to collect organ weight data from different hospital post mortem records as part of the program initiated by Somasundaram to enable defining Indian Standard Man. It was considered important since the internal dose to various organs from intake of radionuclides would depend on the organ masses and the ICRP limits for intake of radionuclides were based on the organ weight of ICRP standard man. Somasundaram foresaw that since the organ weight of Indian standards man would be different there was a need to revise

the safety standards based on the Indian data. K Venkataraman at this time appeared on the scene. Since he had Statistics as one of the elective subjects in his University degree curriculum, he was assigned the job of analysis of data of organ weights collected from post mortem records in hospitals. VKS mentions in a lighter vein that Venkataraman had good Bharat Darshan while compiling the data.

Earlier DV Gopinath who was with PN Krishnamoorthy in the Film Badge Service Section managed to get out of the group, as the job was not to his liking. He approached AKG for suggesting some R&D assignments and established immediate rapport with Dr. Ganguly. DVG had registered with A S Rao for his M.Sc. degree by research. He immediately started working on derivation of formulae for calculations of build-up of radioactivity in natural radioactive series and in reactor coolant under cyclic and continuous irradiation conditions. VKS notes that at that time Dr. Ganguly had suggested to C M Sunta to study shielding calculations and for developing a slide rule for shielding calculations. Even though VKS was not directly involved in the project, he was asked to assist Sunta in getting the slide rule manufactured from a manufacturer of slide rules. The workshop was located somewhere in western suburbs of Bombay. For this VKS had to make a few trips to the manufacturer to supervise the fabrication. Later on a very useful slide rule was developed which could quickly give the estimate of shielding required for various common sources. This was considered as a substantial contribution as an aid for health physics operations.

DVG saw that VKS was not being used effectively especially for one recruited through AEET Training school and he seems to have spoken to AKG about the matter. This led to DVG asking VKS to go through his derivations of the build-up formulae and look for errors. That was how VKS got associated in this work. The R & D group consisting of DV Gopinath, CM Sunta, V Kalyanasundaram, Kotewala, K Santhanam, L V Krishnan, T N Krishnamoorthy and M R Iyer, was a loosely knitted group with which Dr. Ganguly had day-to-day interaction and Gopinath was the de facto leader of this group. Kalyanasundaram later on worked further on deriving expressions for cyclic irradiation and also natural radioactivity build up and published several reports along with Mrs. Damle who joined the group later. She had also pursued these investigations and carried out useful work. She was the wife of Kotewale who had later on changed his name to Damle. VKS do not remember to have had any direct interaction with Kotewale who had left AEET quite early. He worked in TIFR for some time and eventually shifted his base to Pune University as a professor. After Kotewale moved out of AEET, AKG felt that Kotewale's calculations on the

temperature distribution in radioactive solids should be extended to gamma active solids, having completed the work for spheres incorporated with beta activity. This study had a bearing on waste disposal of radioactive solids, a far visionary work in those days. Kotewale had published a paper co-authoring with Dr. Ganguly which was presented in an international symposium by Dr. Ganguly on this. VKS was asked by Dr. Ganguly to pursue this problem dealing with gamma emitters and also extending it to more complex geometry of a cylinder. Two papers materialized out of this work. DVG, in the meantime has got his M.Sc. degree and wished to register for Ph.D. He was looking for a suitable subject and this looked to him as a good choice and he got associated with the work for some time. However, he later on gravitated toward transport theory and concentrated his efforts in solving coupled differential equations which could produce results without the extensive use of computers. He registered for his PhD on this subject under Dr. Narasimhan who was Head of Spectroscopy Division having preferred to do his degree in Physics rather than in Physical Chemistry with Dr. Ganguly. AKG wished VKS also to register for his Ph. D. since lot of ground was covered in his work on temperature distribution in radioactive spheres and cylinders. But VKS says he had his own views about Ph. D. degree and had strong convictions. He says he was further of firm opinion "that I do not belong to that league". VKS was reluctant to consider AKG's suggestion. DVG even went to the extent of procuring the application form from Bombay University and filling up the subject matter, etc. Only signature was required to be affixed before it could be presented to the Guide, AKG. VKS recollects that he stuck to his decision and AKG was not happy about this. As a matter of fact, Kalyanasundaram had in his later years carried out sufficient work for a couple of Ph. D. theses but never had any such ambitions except carrying out the work for intellectual satisfaction.

2.4.1.2 Criticality safety calculation and evolution of radiation transport codes

LV Krishnan, K Santhanam, TN Krishnamoorthy, all joined the R& D Group one by one. TNK took over criticality clearance studies from LVK, who was initially assigned this work by AKG, when he was deputed to go abroad. Then VKS too joined him. They carried out 2-group calculations only in the beginning for this purpose. Along with the input from these calculations and with the help of Criticality Safety Guides, they were giving the clearance for reaction vessels in the reprocessing plant in Trombay which was taking shape.

In late fifties, Dr. Bhabha was reported to have mentioned to PM Nehru that if given the green signal India can develop a nuclear bomb in 18 months' time, but PM seemed to have remarked not to proceed unless specifically

told to do so. Thus Dr. Bhabha seemed to have posed the problem in one of Trombay Council meetings to organize work on critical mass calculations. At that time there was no computer codes – either indigenous or imported - that can be used to arrive at the number. Dr. Ganguly was one of the Heads to take up the challenge. He in turn passed on the problem to Gopinath and his R & D Group members. While Krishnan and Santhanam started understanding Sn methodology to write a code, DVG had different ideas. He started independently working on his Source-Collision Iteration Scheme – the idea was entirely his. V Kalyanasundaram was roped in to do the writing of the code to test his ideas. In those times, there was no computing facility at Trombay and a CDC 3600 computer was installed in TIFR, Colaba. VKS started using this computer facility. He feels that those were really exciting days and he was elated at generating data on critical masses which he felt would be useful for the Centre. This gave him immense job satisfaction. He used to stay till 9 pm to submit the card deck (those were computer card deck days) for the night run after seeing the output of earlier run results. He used to communicate over telephone to DVG who in turn used to suggest changes/ alterations, etc. That was how SCIT was born. Kalyanasundaram got very good matching numbers when he cross-checked the results of SCIT with published data. Apart from this, SCIT was found very useful at generating data for criticality safety calculations. L V Krishnan who was involved in these exercises remembers that SCIT was sent for presentation at an IAEA conference but DVG could not attend the conference. Eventually SCIT was found to be more useful for the much needed shielding evaluations. Out of this came the successful ASFIT methodology of Gopinath. This found later acceptance in ORNL code library.

2.4.1.3 ASFIT Code born

L V Krishnan who was in the forefront of this work adds: Dr. Bhabha's intention was to first establish computational capability for neutronics design. While two group theory was well established and was being used for thermal reactor design, unmoderated systems were a different proposition. AKG, true to his nature got interested in the problem and set DVG and his group on the task. Multigroup cross sections were available in open literature published by ANL. We had to find out by ourselves how to use them even if we had adopted one of the readily available computational methods. Eventually, using the Sn method, we managed to get a result for the critical radius of a bare solid plutonium cylinder that matched with published values. But what was really needed was a system with different reflectors and a cavity at the center. It was in assessment of radiation shielding involving scattering effects that SCIT and

its more advanced version ASSFIT became successful. Thus VKS was one of the first veterans who carried out code structuring in AEET.

2.4.1.4 Adopting and commissioning of Monte Carlo codes for Indian computers

Lot of demand for shielding calculations also started coming in for design in various projects particularly for the Trombay reprocessing plant. TNK & VKS were doing the computations. They had a close study of the entire process lines handling fissile material from criticality safety point of view. They felt the need for a good computer code that can deliver the goods. Later TNK managed to get KENO-II, a Monte Carlo code developed in USA specifically for criticality computations, when he was on deputation in Kernforschungszentrum, Karlsruhe, Germany (in those days West Germany) in 1973. VKS took up commissioning of the code for the CDC 3600 computer in TIFR. For shielding calculations also, they felt the need for a good computer code. AT that time RSIC, Oak Ridge was freely distributing codes, though the versions meant for outside circulation were only sent. This way VKS got access to Discrete Ordinates Codes, ANISN & DOT courtesy RSIC. VKS made these also working first in the TIFR CDC computer system and later in the Russian BESM computer. VKS was perhaps the earliest person in BARC to adopt computer codes for our computer systems.

2.4.1.5 Commissioning of MCNP Code

In the meantime VKS felt that the existing codes were not able to handle complex 3-D geometry of systems for shielding calculations. That was how recourse was taken to employing Monte Carlo code, MCNP, a general purpose Monte Carlo Code for Neutron & Photon Transport. This turned out to be the answer for his requirements. The MCNP Code was commissioned by VKS after necessary adaptations. Through his discussions with MA Prasad who was exceptionally good in the theory of Monte Carlo and with PS Nagarajan who had done some work on Monte Carlo techniques and Dosimetry for his Ph. D. thesis, VKS acquired a good understanding of Monte Carlo technique. VKS says that this was how his association with MAP & PSN started. The editor remarks that perhaps this was the only team work in which VKS was involved apart from his association with TNK in his career. And they carried out pioneering work on Monte Carlo codes in BARC silently. At that time there was no other group working on codes. Later on Reactor Physics Section under Rastogi started carrying out this work. Thus VKS and through him HPD was pioneers in code development in AEET. PK Sarkar had some interesting anecdotes on Gopinath's reservations of Monte Carlo techniques vis a vis his development of ASFIT technique and these are covered in Sarkar's memoires.

2.4.1.6 Development of a hybrid code

Even with the help of Monte Carlo code, deep penetration problems posed a challenge. To get a statistically acceptable estimate of dose at some remote point in a geometrically complex system, one has to run a very large number of histories involving formidable computer run time. PSN & VKS thought of tackling the problem by resorting to a hybrid approach – do the calculations using a discrete ordinate code up to the point which can be described within the framework of discrete ordinate code requirement and then employ a Monte Carlo code to track the transport of neutron or photon, as the case may be, in the more complex geometry section. A paper coming out of this novel approach was presented by PS Nagarajan at an International Conference, Neuherberg, Muenchen West Germany. PSN & VKS employed the above hybrid approach to estimate neutron spectra and dose distribution in the ion-chamber basket of Dhruva reactor.

2.4.1.7 Codes adapted to BARC Parallel Processing Machine ANUPAM

This was all before BARC Parallel Processing Machine (ANUPAM) was born. Then VKS took up developing a parallel computing version of the existing MCNP Code. It proved to be useful in further calculations and was a successful adaptation. Many in DRP also found this version useful for their work. VKS remembers that in all these, he had a free hand without any official restriction or interference and what was more, acceptance of the DRP group in his involvement. To that extent he had job satisfaction alright and he enjoyed his independence. The editor feels that VKS always enjoyed working as a loner with minimum of organizational entanglement. He could have come up as a leader in these activities if he so chose but he was always looked for job satisfaction and not for building an empire around him (Ed).

2.4.1.8 Computer code library of Health Physics Division

As VKS was equipped with a repertoire/reservoir of a number of codes covering applications in almost entire nuclear fuel cycle, he found himself generating data for many scientists in BARC without actually involving himself in their respective projects. And he was not even bothered if they included his name in the authorship or even acknowledged him. There was a time when someone wanted computations using a code, the road always led to Kalyan's room in Mod Labs. For criticality safety studies, he used to get the numbers and TNK used to do the writing of reports to be presented at the safety committee meetings. VKS remarks that somehow writing reports and attending safety committee meetings were not his forte. Except for a couple of meetings where criticality safety calculations were to be presented for RMP, Mysore VKS says he has not attended any other meetings, TNK was his man for that. Similar was the case

in dealings with other workers in HPD as well as groups in other Divisions. For example for M Srinivasan, he has generated quite a few numbers for his studies on long-lived actinide waste hazard potential in Th-U-233 cycle and fusion breeders. One of the codes which VKS had adopted was the fission product code ORIGEN which was very useful in many health physics safety evaluations. The editor remembers that he also had the benefit of using the results provided by VKS.

VKS was basically a code man but his scientific interest in the problems he dealt with is clearly manifested when he says that he had one unfulfilled job regarding safety of Dissolver in Fuel Reprocessing Plant. He feels this is a computationally challenging exercise and was always nagging him even after he stepped out of Trombay Gates. So VKS-as recently as 2011 or so wrote emails to LVK, DVG & M Srinivasan regarding this problem and delineating these. VKS mentions that none of them got back with any solution excepting appreciating the problem. This clearly exemplifies his deep sense of scientific interest.

So in a nutshell the contributions of VKS was in developing, adapting and validating computer codes for evaluation of nuclear criticality safety, assessment of radiation shielding design and fission product and radionuclide inventory in irradiated fuels. This was applied widely in the evaluation of nuclear criticality safety of process vessels in fuel fabrication and fuel reprocessing facilities at Trombay, Tarapur, Kalpakkam, Radio Metallurgy Division at Trombay, Rare Metals Plant (RMP) at Mysore. He also worked out and provided base line data on basic criticality parameters for fissile systems. He had provided very useful design parameters by shielding and dose computations for spent fuel shipping cask, irradiated PHWR fuel shipping flask, and for experimental Reactor KAMINI at Kalpakkam. VKS also carried out very useful evaluation of the shielding efficacy of anti-radiation pads for Russian design tanks manufactured indigenously. The editor when he served as a member of the Tank Design committee of DRDO remembers his association with VKS who provided very useful design evaluations.

2.4.1.9 Reminiscences of Dr. Ganguly

Kalyan reminiscences in a lighter vein that AKG was the first person to call him by name "Kollan/Kolyan" in typical Bengali accent. Subsequently all have started to address him as Kalyan. During early days AKG used to sit with Kalyan to discuss/supervise his work. During one such session while he was doing a series of calculations using Friden desk calculator he used to key in the numbers quite fast. TNK used to get amused seeing him using the machine in such a fast

manner. When VKS produced the result, AKG had his own doubt saying that VKS might have made some mistake while keying in so fast. He offered to redo the calculations – this time slowly and when the same result appeared after the repeat calculation, AKG gave was very appreciative and gave a nod of approval.

Similarly on some days DVG used to bring AKG after lunch to Divisional Lecture Hall to show his derivations. DVG used the blackboard for this purpose. Once while deriving, he came across expression log(a+b) which, in the next step he, in a hurry, wrote as log(a) + log(b) and this was leading to a neat expression finally. Kalyan pointed out the mathematically wrong step. In the meantime AKG who was obviously was just dozing after lunch, suddenly woke up & told " Catch him – catch him Do not let him get away".

2.4.2 Hybrid MCNP code development, Neutron spectrometry and Accelerator Health Physics

My memories of Dr. Anil Kumar Ganguly – the beloved "Doctor"

P. K. Sarkar

2.4.2.1. Prologue:

Dr. P K Sarkar has vivid recollections of how he started his career in BARC. He recollects he arrived in Mumbai by train one day in 1970 to appear for the selection interview for the post of Scientific Assistant A when he was only 19 years of age fresh after graduating from the Calcutta University. He was received by his father's friend and stayed with him at Andheri. His first experience with the city of Mumbai was a homely one, since very much like in his home city of Calcutta the day he arrived the city was observing a bandh. He was advised not to venture out that day but he decided to make an attempt to reach BARC for the interview. On his way hitchhiking to BARC he was prevented from proceeding further. The interview could not take place that day and was re-scheduled for the next day. Sarkar stayed for three more days in Bombay for sight-seeing following his interview and returned to Calcutta. Within a few days after reaching Calcutta, he received a letter that he has been selected and asked to join within a few days. Sarkar asked for an extension since he had another interview scheduled for admission to the Indian Institute of Management. Finally he joined BARC on March 31, 1970 on the last day beyond which the offer would lapse. Thus, his career was at a fork and got diverted from the path of becoming a management executive and took the path of a scientific career. He owes his further progress in his scientific career starting at the lowest level and climbing his way up and retiring as a Division Head in BARC in 2010 solely due to Dr. Ganguly. Sarkar remembers his first encounter with Dr. Ganguly which changed the entire course of his life. Dr. Ganguly was a saintly and wise person. He had said many things that

guided Sarkar throughout his career and he became a successful product of the "Ganguly School". Sarkar remarks that "Now, on the occasion of the birth centenary, I have been asked to tell something about him." In this context, be quotes Pluto: "Wise men say many things because they have something to say, fools say many things because they have to say something." And Sarkar said "something" which are narrated here. Editor feels Sarkar after all said "many things" in his memoires and proved his quote!

2.4.2.2 How it all started

Sarkar went to BARC on March 31 and reported to the Administrative Officer in the Central Complex building. They gave a large number of forms to fill up and several papers to sign. It took more than two hours to complete the formalities. At the end of it, he was told that he was posted in the Health Physics Division and directed him to go the Mod lab and meet the divisional APO. It was lunch time then and so first thing Sarkar did was to take his lunch in the Mod. Labs. Canteen. The APO (P R Rajagopal) checked the papers and asked him to sit in a chair. Sarkar was waiting and the APO was busy with his work. After about 45 minutes Sarkar asked him what he was supposed to do but was told to wait. After another half an hour Sarkar boldly approached the APO and told him that he wanted to meet the Head of the Division. He looked up at Sarkar for some time and then replied, "Doctor is not in town." And Sarkar was confused and retorted that "I don't want to see a doctor, I want to meet the Head of the Division". There was a sarcastic smile on his face and asked me, "Do you know who is your Head of the Division?" "No", replied Sarkar. He started laughing loudly and said, "Dr. Anil Kumar Ganguly, and he is known as "Doctor" around here!" Sarkar was very much excited to know that his Division Head is a Bengali but could not understand why he was called "Doctor". Is he a medical person? In due course of time, Sarkar realized that people call him Doctor out of love and respect. The APO told Sarkar after a few minutes, "You are new, so I must inform you, in BARC a scientific assistant cannot hope to meet the Division Head just like that." After a few moments, he mumbled, "But then Doctor is different!" And the experience of Sarkar did prove that statement. And also some hesitation about the future in starting in a post which the APO seemed to indicate as a lowly one!

Sarkar was asked to sit in the Divisional library to maintain the records, prepare a catalogue and issue books to divisional staff. Sarkar made use of this opportunity to go through different books on various subjects about which he had no idea. It was difficult initially but slowly he started liking it. In the meantime, Sarkar came to know from home that he was selected for admission in the IIM, Kolkata. Unlike what it is today, in those days,

management courses were not much coveted for. Nevertheless, Sarkar had to take a decision. From his childhood days Sarkar wanted to become a scientist and carry out research. He was fond of science fiction stories and had the illusion that scientists are super human beings. Over the years such illusions gradually diminished, nevertheless, some longings still remained. But then how his dream of becoming a scientist was going to be fulfilled, he was not sure, having been given a very rudimentary assignment of keeping stock of books. Sarkar decided to meet Doctor and talk to him to make a final decision about continuing in BARC. Sarkar has only seen him in the corridors of Mod. Lab. And he was an awe inspiring figure.

2.4.2.3 First meeting with Doctor

Finally, Sarkar managed to enter the Head of the Division's room one morning when he was alone. This is what Sarkar says in his own words; I introduced myself and explained my problem to him. He looked up to me. "I would love to get involved in research activities", Sarkar told him and added "But then what are the prospects here? Can I do my M.Sc. and Ph.D. while working here?" Dr. Ganguly replied; "Yes, you can in principle. But then you have to work very hard, not, hardly." "I shall do my best", I interjected. "Let me see whether your best is good enough", he replied. He then added, "Look, whether you want to join the management course or not is your decision, but if you are very keen in doing research, as you claimed, then BARC would the most suitable place for you. You do not have a M.Sc. degree, but still you can do research, can do your M.Sc. and Ph.D." I realized from the core of my heart that these words are very true. I could possibly not do much research anywhere else including as I realized later in other divisions of BARC, with my bachelor's degree only. He added, "Your job is secure here, unless, of course, you physically fight with someone openly in the corridor", his sense of humor was showing up. He then looked at my face with a smile and said, "If you are hardworking and sincere, you may even occupy this chair one day". He pointed at the chair he was sitting on. That was indeed a prophetic statement with premonition since Sarkar did become Dr. Sarkar and was elevated to the post of Head Health Physics Division later and over and above did occupy the very same chair. Sarkar at that time in 1970 could not make out whether it was a benign joke he was cracking or it was his effort to attract a naïve young person to research activities by indicating the benefits he might be able to reap. Sarkar left the room without telling anything but decided to continue, anyway, in BARC, mainly because he found Dr. Ganguly's personality was magnetic, very reassuring and a person on whom one can depend on. The editor would like to underline this sense of premonition and imparting a reassuring feeling

to anyone one who goes to his chamber to seek advice and he himself has noticed in the interaction of Dr. Ganguly with his students.

2.4.2.4 The wheels of research wagon started rolling

After being given training for six weeks, Sarkar was posted in the Apsara reactor as an operational health physicist undergoing round the clock shift duties. Doctor also asked Sarkar to be associated with K. N. Kirthi who was working on neutron activation analysis to estimate neutron fluence in the experimental beam holes of Apsara. I started irradiating the foils for him and started learning about interaction of neutrons with matter. This was my first research assignment. Along with this Dr. Ganguly wanted Sarkar to learn about criticality calculations. Dr. Ganguly enabled Sarkar to attend some of the select classes on numerical analysis, reactor physics and nuclear physics in the BARC Training School, which was then located close to the Apsara reactor complex. Thus the BARC Training School so to say coalesced with "Ganguly School" in a figurative sense and this helped Sarkar very much in his research assignments later.

Sarkar then started working on the response of plastic scintillators to neutrons, gamma rays and charged particles. However, the main aim of the work was to develop a neutron spectrometer and dosimeter as wished by Doctor and also wanted theoretical simulations to be done. For this purpose, Sarkar started learning Monte Carlo simulations. After a couple of years in Apsara, he was shifted to Van-de-Graff accelerator as the health physicist, learned experimental techniques by association with other researchers, carried out experiments with charged particles at Van de Graff at the instance of Doctor. In this process Sarkar became involved in Accelerator health physics which later led him to lead the accelerator health physics group in VECC.

The major hurdle in neutron spectrum measurements was to discriminate the gamma background always associated with any neutron field. Sarkar attempted to use the proton recoil technique using plastic scintillators to measure fast neutron spectra where the associated gamma background is eliminated by using various different thicknesses of the scintillator discs. Among the techniques employed to eliminate the gamma ray background, the pulse shape discrimination (PSD) is widely used and effectively implemented. The PSD technique is based on the difference in the scintillation pulse decay time of electrons from gammas and that from recoil protons due to neutrons. But for a fast scintillator like the plastic, where the difference between the two decay times is extremely small, the PSD technique was difficult to apply. Doctor suggested looking for other properties that can be utilized successfully.

Consequently, the method adopted was based on the fact that the ranges of Compton electrons produced by gamma rays inside the plastic scintillator are much higher than those of recoil protons of comparable energy. Hence, by restricting the thickness of the scintillator, electrons can be made to escape the scintillator deposing only a small fraction of their energies resulting in a smaller pulse height, which can be easily biased off in the electronics from the large proton pulses. After some trials, four scintillator thicknesses were chosen to cover the neutron energy from about 1 MeV to about 18 MeV based on the transmission (escape) of practically 100% of Compton electrons.

The practical realization of such conceptual design of a neutron spectrometer involving four different thicknesses of plastic scintillators needed extensive support from theoretical simulations involving computations based on condensed random walk techniques, of which Sarkar initially had no idea except that it was a highly computer intensive work and is very much different from the normal random walk methodology used in Monte Carlo simulations. When he informed working on the problem to Doctor, told, "Go, find out yourself who can help you. There must be someone in some corner of BARC, hidden behind his desk, doing this type of work!" Sarkar went for the man haunt. Finally, he could discover that one M. A. Prasad of DRP (presently RPAD) was doing similar calculations but for different problems altogether. Prasad was of a very helpful nature and agreed to help Sarkar and this started a new type of collaboration outside his own Division and finally proved to be a significant turning point in his research career.

The pulse height spectra from four different detectors were mixed to give the pulse height spectrum of the combined detector system. The corresponding combined response matrix of the detector system that resulted from the mixing of calculated (Monte Carlo) response functions of the individual detectors using Monte Carlo method was constructed. Since no available unfolding code was found suitable for the proposed detector system, an unfolding program had to be developed exclusively for this purpose. It was because of the insistence of Doctor, both the computer programs for calculating the response matrixes as well as the unfolding were written by Sarkar. These algorithms, though not written efficiently or professionally, gave a valuable experience and knowledge of solving research problems, even if it was done rather crudely. Sarkar's first publication in an international journal came on this topic with Kirthi and Doctor as co-authors.

Another research problem which cropped up during this period was the gamma sky-shine estimation due to gamma rays from that go up, gets scattered by the air molecules and comes back to ground at a distance away from the source.

When one moves away from a strong radiation source in an open field, the intensity of the radiation reduces with the distance. Then suddenly after a few hundreds of meters the intensity increases because of the contributions from sky-shine radiation. Doctor was interested in studying this problem since this phenomenon can lead to radiation dose away from a nuclear facility adequately shielded on the sides otherwise. Janardhan Swarup was carrying out experimental measurements of sky shine energy distribution of gammas from a strong Co-60 source located inside the gamma garden of BARC. Doctor asked Sarkar to do theoretical calculations to estimate sky-shine gamma energy distributions to match the experimental results. Sarkar started work using Monte Carlo simulations with the help Dr. P. S. Nagarajan from whom he learned the basics of Monte Carlo radiation transport simulations. To his surprise, Doctor showed quite some interest in this work. Sarkar was surprised mainly because at that time, Dr. Gopinath with a group of several scientists was already involved in deterministic radiation transport calculations and have established a till then unexplored technique of solving the integral form of the Boltzmann transport equation. Doctor was immensely interested in that work and was spending almost every evening discussing with them. Once Sarkar asked Doctor why he wanted him to work on Monte Carlo when he can easily get the results from the deterministic calculations. "We must explore all the avenues", he replied. Sarkar and Prasad presented their results in a conference where both Doctor and Dr. Gopinath were present. Unfortunately, the Monte Carlo results did not match the deterministic calculations; mainly due to the limitations of the available computational facilities the Monte Carlo results were associated with large statistical uncertainties and hence were imprecise compared to deterministic results. This resulted in huge arguments and counter arguments during discussions. There were severe criticisms of our work. But Doctor supported us by telling, "I understand that there is scope for improvement, and this work should continue". Shortly after, Dr. Ganguly arranged to send Sarkar to carry out gamma spectrum measurements in and around Jaduguda mines. Sarkar's involvement with the sky-shine problem proved to be beneficial in later years when he started working on neutron and gamma sky-shine estimations from accelerators and as suggested by Doctor.

Once we were visiting Jaduguda along with Doctor. While returning we had to catch the train from a station called Ghatsila which is about 25 km from Jaduguda. Raghavayya, who was in-charge of the Health Physics Unit, Jaduguda arranged some breakfast in a popular sweet shop in Ghatsila. Two Samosas, two Rajbhogs and a cup of tea for each was arranged which was enough for a decent breakfast. Doctor announced that he wanted one extra Rajbhog.

Raghavayya agreed readily. After finishing the food Doctor told, "Raghavayya, I will not take tea, instead, can I get one more Rajbhog?" "Yes Doctor, you can have one more Rajbhog and tea also" replied Raghavayya. After finishing that Rajbhog, Doctor repeated, "Raghavayya, I will not take tea, instead, can I get one more Rajbhog?" This way, he consumed a total of six such big Rajbhogs! Sarkar was amazed by his appetite and love for food.

Sarkar found that his working with Monte Carlo radiation transport was becoming increasingly difficult because of the constant criticisms he faced with established scientists in the Division who worked in the field of radiation transport. This caused some disappointment as he faced unfavorable remarks in scientific discussions from time to time. Once Sarkar went to Doctor and asked him whether he should change my subject. "No, you shouldn't", he replied, "Criticisms should motivate you to do better". Then after a pause, he told, "If you are not convinced about the advantages of Monte Carlo, read more and convince yourself. Then go ahead and try to eliminate the drawbacks". Sarkar following Dr. Ganguly's advice started reading research papers, text books and articles and discussed with Dr. Nagarajan and Prasad to seek clarifications and finally started working on Monte Carlo variance reducing techniques. Sarkar wanted to register for Ph.D. under Dr. Ganguly, but could not find any suitable research problem that could lead to a Ph.D. degree. Sarkar did not meet Doctor for long time since he had already told that he will not register Sarkar as a student with any run-of-the-mill problem. One paper appeared suddenly, where the authors indicated how to estimate 'a priori' the statistical uncertainty or population variance associated with Monte Carlo radiation transport results. The concepts were complicated and not easy to comprehend even though the paper dealt with only analog Monte Carlo simulations. What was needed was similar formulations for non-analog simulations incorporating different variance reduction schemes, so as to compare their relative merits. Prasad was optimistic though such formulations would involve incorporation of highly complex probability theory. With the help of Prasad, who became his mentor in navigating through such complicated issues of advanced algebra and probability theory, Sarkar started working on this problem. After a few months some rays of hope emerged and they found out that the problem may be tractable. Armed with this breakthrough Sarkar met Doctor with a copy of that published paper and explained him everything and also told him that finally we may end up some outcome. He looked at the copy of the paper I was carrying, glanced at it started looking blankly at the wall in front of him. After sometime he said, "Go ahead". Thus Sarkar got registered under him for the doctoral degree making true his premonition when he met Doctor first.

Thus Radiation transport using the Monte Carlo technique involving the theory of variance reduction techniques was initiated. During this time, the research environment related to radiation transport in my Division was making progress based on a newly developed in-house technique involving the solution of the integral form of Boltzmann transport equation instead of the more popular integro-differential form. The Monte Carlo technique was criticized for its mathematically non-rigorous approach. Nevertheless, Doctor supported the Monte Carlo method of approach. He suggested research on reducing the statistical uncertainty associated with the results. He pointed out that the Monte Carlo has the advantage of faithfully modeling the geometry of complex problems. In this context the editor recalls Dr. Ganguly's own tryst with Monte Carlo in his Radiation Chemistry work in Notre Dame. Prasad and Sarkar toiled very hard and could finally come up with the analytical formulations for the score accumulation probability in non-analogue Monte Carlo simulations involving different variance reduction techniques. The score accumulation probability is in fact an 'a priori' knowledge of the probability that a particle at any point inside a medium will give certain pre-assigned score in all its future interactions. The complications in the formulation were enormous but with the help of Prasad Sarkar could cope up with the situation. Finally, they could get interesting results that were useful for the development of Monte Carlo simulations. The manuscript reporting the results was accepted in a reputed and prestigious journal. Several papers followed from different parts of the world citing their work as the pioneering one. When Doctor became aware of this, Sarkar could see a broad smile on his face. He told, "The work is not complete yet. Do as much as you can, before others do it instead of you". We published some more results and Doctor agreed that Sarkar can submit his Ph.D. thesis. By this time, however, the criticisms about Sarkar's work almost stopped.

Doctor wanted to have a look at the thesis draft but there was not much time in the office and progress was slow. He had many queries, which took long time for Sarkar to explain. The discontinuity in the discussions caused lots of problems. Sarkar became worried whether such discussions will ever come to a fruitful end. Dr. Ganguly then suggested that they continue the discussion on Sunday mornings at his residence. This became more fruitful. For me, apart from the discussions, the Bengali food which Mrs. Ganguly used to prepare and offered Sarkar was more attractive. This went on for a few months and finally the draft after numerous corrections was approved for final submission. Two examiners, one Prof. Harvey Amster from University of California, who had published the first paper on this topic and Prof. Vasudevan, an eminent

mathematician from MATSCIENCE, Chennai were selected by Dr. Ganguly. Sarkar was very much apprehensive about the second person being such a renowned, full-fledged mathematician, who, it seems, was suggested by Dr. Gopinath. Once Sarkar told Doctor about his apprehension about Prof. Vasudevan who will be conducting the viva-voce examination that he was not confident in facing a mathematician of his stature. He told me, "If you are sure what you have done is correct and can explain your work properly, why do you bother about what anyone is going to ask you".

A very favorable response was received from the foreign examiner, praising the work highly. Doctor was visibly very happy and showed the report to many. After sometime, Prof. Vasudevan also sent a positive report. The date of viva-voce examination was fixed. Prof. Vasudevan was a highly knowledgeable person and was saintly almost like Doctor. Sarkar felt that he could not answer all of his questions, but realized he was trying to probe out how much I knew rather than how much I did not. Sarkar became Dr. Sarkar after a couple of months again substantiating the premonition of Dr. Ganguly!

After this the interactions with Doctor became less and less with time, mostly because Sarkar was transferred to the Health Physics unit at Variable Energy Cyclotron Centre at Calcutta. Whenever, he used to come to Mumbai he made it a point to meet Doctor. Each time he asked Sarkar whether he was continuing his work on high energy neutron spectrometry as well as neutron sky-shine problems. These problems were very specific to accelerator radiation safety and were not so popular radiation safety related research problems neither in India nor perhaps internationally. Nevertheless, Doctor insisted that we take up such problems. His interest in accelerator radiation safety amazed me. From Muthukrishnan, who was the health physicist in-charge of the Variable Energy Cyclotron Centre, Calcutta, Sarkar came to know that Doctor took active interest in the safety design of the proposed Cyclotron facility, starting from the estimation and finalizing the shield thickness, ventilation rates in the machine vault, safety interlocks. Interlocking the accelerator operation with the neutron flux monitors located in the corridors outside the cyclotron vault was his idea. This restriction in machine operation was finally implemented on Doctor's insistence despite strong opposition from the cyclotron operation personnel. He was much aware of the safety related design of accelerator enclosures elsewhere in the world. He supported Muthukrishnan in strict implementation of the safety guidelines which were formulated with active involvement of Doctor. Subsequently Sarkar changed his topic of research mainly to nuclear reactions and carried out experimental measurements using the accelerator produced high energy charged particles. Doctor never asked

why Sarkar changed his field of research but always advised to do the work sincerely and to have a thorough understanding of the subject. Sarkar could not meet him during the last several months of his life. When he visited Mumbai consequent to his demise, he could only talk to his eldest son, who was doing excellent work having joined health physics division as an electronics engineer. Dr. Pradeepkumar Sarkar and Pradeep Ganguly become close friends to share the similar fatherly love and affection that Doctor used to bestow on both.

2.4.2.5 Epilogue

After spending about 32 years in the Variable Energy Cyclotron Centre, Kolkata, Sarkar was transferred back to BARC, Mumbai - this time, as the Head, Health Physics Division making true the premonition of Dr. Ganguly a third time. A large framed photograph of Doctor was hanging in the wall of the room which Sarkar was to occupy as the Head of the Division. It caught Sarkar's sight the moment he stepped into the room. It was an emotional tryst and Sarkar observed a faint welcome smile on his lips? Sarkar was emotional as he was going to occupy the same chair that he used to occupy when he met him for the first time. It may not be physically the same chair (I am not sure, but it is very unlikely to be so). Suddenly, the words of Dr. Ganguly started echoing in Sarkar's mind which was forgotten for so many years. A film director would have been enormously tempted in this situation to insert a flashback of my first meeting with him along with the words, "If you are hardworking and sincere, you may even occupy this chair one day". Great old Shakespeare has put similar incidences in many of his plays and is generally known as the dramatic irony. I still wonder, whether he believed what he said that day, or it was just a comment made jokingly, or a mere coincidence or a sense of premonition generally associated with Doctor.

2.5 Health Physics in research reactors, Fission Product and Fission studies, Safeguard NDA Techniques, Radiation Safety Systems

Reminiscences of Dr. Ganguly

M R Iyer

2.5.1 Introduction

The uncompromising scientific acumen in Dr. Ganguly made him brood on the lack of nuclear data on fission products to carry out nuclear accident impact analysis. This led him to look into radioactivity and energy release from fission products at short times after fission. The research initiated by him led to pioneering work on generating basic data. When calculations did not provide the answer due to lack of nuclear data he suggested conducting experiments on total fission product decay by innovating methodologies which generated basic data down to times of a millisecond after fission for the first

time. This further led him to carry out investigations on understanding the phenomenon of fission along with me (M R Iyer) and proposed a model for the fission process which resulted in several publications including many in the Physical review. Dr. Ganguly had applied thermodynamics of chemical systems to nuclear fission in evolving the model taking cue from his earlier work in radiation chemistry. All these investigations initially were carried out under the constant guidance of Dr. Ganguly by me more or less single handed. The model intrinsically provided explanation for the asymmetry in fission based only on the systematics of stability of nuclides and an early charge polarization during the fission process. Many fission parameters derived from this model agreed well with those observed experimentally. I am narrating my close collaboration with him just to show case the work on fission and fission products was in reality carried out by Dr. Ganguly himself and my contribution was only in implementing out his ideas. He was the brain of the work on fission with me as an errand boy! For a decade it was a two man group with me running around to implement his ideas. The work he has carried out with his other students may be more or less the same manner but here was a case in which I carried out as a solo operator under him until it started attracting the attention of people around. My association with him taught me to move around obstacles not only in implementing his plans but also gave me lessons in my later life when he was no more available for support to maneuver around, to shift gears and even change path to produce results to the likening of the later managers and earn their bouquets. He believed that science does not have boundaries of partitioning of divisions/sections and carried out what he considered which ought to be done even in the face of fierce opposition and nobody could ever stop him. I can see the far off ripples of his strong convictions still in the organization with the members of his school occupying top positions. It was thus I shifted from operational health physics, to fission products to fission and to NDA techniques for safeguards and full-fledged safeguard applications, to microprocessor technology, then applied it to down-to-earth practical instrumentation which produced many dramatic results and enabled me to end up in managerial levels and then on to my career in the international arena as an instrumentation specialist with the IAEA Safeguards division. This even led to my being the only Safeguard inspector from India accredited to several countries including North Korea. The two decades of closely working with him enabled me to instill enthusiasm in my colleagues and resulted in about 15 of them earning their Ph.D. and M.Sc. degrees. Finally it paved the way to associate myself with overseeing the regulatory activities of AERB in the area of accelerators for full 15 years post-retirement and even in 2017 my being associated with the AERB advisory

committee on Nuclear and Radiation safety. I consider that the distant effect of association with Dr. Ganguly is responsible for my being able to contribute to the cause of promoting nuclear energy in the country in 2010-11, when I was nominated by the then Chairman AEC, Banerjee to the Kudankulam Expert Group for allaying the fears of the public about nuclear power. This was also sequel to my role as a constructive critique and free-lance writer on nuclear power in the wake of the talk on Indo US nuclear collaboration in 2005, encouraged by late Dr. P K Iyengar. In all these I owe my success to the lessons Dr. Ganguly taught me with his uncompromising quest of science and being bold to express ones views and followed his advice to "find one reason why I can do it and not 99 reasons why I cannot"!

2.5.2 How it all started

On reporting for joining AEET in Feb 1958, I was directed by the Personnel Division of AEET located at the Indian Express buildings at Church gate, since the buildings at Trombay had not come up and all the offices and labs were located at different rented locations in Bombay. The Administrative Officer there, I think it was the AO, Raghavan, asked me to go to Old Yacht Club building and meet P N Krishnamoorthy and scribbled something in my appointment order. So I proceeded to the OYC building after getting directions from him. I entered the building with wooden cracking floors after gazing at the marvelous Gateway of India wondering what an old yacht club has to do with atomic energy! On being directed to PNK's room I saw a frail lady sitting in the lobby of the room at her table doing some calculations or writing. It was Gnanapurni! She looked up at me and glanced the paper that I handed over and thought for a few minutes and told me that Krishnamoorthy was away and rang up Raghavan. I was nervously sitting in a chair waiting for the next step. She then told me to take a shuttle mini bus from OYC to the TIFR building in Colaba and meet Dr. Ganguly. I was wondering how this is all going to take shape. But when the bus arrived at the huge TIFR complex under construction and realized that was the location I gave my interview a few months back. On enquiry I was directed to go to Hot Labs building in a corner of the huge compound which had many naval barrack sheds wondering what was hot about the building! It was at a slightly elevated level and there were two or three rooms. A few people were sitting in the outer room and they showed me the room behind a door. I tapped and entered. A man with shabby hair and thick glasses and a loose half sleeve shirt was sitting at the chair behind a table pouring over some papers. He looked at me and asked me to sit and I nervously sat at the edge of the chair. I never realized that this was the man who will change my life! He looked at me and inquired what I have done

in my college. I told him that after my B.Sc. Physics in the University College Trivandrum, I am currently in the end of the first year of Statistics M.Sc. He asked me why I am leaving my studies and I mumbled something that physics is my more favorite subject and hoped to do physics in AEET! Then he gave me gist of the work going on briefly and said I have to learn quite a lot. He also mentioned some typical problems in nuclear physics. He said that fission gives rise to a lot of radioactive products and one of the unsolved problems is how the yield follows a two peaked curve. And those radioactive products posed all the challenges of the profession. I did not follow most of what he said partly due to his Bengali accent and partly due to my ignorance. Today looking back it is a strange coincidence and perhaps his premonition that he mentioned this problem to a fresher like me on which my career was built! Further I never realized this was to be the bonding between me and the man who became my mentor. He did not talk much on radiation safety but said that these fission products are the genesis of health physics!

Then he directed me to Somasundaram who was sitting in the next room. And one Parameswaran sitting behind a typewriter took the papers from me. He was the PA to Dr. Ganguly. I don't exactly remember what Somasundaram told me. A few persons were also sitting around perhaps Subbaratnam and others. Somasundaram chatted with me and I was happy to know that he is also a Tamilian and was very gentle. He told that my sitting place would be is in the basement of the multi storied TIFR building under construction where I found five or six people were sharing a half plastered room. So I started at the first step of my career. I found Gopinath was doing some calculations on activity build up in natural radioactivity series using a Friden electric calculator. I tried my hand on this one and was excited as this was a luxury in my statistics M.Sc. class, we having been provided each with a mechanical calculator which involves hand rotation with a spindle and shifting digits with a shift lever to carry out basic arithmetical operations! A few electrical calculators were a luxury at the college having been the monopoly of professors! At times Gopinath would ask me to do a piece of calculation and Somasundaram used to give odd assignments. I also assisted A Ramamurthy Sr. who used to go for radiation monitoring in the various labs. I was rather floating amongst all these. Sunta was there and mentioned he planned to do chemical dosimetry. Kotewale was a mathematician to whom Dr. Ganguly had given the problem of analytically solving temperature distribution in glass spheres incorporated with radioactivity. He told me that he will solve those integral equations first and then and apply it to a sphere containing radioactivity. During our afternoon coffee session he often used to mention of his dream to become a theoretical physicist in

TIFR. Somasundaram told me to look after the safety of the "Radium Hut' in which all radioactive sources including some Ra Be sources were stored for calibrating radiation monitoring instruments and I became custodian of this source room. Somasundaram was always editing something or other and once asked me to make a safety manual for the Radium Hut. And this proved to be my first training in scientific documentation and Somasundaram guided me well. He polished my crude write up and produced a ten page manual which he got cyclostyled and produced copies. Incidentally the noticeable hazard in the source room was not radiation but snakes! I was the custodian of the key with the master key with Dr. Ganguly.

2.5.3 Beginning of FP activity calculations

I used to go and meet Dr. Ganguly often and no appointment was required but had to wait until someone with whom he is discussing has finished, exploring to see if I can also get a problem like others are working on. He again used to mention to me about the un-solved problem of the double peaked fission yield curve. He also mentioned about temperature distribution in radioactive spheres which Kotewale was doing in order to assess the temperature to ensure that the matrix is not affected by loading radioactivity. I realized later that it was really a visionary work in 1958! We have after 6 decades just taken up the project of vitrification of high level wastes!! And he said that for this we need a single expression for gross fission product decay and suggested to me to see if I can start fission product activity build-up calculations. I thought it was a good problem similar to the Gopinath's activity build up calculations in radioactive series. Gopinath was using Bateman solutions for activity build up in natural radioactive series but I decided to organize my own scheme for Bateman constants which was easier to handle in calculators. Following Dr. Ganguly's advice to carry out literature search I stumped across the Oak Ridge report of Blomeke and Todd of 1954 who had given an extensive compilation of fission product yields, half-lives and energy data. I requested a copy of the report from the authors and received 5 volumes which became my valued possession. In those days Somasundaram had thoughtfully designed a reprint request card and got it printed so that as soon as we come across some reference, fill up the card and send it to the author and he invariably used to send us reprints. The Divisional library was started building up on such reprints.

The fission product activity calculations involved calculation of activity of each fission product using Bateman equations for each fission product decay chain for various decay times and summing it up to get the beta activity, gamma energy, and gamma spectrum in various energy groups. Some 80 fission product decay chains were involved, each chain having 6 or more products

with numerous gamma emissions. Those days no computers were available, not even electronic calculators. The exercise using an electromechanical Friden calculator was a laborious process manually tabulating the results for some 6 decade of decay times! The idea was to provide easy-to-use fission product data for shielding and dose calculations. I was proceeding with my calculations and one day in 1958, Dr. Ganguly asked me to shift to Apsara reactor and start working as a health physicist. He added that you can continue with your calculations. I managed to take one of the Friden calculators since Gopinath who was working on it was also a frequent visitor to Apsara where he was carrying out experiments on reactor coolant activity. He was working for his M Sc thesis in Physics registered under A S Rao. By and by Dr. Ganguly allowed me to register for M Sc under him in Physical Chemistry as he was a recognized guide only for Chemistry. I was a bit disillusioned with my dreams to become a physicist but he assured me that will not be a problem. Thus, I found myself in the company of KC Pillai TNV Pillai and A Ramamurthy Jr. as his first students in AEET and me as the first student with a Physics problem!

2.5.4 Operational health physics - first steps in Apsara

As a matter of fact I was floating with various people but decided not to lose sight of my mentor. In Apsara I was put in shift duty by Kolhatkar who was in charge of HP there. He was basically an electronics diploma holder, not having much of scientific temperament. But I took scientific interest in the work which enabled me to handle counting systems and radiation monitors and started dreaming of doing some experimental work someday similar to what was going on around in the Apsara reactor hall. One of my duties was to manage distributing and keeping records of film badges and this enabled me to become familiar with names of all persons working in Apsara; even now I remember all the names with initials! M Srinivasan of NPD had the same initials as a reactor operator, so I prefixed an "A" and his name in records became A M Srinivasan! There was V P Duggal with his single crystal neutron spectrometer, N Sharma with his neutron chopper experiment, Umakanth and P K Iyengar had started organizing the setting up of an advanced crystal spectrometer on which he had worked with Dr. Brockhurst in Canada. Ramanna and his fission physics group consisting of PN Ramarao, SRS Murthy, B R Ballal and JN Soni later joined by SS Kapoor in 1959, were carrying out angular correlation of fission fragment experiments at the thermal column of the reactor. They had produced a classical paper at the II Geneva conference in 1958 on angular correlation of fission fragments. It may not be out of place to mention that PK Iyengar was my 5 years' senior in the University College in Trivandrum and I had an introduction letter from his father through my

father when I arrived in Mumbai. Soon after joining I met him once in his TIFR hostel room in Sargent house opposite to OYC. He had just arrived back from Canada. He mentioned that I should have continued my M.Sc and joined BARC after finishing. He asked me to continue with Dr. Ganguly. I mentioned this particularly, though I had except for casual contacts with him in the Apsara did not have any worthwhile contacts. But much later after his retirement he became an influencing factor in my career and I sensed his appreciation of Dr. Ganguly. But in those days he was not quite not happy that Dr. Ganguly does nuclear physics of his own and used to run down our work whenever we rarely crossed paths or I got an occasion to present a paper in local conferences in his presence. He used to come to collect the manuscript of our Geneva conference paper on fission products, since he was coordinating the participation in Geneva conference in 1964.

In 1959 as CIR was getting ready for commissioning, Kolhatkar with his experience in operational health physics was shifted to CIR and Dr. Ganguly made me HP in charge for Apsara unofficially. Somasundaram was supposed to be the group leader but more or less AKG used to give me assignments. Since the temporary laboratories at the electronic shed in Trombay was not yet ready Dr. Ganguly used to sit in a room in Apsara for some time directing the health physics operations at Trombay. That gave me a golden opportunity to be in contact with him since I was posted there.

2.5.5 Health Physics coverage for TRIGA reactor Delhi

Toward the end of 1959 a 100 KW research reactor TRIGA manufactured by the General Dynamics Corporation, USA was to be erected and operated at the USAEC Pavilion of the World agricultural fair in New Delhi and participation by AEET was planned in safety, and isotope production. AEET even set up a small isotope lab and processed small quantities of radio isotopes produced in the reactor and supplied these to various hospitals in Delhi. This might not be possible under the modern day regulatory norms, but demonstrated the safety of such operations in a public domain. M G Kolhatkar was deputed to go to Delhi to supervise the installation of the reactor. After start-up of the reactor A S Rao on the advice of Dr. Ganguly directed me to proceed to Delhi and provide health physics supervision for the operation of the reactor toward the end of 1959 and I had spent around 45 days working with the GD (General Dynamics) staff. As an aside remark, we were given Rs. 4 as daily allowance and provided an unfurnished Central government quarters apartment for our stay. With no beds we protected ourselves from the biting cold by spreading cardboard cartons from the exhibition grounds for sleeping! But we were provided with transport for commuting to the exhibition grounds daily. The

assignment gave me wide experience in working independently and in the association of the US personnel at the reactor. This was a unique opportunity and looking back at it reflected the amount of confidence Dr. Ganguly had in me in selecting a very junior staff of his division for this assignment. I learnt quite a lot as if it was a deputation abroad for me in working with the health physicist Griffith and reactor operators Cassoday and Beojourned and learned quite a bit from their style of orderly working and the health physics techniques they adopted. The USAEC representative Cassoday even issued me a certificate as an approved TRIGA operator after giving me instructions and named me as "Milli Roentgen" Iyer for M R Iyer! I never thought of my name being so much connected to radiation protection and to the pioneer of x-rays till then! It was a 100 KW pool type reactor located in a below ground level reactor pool. The reactor was a unique one and with a unique fuel uranium-zirconium hydride which provided abundant negative temperature coefficient to enable it to be flashed by withdrawing all the control rods and the reactor power peaked to around 15 MW for a few milliseconds giving a brilliant Cherenkov radiation and shut down of its own. This was dramatically demonstrated twice to the public every day. It was a unique occasion for the public to see themselves freely how a nuclear reactor operates. The reactor was also used to irradiate several isotopes using its excellent pneumatic transfer system. The isotopes were separated and packed and distributed to the hospitals in Delhi by the Isotope division and T S Murthy was in charge of this lab. The isotope cell had another health physicist R Kahtua for providing health physics coverage there.

The 4 staff members of the GD did all the work in a neat orderly manner. I provided the health physics surveillance using their instruments as well as the Trombay electronics instruments. I did not lose opportunity to do some investigations on the air activity during flashing by collecting air samples which showed some short-lived activity in small quantities. The dose due to N-16 was also measurable during the flashing. I wanted to map the decay of this dose rate but did not have any recording device with me! But the total dose during the 10 msec of flashing was negligible as measured using the monitor in integrating mode.

Srinivasan and Subbaramu from NPD carried out some "danger coefficient" measurements at this reactor and produced a paper. After the exhibition concluded there were some discussions as to whether the reactor is to be re-erected in AEET or shipped back. GD had volunteered to leave the reactor back in India and install it in Trombay but Dr. Bhabha did not accept the offer since GD had submitted one of the tenders for the Tarapur reactor at that time and he did not want to even remotely seem to show any favor to

GD by this gift! However he accepted a Co-60 irradiation source which was exhibited by USAEC for demonstrating irradiation of agricultural products and Pusa Institute was the main user. It was later installed in Trombay since it was from USAEC! Kolhatkar wanted to go to Delhi for the decommissioning but I understood that Doctor told him that "Ramakrishna will do the job!" (He used to address me by my first name often). I was asked to stay back and provide the HP supervision for dismantling and shipping back the fuel to USA. When the time came for dismantling and shipping back to US, the hot fuel Dr. Ganguly instructed me to stay on and supervise the decommissioning operations. Thus, I had the unique distinction of providing HP supervision for the reactor operation and decommissioning. The hot fuel elements were loaded into the fuel casks using make shift handling with tongs and pulleys and neatly packed into the shipping casks for transport. The personal exposure during the whole operation was minimal. The pool showed some activity on the metal sides and was carefully filled up and concreted on the top and with scribbling that the reactor operated at this site and should not be dig open. There might have been some discussion in this regards with AEET authorities before this decision. I was informed about this decision by Dr. Ganguly. I reported the safe handling of the decommissioning and filling up the tank to Dr. Ganguly and A S Rao and asked them if it needs some proper certification someone may be sent. I was not a Gazette Officer at that time and was not sure if the protocols required such a certification! And they sent K Santhanam who came and concurred with my measurements and made a certification. On my return I made a report of the operation and decommissioning work which was edited by Somasundaram and it was issued out as an AEET report. Once A S Rao while visiting Apsara and chatting with Ramanna called for me and introduced me to him saying that "this boy did all the health Physics work at the Triga reactor single handed including de-commissioning" and that was a moment of great satisfaction to me. On seeing the report Dr. Ganguly was greatly satisfied. And thus started my tryst with operational health physics in the midst of involvement with fission product investigations. This along with my experience as the Health Physicist-in-charge at the Apsara reactor for around three years including giving coverage for a couple of special maintenance operations came handy when I was given responsibility to supervise the HP operations in Trombay as Head of the RHC section in 1987. The operational health physics activities were the backbone of the Section and many challenges were met. Dr. Ganguly used to remind me that these were more like earning our "bread" from the profession and the R&D is like "cheese on the bread" and should not be ignored. My earlier experience in operational health physics was an asset in meeting the challenges.

2.5.6 My tryst with fission product research

By and by Dr. Ganguly indicated his intention to shift me from the routine health physics work to R&D work to concentrate on securing a research degree. He said he is giving a replacement and selected Krishnamony from III batch of Training School and posted him in Apsara in September 1960. He was my class mate back in College in Trivandrum. After a few months of his getting familiarized with the work and informally asking me about his progress, AKG told me to leave Apsara and occupy Gopinath's corner in Electronics shed and asked me to carry out my fission product work from there. Gopinath's group was a loosely knit group of around 8 persons each doing an assignment of his own under Dr. Ganguly.

The group consisted of Gopinath, Santhanam, L V Krishnan, T N Krishnamoorthy, Kotewale, Sunta and Nambi. Kotewale had left to join TIFR. Hari Sigh joined in 1962 and later Mrs. Damle joined the group and were doing cyclic activity build up calculations with Gopinath. Hari Singh also was working out theoretically n, 2n cross sections important for calculating transuranic build up in a reactor. He also made a huge nuclear chart to show all possible modes of formation of transuranic nuclides as suggested by Dr. Ganguly. Mrs. Damle and myself tried using the TIFRAC computer which was a machine indigenously hooked up by the TIFR computer group of Prof. Narasimhan in 1957-58 for my fission product activity calculations. The I/O device was paper tapes and it was laborious to input the data in bits and I found I can do it faster with my Friden calculator! However that was my first tryst with computer programming. Kalyanasundaram then gravitated toward procuring Monte Carlo computer codes and commissioning it for the CDC computer first and then the BESM computer in BARC. This made up of Dr. Ganguly's R&D group. To this group I was attached like an electron in outside shell doing my fission product research and "later entered the nucleus" doing fission physics research directly under Doctor.

In order to have an up-to-date data on fission products I went on a literature hunt in the library to collect all possible information on fission product decay energy data by laboriously going through all nuclear data sheets and prepared an up to date compilation on Fission product nuclear data after a few months of intense work. I included all these to upgrade my fission product activity calculations and even produced the gamma energy release data in several energy groups which were optimally chosen to suit dose/shielding computations. I was feeling that fission product activity calculations have come to a stage to complete my MSc thesis. But AKG said no. He said that the gap in the results

at short times of decay is glaring and the fission product decay data at short times is incomplete since we have not taken into account short lived fission products for which no nuclear data was available. Then I came across a paper on fission products decay by Perkins and King and got an idea to adopt their methodology to predict the energy and decay data of short lived fission products in the beginning of each decay chain. I carried out a detailed study of beta decay theory and used the empirical relationship between half-life and decay energy and used this to improve the individual fission product decay data. When these few dozen of nuclides were included the results dramatically improved but again fell short of the scanty experimental data available on gross fission product decay. I even fitted the gross decay curve of the summation of activity calculated from individual fps, and derived a 3 component exponential function and allotted half-lives for these hypothetical components. Gopinath used to tease me that these are iyerium, gangulium, etc. I thought the thesis could be completed with this. But Doctor was not still happy!

In between I had also carried out a computational work as suggested by Soman on the gross Maximum Permissible Concentration of fission product mixtures as a function of decay time using my fp activity data and the ICRP data on MPC of radionuclides in air and water adopting the laws of mixtures. In this I took the support of TN Krishnamoorthy and we together presented a paper for the Health physics society meeting in Los Angeles. Much later in 1973 I extended this work to compare the radio toxicities of fission products from U 235, Pu 239, and U 233 and showed that the toxicity is less for the U 233 fuel cycle than for U 235 cycle.

2.5.7 Fission product at short times - experimental investigations

Once while reviewing the work Doctor suddenly looked at me and said that in order to fill in the gap why not do some experiments. I was rather stupefied and wondered how I am going to carry out experiments. But he prodded me on and on. Earlier Dr. Ganguly was impressed with the computational work but told that the work is good but we need to do something more substantial by experimentally augmenting the data going down to short times after fission. Following mention of experiments in literature, I started planning to do experiments with circulating uranium solution exposing to neutrons at a beam hole in Apsara and using a NaI detector. I had purchased a pump from the market from own money! The sample being natural uranium and the beam hole mouth providing a low flux of E7 neutrons, the experiment was not a success. Dr. Ganguly then suggested to me to set up a pneumatic sample transfer assembly to attack the problem. I tried and set up a miniature pneumatic transfer system consisting of an evacuated large flask connected

through a valve to a glass tube of around 50 cm kept horizontal to the neutron beam through a valve. The beam hole itself was a tangential one to the reactor core in Apsara and provided relatively low gamma background to enable me to locate the NaI detector at the counting end of this tube. Using tin foils at the end of the tube to get an electrical signal to start a scalar counting pulses from a single channel analyzer when the U sample reach the detector. The timings were measured by another scalar counting the output from a pulse generator. Times of transfer of 10 msec could be achieved. A sample of about 100 mgm of highly enriched uranium which Dr. Ganguly arranged for me was used for the experiment. It was contained in a double Perspex capsule which shuttled in the tube.

After a thorough literature search when I produced proof that no experimental data existed on fission product decay at times less than a second, Doctor insisted that I should fill in that gap. I also found that about 20 per cent of the prompt fission gammas are emitted from fission products within one second. He pointed out to me that in criticality accidents this would be substantial. He was indeed excited. He made visits to Apsara beam hole where I had set up the experiment. He told that we need a fast recorder to collect the data. And looked around and found such a complex equipment was with the Reactor Control Division to measure the control rod drop speed. But who would loan such costly equipment to a junior fellow like me! So on remembering the AKG mantra "tell me one reason you can do it and not 99 reasons you can't do it" which spurred me to think of that one reason, I tried to record the counts using a set of relays to switch the SCA output for different times to a couple of scalers but could not achieve times of decay of less than 6s.

One day Doctor looking at me asked why can't we record the Dekatron scalars counting in decades using a movie camera. Then he suggested he will contact films division of GOI and arrange for a cameraman to take movie photos of the counting scalars at 16 frames a second! The films can be read to note the reading at each 1/16th of a second. One day after arranging and checking the pneumatic system several times, as per plan I proceed to the films division studio in Pedder Road and approached the cameraman Mr. Singh that I am ready to take him to Trombay for the recording. He had earlier seen the location and secured the required permission. I must point out I was a loner in all these efforts. I was about to hire a taxi to take the cameraman along with his paraphernalia but it started raining heavily and already past noon. He expressed his apprehension about the whole attempt saying that it will be late night before he gets back! I was mumbling myself that is my daily routine anyway! I told him the efforts I have to make and prepare for this and ensure

that the reactor is operating, etc. He finally softened and consented looking at my plight and I called for taxi for which I paid and we proceeded to Trombay.

After a few anxious moments I shot the target irradiated for 10 sec and called out to the cameraman to shoot pictures! And kept my fingers crossed! The Scalars started clicking on counting the output from the detector and SCA and another one below it counting 1000 Hz pulses from a pulse generator to provide the time scale. We made several runs with singe channel analyzer set to various energy windows. Dr. Ganguly had told me not to lose the chance to record gamma spectral data as well. And finally it was accomplished. The camera man produced three reels of films of scalars quite different from his routine assignments and wondering about the crazy exercise. Now came daunting job of taking down the readings. I was faced with the formidable task of projecting each frame and taking down the reading 16 frames a second each set for 100 seconds and about a dozen shots for gross gamma and for gammas in 7 energy groups. But the thought of producing fission product data for the first time under one second drove me to undertake this tiring job for a month or so all alone. I informed Doctor and he was impressed and even spared time to look at the projection once. He complimented my perseverance.

I evaluated the data and produced after some analytical treatment the decay curve for gross gamma activity from 10 msec to 100 sec. The gap in information was completed dramatically! But then Dr. Ganguly was still not happy. He asked me why not analyze the data on the fission product gamma spectrum at these short times and submit the thesis directly for PhD which was possible under Bombay University rules. He said he was convinced that I will be able to do it! For me it was the almost the last straw on the camel's back. I tried to work out the gamma spectrum from the data collected in 7 energy groups. This posed formidable problems in convoluting the gamma spectrum from the observed spectra from the NaI detector after generating the response function for the detector. I thought over the matter for a few weeks and spent some sleepless nights! I wanted somehow to convince Doctor to agree to my finishing the MSc thesis first and then look for further work on gamma spectra, since a bird in hand is worth twice in the bush and all my 3 colleagues had by then submitted their thesis or on the verge of submitting it! After several weeks of meetings, he finally agreed for completing the M Sc thesis and then he said I should proceed to do PhD in a US University. I spent several sleepless nights in organizing write up of the thesis on my calculations and experiments. Though the thesis provided very useful data, Dr. Ganguly was looking for something more fundamental and epoch making! He had already realized from my extensive literature search

that what we had with us were unique results since this was the first data available anywhere in the world on the fission product decay characteristics at decay times lower than 1 second down to about 10 milliseconds. After several sittings and close scrutiny he finalized my thesis and asked me how I am going to get it typed. When I told him that I planned to do it myself he was stupefied and shouted at me, don't spoil the excellent work by shabbily typing it myself. I informed him I am also a qualified typist having passed type writing exam with distinction in my school days and am confident of doing it. However he was skeptic! I borrowed a portable type writer from Santhanam who had procured it during his deputation to ANL and started typing the draft. Incidentally Santhanam has during his deputation worked on fission product activity calculations which was on the same line as I did but his stress was for reactor safety analysis.

At last the final typed copies were prepared along with graphs on tracing paper drawings by the draughtsman from which ammonia prints were taken. Dr. Ganguly was not quite keen to include the MPC calculations for FP mixtures but wanted the thesis to be concentrating on the unique contribution. But finally allowed me to include it in a separate chapter. The content of the thesis was brought out as an AEET report and the elaborate compilation of nuclear data I had prepared was brought out as another report which was referred to in the thesis. Finally when it was done he used to remark to many in my presence that this boy not only did the work for the thesis but typed it neatly in the final form. I did not tell him the sleepless nights I have spent at home typing, correcting and compiling it with the help of my wife!

2.5.8 Fission product decay at short times – Geneva conference paper

Dr. Ganguly after several sessions was impressed and told me that we have arrived a stage when we have to announce the data and he planned to present it in III Geneva conference 1964. At this proposal I was rather getting embarrassed and nervous and said that the experiment was a crude one and wondered if it is worth presenting at an august assembly. But Dr. Ganguly insisted that he is convinced about the importance of the result and this need to be announced to the world. Finally after several iterations and days of hard work it was finally cast into the form of a paper just in time for submitting for presentation at the III Geneva Conference. There were three papers co-authored by Dr. Ganguly and his students and mine was one of them. In all there were a dozen papers from AEET. Once Dr. Bhabha had called for Geneva conference authors to his chamber in OYC building. I got intimation from Soman since Doctor was out of station. Both of us waited outside his chamber nervously with others venturing inside. We were told

that Dr. Bhabha had exhorted the authors to prepare posters of their results so that it can be exhibited in the Indian pavilion at the Geneva conference. Dr. Ganguly attended the conference and presented the results. And so my thesis was completed in 1964 and the land mark paper was presented at the Geneva Conference by Dr. Ganguly,

2.5.9 Application of the fission product studies.

We had noticed from my work that the fission product gamma spectrum qualitatively indicated hard gammas at short times after fission. So we thought of using it for measuring enrichment in uranium samples. The irradiation time selected was 20 seconds and counting gamma pulses for 20 seconds following a standard 1 second delay. The counts in the set timing were recorded in a scalar after gating though a SCA selecting pulses above 2 MeV. Dr. Ganguly had by this time inducted P P Chakraborty into these activities and directed him to set up a more rugged pneumatic transfer assembly in CIRUS reactor. This was in progress. The Apsara tangential beam hole with relatively low gamma background was also equipped with a revamped pneumatic set up and was used for establishing the application of enrichment analysis. Fortuitously when this was ready and we were looking for applications, the Trombay Advisory Committee discussed the immediate requirement of analyzing U235 content in a large number of reprocessed depleted uranium samples which was necessary for fabrication as fuel pins for initial loading in RAPS reactor core for flux flattening. Dr. Ganguly used this opportunity to announce our method and volunteered to carry out this. Some other divisions like radiochemistry also volunteered.

So we standardized further the quick activation method to analyze uranium enrichment in samples and established 2 per cent precision and with few mg of the sample we could provide the result. The method itself was non-destructive and repeated analysis on the same sample could be carried out. K K Sinha of AFD was fabricating the depleted reprocessed uranium pellets in NFC for the first loading in RAPS reactor and needed the enrichment results. He had a stint of training in US and had procured a few low enriched uranium samples and gave us a few gm of these standards. We used these standards along with one sample of 93 per cent enrichment we had and constructed a calibration curve for assessing enrichment using our method. The high energy gammas enabled the signal to be more specific to U 235 fission products and also reduced the stray scattered backgrounds in the detector.

Dr. Ganguly spent lots of time personally at the set up at Apsara with me and Chakraborty to ensure and evaluate the method and still more time in his

office closely analyzing the results. Dr. Ganguly had asked PP Chakraborty to associate with me in this work. Soman was also impressed and provided support in carrying out this work.

Finally Dr. Ganguly scrutinized the results from more than 89 samples and reported to TAC. Needless to say no one else could come anywhere near in meeting the target. Doctor had good faith in us that he declared that these results can be used. But TAC insisted on cross checking the results by sending a few samples for mass spectrometric analysts in France as there was no facility available in Trombay in those days. A few samples were sent and the results from France showed a couple of discrepancies. Dr. Ganguly called for me and Chakraborty and almost after a week of close scrutiny of the results, he intuitively interchanged the sample numbers in the French results and all French measurements agreed with ours. In order to confirm few samples were again measured for enrichment in our set up. Now he was fully convinced that our results were right. Armed with this he announced in TAC that his boys were right and French results were mixed up and asked TAC to send the samples again with jumbled numbers amidst some derisive murmurs! And the feedback from France proved Dr. Ganguly right. Such was the confidence he had with his students. Sinha who later divulged to me the transactions in TAC and told me about the abundance of confidence AKG had with me and seem to have mentioned my name! So after all, my work led to some positive contribution to the Centre's activity.

2.5.10 Pursuing experimental studies on fission product beta decay at still shorter times

Dr. Ganguly was never satisfied with the work of his students and was always impatient to spur them to further work and greater heights. He was a teacher and guide par excellence. He was always dreaming of carrying out the fp experiments using a time analyzer and simultaneous pulse height analysis. He was spurring me to beg borrow or steal or even construct the electronics units to meet this objective. The period soon after getting my M Sc degree was spent in further pursuing the dream of electronically recording the decay rate and spectra of fission products at short times of decay. In parallel Dr. Ganguly encouraged me to start looking into securing admission for doing PhD in some US university and he even got my special leave sanctioned which meant I will receive the salary India when I pursue my doctorate in USA. Collecting information on Universities was a far cry from what is today and I had to spend many long days collecting this information and noting down at the University Centre. Although he helped me to secure admission in a couple of universities the proposal could not be carried forward due to personal reasons.

Dr. Ganguly was not very happy but consoled me that I can register for PhD under him and then go for post-doctoral research.

Meanwhile I was making progress in my fission product work and planned to fabricate a 10 channel multiscaler to carry out more sophisticated fission product decay measurements down to 1 millisecond. I approached Raghupathy who had joined AEET along with me and had fabricated a MCA for fallout measurement studies in Air monitoring Division. The air monitoring program owes its achievements due to his pioneering work in the aftermath of Chinese explosion and its success was solely due to the instrumentation support of Raghupathy. To start with I did not know even fundamentals of electronics. But decided to meet the challenge and took lessons from Raghupathy and referred to some text books. He made a circuit diagram using valve gates for a 10 channel multi scalar. He explained the operation and scribbled a list of components and taught me how to solder without dry solder. He was absorbed in his own work and obviously did not have time to wire the circuit. But then the vision of Doctor appeared before me and made me to plunge into it.

There was no time or funds for me to order those components for making a modest 10 channel time analyzer. Raghupathy told me that there is a huge dustbin in Electronics Production division in the Electronics shed into which the discarded valves and other components were collected. I spent some time collecting the components required for fabricating the time analyzer reminding me of rag pickers at street corners! I procured a soldering iron and secured a corner of an electronics work table adjacent to my table and started wiring the unit. Gradually I usurped the whole table. Raghupathy raised the question of recording the counts in different channels. I suggested the crude method of stacking 10 decade scalars (valve units) for this purpose. Again begged and borrowed 10 scalar units and stacked them on the working table to an impressive height of 5 feet. Raghupathy helped me in commissioning the unit. It was a matter of great achievement when the scalars ticking and started recording the counts in pre-set time slots of 1 msec onward from the test input from a pulse generator. I brought Doctor and demonstrated to him as a child would show his toy to his father! He was impressed and told me that you are in business! Then we were looking for innovating an experiment to record fission product decay down to a millisecond. From the theory of beta decay process I realized the lower limit of beta decay half-life would be in the range of a few milliseconds. Dr. Ganguly suggested to me that I should construct a slow neutron chopper using boron or cadmium at the Apsara beam hole and carry out experiments using the new time analyzer. This was an innovative idea and I fabricated a neutron chopper using a slow motor

of 4 RPM. The 50 cm dia boron plastic disc which produced no secondary gamma radiation was used in preference to cadmium. It had a slot of 5 cm at the circumference which allowed the neutron beam to fall on the sample cyclically. I had observed Nataraja Sarma setting up a conventional neutron fast chopper for neutron spectra studies in earlier days at Apsara. The target consisted of a doubly encapsulated plutonium sample contained in a plastic sleeve to allow betas to penetrate and vertically mounted on a plastic sample holder. The sample viewed the beam and the heavily shielded end window GM detector at right angles. I used this set up in Apsara to record the fission product beta decay. The sample got irradiated for 5 seconds and the analyzer started the time analysis on receiving a pulse signal from a photo diode. After recording the counts in 10 pre-set time channels it allowed the sample to decay for the rest of the rotation for more than 10 times the irradiation time. The cycle was repeated several times to collect the data. The data collected over several cycles provided the fission product decay down to a millisecond. Doctor was very happy with this system through which I implemented his dream. He visited the set up at the Apsara beam hole and was excited about it and gave many suggestions. This set up was much more refined than our recording the movie photo of the scalars using the pneumatic sample transfer assembly and allowed any number of repetitions and the measurements were precise. It was an exercise in innovation and both I and Doctor were excited about its success. Dr. Ganguly suggested carrying out a feather analysis using aluminum absorbers to get an idea of the beta spectrum as well. The fission product beta decay at short times down to a millisecond was published in J Nul Energy 1970. It also established the lower limit of half-life for beta decay as about 2 milliseconds.

I occupied Gopinath's corner and later on with him in a hall in mod labs. Eventually with Gopinath and L V Krishnan shifting to Kalpakkam, Santhanam moving to Delhi, I started gradually consolidating the instrumentation group. Gopinath suggested to Doctor to shift me to Kalpakkam along with him. But he retorted back "you take everybody and what do I do here!" And so I remained in the Mod lab room pursuing my fission studies. Dr. Ganguly had recruited an electronic person Choithramani to help me in the experiments. Choithramani fabricated a modified 10 channel multiscaler with incorporated scaler. I enthused him to register for MSc with Dr. Ganguly and guided him for a thesis on the instrumentation for fission product experiments. Since Choithramani was also asked to look after the photographic lab the equipment for which were received under the Project Marina and in order to help him another assistant Raman was later recruited. He also was enthused to do

research and earn an MSc degree on U 233 and U 232 build-up calculations augmented by some gamma spectrometric experiments. Gradually I was gravitating toward an R&D group of my own.

On the suggestion of Soman a scanner for differentiating pellets with three different uranium enrichments handled in NFC for production of fuel pellets for TAPS reactor was made using 185 keV gammas and was in use there for some time. Another useful result was the setting up a fission neutron irradiation facility in CIRUS by Chakraborty on Soman's suggestion. This was a modified pneumatic sample transfers system with a concentric aluminum cylinder packed with Uranium oxide surrounding the irradiation position. This enabled soil samples to be irradiated in an approximately Fission Neutron spectrum and found use in studying activation of soil for PNE

2.5.11 Fission Physics studies

Dr. Ganguly had already enthused me to start theoretical work on fission which was his obsession. To start with he had given me an exercise to calculate the neutron evaporation spectrum using its excitation energy for each fission fragment modified with its kinetic energy and weighing with its yield to arrive at the gross fission neutron spectrum. This work when completed he decided to get it published in the German journal Nukelonik in 1966. He seems to have passed on a copy of the paper to Dr. Ramanna who after glancing through it suggested that I meet SS Kapoor who was pursuing fission studies under him and explain the work. I had a long session with Kapoor and on his instance showed how the expressions were derived. After questioning me he found the method OK but felt that it was perhaps only a good exercise.

Gradually Dr. Ganguly introduced me to the Order-Disorder phenomenon in alloys and asked me to study the book Theoretical chemistry by Glasstone which became my constant companion since then. Doctor would ask me to take a particular page in the book, quote a formula from memory! This fit in with the description of his photographic memory mentioned by Jagdish Shankar in his INSA memoires. Dr. Ganguly used to give me erudite lectures on the salient points in theoretical chemistry from his tryst with radiation chemistry in Notre Dame and from relevant portions from Prof. Chandrasekhar's "Random Processes". Often I used to feel I am almost there! He drew parallel of fissioning nucleus with chemical systems and how the nucleons get disordered with the excitation energy in U-235 nucleus after absorbing a neutron and get structured into two nuclei soon after. As it evolved the model essentially based on the fact that in the fissioning nucleus there is an earlier polarization of protons. We proposed that as a consequence of this

the protons gradually re arrange itself into two halves along with a certain number of neutrons. We surmised that this must be naturally based on the energetically most stable configuration of neutrons for each of these halves. Working at it we arrived at a certain number of "balance" neutrons which are left and these get shuffled in the second stage of the fission process finally forming the two fragments. One of the notable features of this model was that these balance neutrons had a strong correlation with the fission fragment yields and had higher number of neutrons for symmetric fission with low yields and lower number of neutrons for asymmetric modes with higher yields. This significant correlation came intrinsically, only by using the systematics in of stability of nuclides from the chart of nuclides. And did not involve any per-se assumption of magic numbers as most of the models were based on. Dr. Ganguly then applied the similarity of the fissioning system with the binary alloy systems and applied the Order-disorder model (ODM) to arrive at the fission yields. This model showed that the nuclear charge of the fissioning parts is more fundamental and basic in fission than the mass of the fragments on which most measurements were based. Nobody had perhaps appreciated this, since in radiochemical experiments of fission product yields the mass is an easier parameter to follow due to the nature of fission product beta decay chains. Even fission fragment experiments used the mass parameter. Perhaps we were the first to present fission parameters like yields as a function of the atomic number of the fragments.

At that time the new CDC computer in TIFR was in operation and I started carrying out programming the elaborate calculations based on our ODM model using that computer. Gopinath was there programming his ASFIT code along with Santhanam and K Venkataraman was doing statistical analysis on Indian standards man data. Kalyanasundaram was busy adopting neutron transport and shielding codes for the CDC computer. Lots of other people from BARC, PPED and SINP were using the computer for which we had to write the program in FORTRAN, get it punched in cards and submit for running and we used to get only 2 or 3 outputs per day. And we had to invariably try to debug it. Mutual discussions with the other users in the User Room were very helpful. I wrote two programs named ODM and FISHY in FORTRAN for calculating mass and charge distribution in fission based on our ODM model. Another program was structured on calculating the various parameters such as fission fragment kinetic energy distribution, charge distribution parameters based on the ODM model. These were fairly large programs which I wrote from the scratch and when the results started coming and compared well with experimental data, Dr. Ganguly was impressed. Often I used to be away in

TIFR to pursue these programming exercises and doctor once even personally came to my residence to inquire about the progress.

It was at this time Dr. Ganguly had a setback in his eyesight and almost lost sight due to retinal detachment after a cataract operation. His eye sight was initially weak with myopia and power of double digits. He had to be hospitalized in BARC hospital wing in JJ Hospital and was advised complete rest with eyes blind folded when avenues were being explored by Director Sethna to send him to UK for laser treatment. I used to avoid visiting him lest it may be construed as disturbing him. Once he repeatedly sent word for me to see him with the results of the ODM program. He was anxious to see if the model could intrinsically reproduce the double humped curve of fission yield. I took the final graph and informed him the success we had. He insisted on seeing the results! I was wondering how to make him happy with the results as he was blind folded. He quietly asked me to sit on his bed and keep the graph on it and asked me to hold his index finger in my hand and slowly trace the graph several times. When he sensed that the results had reproduced the double hump he was excited and told "Ramakrishna, you have arrived at the results. I am eager to see it but unable to do so". He said he will comeback after treatment and see the result physically. I did not know how to react but certainly cried within myself. Look at the man and his scientific interest even when he was doubtful if he will gain his sight back! I shall never forget this scene which instilled in me the urge to proceed even in the face of strong obstacles. His strong will can be easily seen when he quit chain smoking almost overnight on doctor's advice when he had this setback in eyesight. He was excited with the success of explaining asymmetry in fission using a novel approach though he had to wait for a few months before he could get back to see the results for himself. This perhaps would have given him many uncomfortable moments during his surgical treatment in UK.

Meanwhile the work on the two computer codes were making progress and re produced a whole host of fission data which agreed well with the experimental observations. We had on request secured the original experimental data on fission fragment kinetic energy measurements from Dr. Schmidt along with the radio chemical yield measurement data from Prof. Wahl for comparative studies. It also reproduced the radiochemical charge distribution parameters such as width and peak of the Gaussian distributions and its variation with mass of the fission product, kinetic energy of the fragment, and odd even effects and various other parameters. One of the significant results we got was that the model reproduced the experimental observation of bunching of heavy mass fission products yield curves with the lower peaks getting staggered to

account for the mass and charge of the fissioning nucleus. The model could predict these for a host of fissioning nuclei including hypothetical ones. The disappearance of the asymmetry with increasing mass of the fissioning nucleus was another feature which intrinsically arose from the model. To this day I am convinced that the ODM model has some basic foundation with nuclear theory which has not been pursued enough further!

On Dr. Ganguly's suggestion I prepared the draft of a paper containing the results and he personally corrected the draft several times. He suddenly announced that we will send it for publication in the Physical Review at least for getting constructive remarks on the model. The first paper when submitted to Physical Review was returned as rejected. This was expected since we belonged to a school which was not known to the outside world as a recognized school of fission. But we replied to the editor that the referee seems to have been casual in his remarks. We sent a strong rejoinder with our remarks contesting on a word by word basis quoting extensively the literature to show why we were constrained to disagree with the referee and suggested a second reference. It was finally accepted for publication in 1971. The second paper which worked out a host of parameters on fission was also subsequently accepted.

Armed with these two papers and the paper on short lived fission product decay experiment using the neuron chopper, the preparation of the thesis for my PhD was somewhat easy. One of the international stalwarts on nuclear fission charge distribution Prof. A C Pappas, who had worked in the Manhattan project, evaluated my thesis for PhD degree in 1971.

Dr. Ganguly tried to strengthen the activities in fission physics by recruiting a top ranker D N Sharma from the BARC Training school in 1971. He did his MSc on the continuation of the fission charge problem by extending it to 14 Mev fission by incorporating an addition nuclear temperature term. Chakraborty also pursued his PhD degree working on the ODM, model and also included experiential work on fine structure differences in the gamma spectra of fission products from Pu239 U 233 and U 235. These results formed the subject of a paper which was sent for presentation at the III IAEA Safeguards symposium in Vienna in 1975. Thus a change in our path was already in the offing. Gradually the work started as a solo effort was now getting evolved as a team or a group.

2.5.12 Safeguards methods work

Dr. Ganguly showed his interest to develop a model for nuclear forces based on a gluon binding model. He suggested that being short range forces this could provide a clue. In fact I had started working on this by building models

using glass beads and mathematically solving the optimum contacts. But with my deputation to Karlsruhe to work in the safeguard project these activities took a turn. Some perhaps even thought doing fission/nuclear physics in HPD may be to their determent and did not pursue the topic with vigor. Dr. Ganguly's efforts to secure me a post doc position in fission physics in University of California LA was successful but was not supported by the Physics Group. Another attempt to apply for a Van Humboldt fellowship also met with resistance from the Centre. Doctor was somewhat disillusioned but he was a person who will never say die. He explored other avenues for me determinedly and secured a deputation with the Safeguards division of the KFK center in Germany which was then headed by Dr. Dipak Gupta who was earlier heading the heavy water division of BARC and was a friend of Dr. Ganguly. I was also frustrated with changing my topic of research having toiled for 15 years with success and lots of self-satisfaction in spite of resistances. But the fatherly figure of Doctor consoled me saying that research does not have boundaries and one should look for new avenues. That was a great lesson for me which stood in good stead later in my career when I had to shift gears which lead to success!

Further, some work connected with nuclear safeguards was allotted to Dr. Ganguly in BARC. Once IAEA was interested in inducting BARC to carry out a comprehensive project on nuclear fuel cycle and isotopic correlation and Dr. Ganguly was designated to evaluate the proposal. A large delegation from IAEA came down to BARC with these proposals and the discussion and evaluation on this was carried out by Dr. Ganguly along with Srinivasan of PP and others. BARC was not keen on this project since it would mean giving some data or other which might give an indication of the work being carried out in the center. Dr. Ganguly handled the matter very deftly by diplomatically raising many scientific points such as the isotopic correlation would be pointless unless they start a project to the effect of varying enrichment from uranium of different sources. Finally the efforts of the IAEA team could not find foothold on the project with BARC. In this process Dr. Ganguly had come into contact with the safeguards activities of the KFK center under Deepak Gupta. As a spin off I also got associated in evaluation of fuel performance work by isotopic correlation initiated by Radiochemistry division.

2.5.13 Development of Pu waste monitor under Indo German collaboration program

Meanwhile I and Chakraborty were carrying out experiments to compare the fission products gamma spectrum from U 235, Pu 239 and U 233 at short times of decay using the pneumatic sample transfer facility. We noticed

that for the same counting geometry and similar quantity of material fine structure differences in the spectra in spite of the poor resolution of the NaI detector used. We used this to arrive at the Pu to U ratio in samples which we thought might be useful in the planned fast rector program of DAE. Taking ratio of the counts in various spectral regions we successfully correlated it to Pu to U ratio and a paper was sent for presentation at the Safeguards symposium of the IAEA in 1975. Dr. Ganguly enabled my participation in this conference for presenting this paper. Making use of this opportunity he proposed to Dr. Deepak Gupta who was heading the Project Safeguards in Kernforschungszentrum Karlsruhe, Germany to arrange for me a deputation to work on safeguard methodologies with Dr. Ottmar and his group at the Institut fur Kernphysik at KFK under the Indo German collaboration program. Thus started a new chapter in my activities under the guidance of Dr. Ganguly. I met the KFK group in Vienna during the conference and my tryst with safeguards began. I was wondering how this all is going to fit in my existence in the health physics division as Dr. Ganguly was due to retire in a couple of years.

In KFK I was given the problem to develop a Pu waste monitor which was urgently required for analyzing Pu in large number accumulated radioactive waste packets. I along with Ottmar and Mattussek set up a waste monitor using a large NaI detector and a MCA. The energy gates were optimized to increase the contribution for the 430 keV gamma rays from Pu 239 after subtracting the Compton continuum and was calibrated using waste bags containing known amount of Pu. In order to reduce the inhomogeneity of the material inside the bag the sample was rotated during counting. The counting time was optimized for the required sensitivity at 10 minutes.

On discussion with Dr. Ottmar and his group and after approval from Deepak Gupta I indicated that BARC would be interested to set up a similar system under the Indo German collaboration program. The proposal was put up by Dr. Gupta to Dr. Scharmer who was the coordinator of Indo German programs for approval. The project was then mooted to BARC by Scharmer and on my recommendations through Dr. Ganguly it was accepted. The program so started led to much useful collaboration and was the genesis of many new activities launched in the Health Physics Division, BARC. It also resulted in the successful installation of the Pu waste monitor in BARC consisting of a 1K MCA, a 3" NaI detector and the necessary electronics units. The equipment was gifted to BARC under the safeguards collaboration project. Dr. Ottmar visited BARC for the handing over of the Pu Waste Monitor. Ottmar proposed further development of the waste monitor under the joint

program to incorporate a self-attenuation correction using multiple energy windows from the Pu spectrum. As a further innovation Matussek offered to use the then recently introduced microprocessor technology to incorporate the method to arrive at a microprocessor based Pu Waste Monitor directly displaying the Pu content.

Since this involved instrumentation development, I prevailed upon Dr. Ganguly to depute Choithramani to KFK Karlsruhe to work on this and in the process to get him trained in use of microprocessors. I had also in mind a plan to secure the technical details of the shift register technique of differentiating fission neutrons from random (a, n) neutrons by following the life time of the pulses in the moderator electronically to estimate Pu content in various types of samples. This method was an invention by Dr. Bohnnel in the Institut of Neutron Physics in KFK Karlsruhe and I had discussed with him the details during my stay in Karlsruhe. I thought this would be useful to estimate of Pu in wastes mixed with fission products and for the MOX fuel development program for fast reactors. I had requested Ottmar to get Choithramani briefed in the electronics required for this method. On his return I initiated work on this and along with Choithramani and Ravetkar whom Somasundaram recommended, developed Shift register unit to measure Pu content by identifying fission neutrons and thereby estimating the Pu 240 content in all type of samples. The unit worked admirably and was offered for use in Radio metallurgy Division.

During my first term in KFK I found that Ottmar and Mattussek were working on precision measurement of Pu isotopic composition using high resolution gamma spectrometry. I evinced keen interest in the work and secured several gamma spectra which they had taken and analyzed them using a computer. I indicated to them that if a deputation later could be arranged for me I would like to participate in this program. Dr. Dipak Gupta agreed to this and I was deputed to KFK again in 1978. During this period PP Chakraborty from my group was also deputed to Karlsruhe to work on these problems. The work on the measurement of isotopic composition was presented as a joint paper at the IAEA safeguards symposium in 1978 in which I along with Chakraborty attended.

Making use of my presence in Germany Dr. Ganguly wanted me again to pursue work on short lived fission products in KFA Juelich and made an opening for me to work on ultra-short lived fission product gamma spectrometry. Dr. Sistemich at KFA Juelich had developed an on line magnetic fission fragment mass separator and carrying out high resolution gamma

spectrometry. I had already come across the pioneering work of Sistemich and his mentor Armbruster in Darmstadt during our own work on short lived fission products.

At the end of my deputation to Karlsruhe I proceeded to Juelich to work with Sistemich analyzing the large number of gamma spectra acquired event by event directly from the ADC on magnetic tapes from fission fragments within a few microseconds. My plan for carrying out further work on the mass separator could not be realized since the reactor was under long term maintenance. Working with Sistemich I had an opportunity to use gamma spectrometric analysis programs such as SAMPO. I also secured an intrinsic Germanium detector for our use in BARC under this program. Thus assimilation of technology and equipment resulted from this very useful program.

Dr. Ganguly along with his designated successor Dr. Kharkanavala visited KFA Juelich in 1978 in connection with another Indo German program on measurement of trace elements in which Dr. Pande and Dr. R K Iyer participated. I had an opportunity of briefing my work with short-lived fission products to Dr. Ganguly. I even mentioned to him the scope for setting up such an online fission fragment separator in BARC. He gave only an enigmatic smile. Time was running short for Dr. Ganguly. My distant dream of setting up a mass separator for fission fragment gamma spectrometric study in BARC remained unfulfilled. Dr. Ganguly had retired from service soon after and his patronage was no longer available! So was my dream of at least working on that in Germany with Sistemich under a van Humboldt fellowship!

By the time I returned Dr. Ganguly had already retired in 1978 and I missed the farewell function organized by his students and colleagues. Dr. Patel brought out 6 volumes of the papers of Dr. Ganguly. I had borrowed these from his son Biswajit Ganguly to extract information for this compendium. The list of papers in these volumes are given in Annexure.

Back from my deputation, I had proposed to continue work on the Indo German collaboration program on safeguards and along with Ottmar proposed an intrinsic matrix attenuation correction technique in waste monitors and to incorporate it in microprocessors. I somehow managed to convince Soman who had become Associate director of the Health and Safety Group. He took me with him for a meeting with Director Dr. P K Iyengar for getting approval for the proposal and a new lease was given for the collaboration. The computerized waste monitor employing a quad single channel analyzer incorporated the data processing using an Intel processor chip was also developed under the program

and later Mr. Matussek visited and installed it in BARC. This was later used in Pu plant and in RMD. This was how the microprocessor technology for various applications in HPD started.

A low energy photon Germanium detector LEPS was also received by BARC under this program. This detector was widely used in various investigations and methods were developed for precise estimation of Pu isotopic composition. As an additional feature an Am241 ring source was also supplied which was used extensively for XRF analysis of various samples in HPD. The LEPS detector was used to evaluate the branching ratio of Pu isotopes using method developed under this program and was successful in pointing out some discrepancies in nuclear data of gamma yields from Pu isotopes and was published as a paper. It was also used to develop a method for I 129 in samples using x rays. These equipment led to several publications and theses in the group. It was also made available to a few Ph D students from Mangalore University and Andhra University to carry out decay scheme studies.

2.5.14 Microprocessor technology

My having already branched off to safeguards techniques the fission physics era came to an end. At this stage Dr. Ganguly had retired but the impact of the work he initiated continued to guide me in innovating programs in HPD. A few Intel microprocessor chips which were gifted by Ottmar and Mattussek when they visited BARC and this enabled the group to have our first tryst with microprocessors. With the training he got in KFK Choithramani fabricated an Intel 8085 chip programmer which could be programmed bit by bit. This was used extensively in developing software and incorporation in microprocessors. D N Sharma and N Raman specialized in assembly language software which was extensively used.

With the change in leadership I was given indication that the programs in the group need to be redefined with activities that will be of immediate application in HPD. And indications already emanated in sending me off to an assignment in Delhi though I decided to resist it and continued in BARC and to follow the lessons taught to me by AKG in how to face a situation and veer about obstacles.

The microprocessor technology imbibed by us in setting up a Pu waste monitor came in handy. Our aim was to further innovate more applications to survive and excel. We developed a met data processing system using microprocessors following Soman's suggestion and delivered the system thanks to the efforts of Sharma, Sharangpani, Pradeep Ganguly and Raman. Soman conceded that

this will be useful and asked us to supply it to all met labs. which were all using analogue recorders followed by tedious manual data reading and processing. The microprocessor based systems enabled fast data acquisition and analysis. But still the acceptance was far off!

Pulse heights analyzers were a rarity in those days and was the workhorse for an effective health physics program. I and my colleagues then suggested to Soman that we can solve the problem of availability of MCAs using the newly found microprocessor technology using Intel chips. For this I proposed that we make only data analysis without involving ourselves with making ADC convertors, which we found was available with an Italian manufacturer, Silena. Soman allowed us to import these ADC modules in numbers which we modified to fit into locally made ECIL Bins. And we found an outside party who will make the microprocessor module as per our design which can be mated with the ADC. An ECIL bin compatible digital oscilloscope display was designed and we got it fabricated in numbers by another outside private party and together it formed the so called HPD 4 K MCA with minimum effort in fabrications. Anybody who wanted a 4 K MCA was given a set of "indents" and they could procure all units and the group effort was only putting it together along with the software and commission it. Thus we produced around 80 of these units with minimal manpower. These were used extensively in the Health Physics program. And "we were back in business" as doctor used to remark! Eventually the news reached 7th floor and Dr. Iyengar suggested to Soman that we donate a unit to Philippines with whom they had a joint project. And before dispatch Dr. Iyengar visited our labs to see a demonstration. And this proved to have done the job of installing me and my group in the order of things in HPD.

And Mr. Soman re organized the instrument group in his H &S group with me as the group leader. During this time Kotrappa who was my senior decided to leave and proceeded to USA and launched a private venture using his innovations of Electret dosimeters which he developed in BARC and this turned out to be a successful multimillion dollar venture of using electret radon dosimeters which were accepted by EPA for the mandatory monitoring of radon in dwellings. Somasundaram was also being shifted to AERB so the choice of Head, RHCS fell on me. Somasundaram coaxed me to apply for guiding students for PhD and MSc of Mumbai University since he found that there were none to undertake this in HPD after Kotrappa left. Many of his students he transferred to me. I was soon full of my quota of 10 students for guiding for post graduate degrees from HPD and other divisions. But for Somasundaram's coaxing I would not have ventured into this. Eventually I guided around 15 students for their PhD and M Sc degrees. D N Sharma,

Krishnamachari, Choithramani, Tapas Bandyopdhyaya, Manian, Sahasrabudhe, Pradeepkumar, R K Gopalakrishnan, Sanyasi Rao, Malvankar, Srivastava, Narayani, Raman were some of them. I continued to complete many thesis even after I had proceeded to IAEA. The training Dr. Ganguly gave me in asking me to provide help for several of his students earlier enabled me to carry out this onerous task of extending the "Ganguly school".

Eventually I was elevated to the responsibility of Head, RHCs in 1987 and Somasundaram guiding me and enabling this to happen since he was being shifted to AERB. This enabled me to moving in to the very room in which Dr. Ganguly had guided the destiny of HPD for almost a decade. It was exhilarating to sit on the very same chair he used to sit. But I felt too small for the chair. The room had a unique light display to show if his is busy in meeting or someone can meet him. But that was not used by any one after he left for 7th floor in Central Complex on becoming director of the Chemical Group. Sarkar might have the same experience occupying the chair a decade later! Head of RHC Section also involved leading all the health physics operations in Trombay. All though there were some murmurs from my equals, Soman handled it deftly. Dr. Ganguly was alive at this point of time and blessed me when I visited him to inform him. Soon after in 1988 he expired and I felt bad I could not spend as much time I desired, with him in his last days due to my increased responsibilities. He was somewhat lonely after the demise of his wife a few months before, full of remorse to have neglected her during his career and not having taken her abroad even once as he divulged to me.

Following his tenets, many developmental activities were undertaken in RHC Section during this period. One was an attempt to develop a system using high resolution gamma spectrometry for on line analyses the Dhruva coolant which had problem of failed fuel. And identification of the failed fuel was posing some problems. Using the fission product ratios a methodology could be standardized to approximately determine the burn up of the fuel that had failed which, in addition to the indications from the failed fuel monitor help in identifying the fuel. The feasibility was established and presented to the operations of Dhruva. We tried to resurrect the electret research initiated by Dr. Kotrappa and started a program to develop environmental monitoring using electret dosimeters. Dosimeters and readers were developed and demonstration systems achieved. The idea was to deploy these in the field with periodic dumping of electret data using a microprocessor based reader from the local storage in the dosimeter units. But it did not go beyond the demonstration stage due to leakage problems in humid atmosphere. The utility of these activities in the health physics program found acceptance.

And I am happy the colleagues who were involved in these programs became leaders later.

I started development of a low dose recording micro-R monitor which was first tried out by replacing the GM Counter of the ECIL GM survey meter a large volume LND GM counter. This quick solution was a success and led to the design of micro-R survey meters for use in environmental monitoring in and around power stations and also for the countrywide radiation background monitoring program initiated by Nambi. The micro R survey meter was tested by mapping the radiation background in a domestic flight from Mumbai to Trivandrum and succeeded in demonstrating the variation of background due to cosmic rays and again during landing the dose rate from monazite areas. These were then got fabricated with RAM memory and provision for transfer of data to a PC.

The vehicle mounted background survey system developed later with GPS helped on many occasions in the reconnaissance of lost sources in the country. The Chernobyl accident happened in May 1986. The air monitoring division had immediately started a country wide program to follow the fallout from the accident. Innovatively they used to secure swipe samples from the commercial aircrafts which had flown in the area and measured the global fallout pattern. They had used a similar technique in detecting the fallout from the first Chinese tests in 1964. And the activities we had initiated came handy to analyze a portion of the swipe sample which I had I succeeded in getting and proceeded to analyze the sample using the high resolution detector which we had secured under the Indo germen program. I analyzed the spectra from the sample and worked out several isotopic ratios and could arrive the possible burn up of the fuel which could have given rise to the activity release. We could guess the unit which could have undergone accident before the details started emerging from the Russians. I prepared a report of the findings quickly and presented to Soman, the then Head of the HP division. I had the satisfaction of giving some useful results due to our experience under the Indo German program. I felt the absence of Dr. Ganguly in spurring me to further work in this.

2.5.15 Radiation Safety Systems

Time rolled again! After Soman became the chairman of AERB Dr. Gopinath was shifted from Kalpakkam as Director of Health and Safety Group. Once back in his original moorings Gopinath brought many changes in the structure and re organized the group separating the R&D and operational heath physics in Trombay. A new outfit named Radiation Safety Systems Division RSSD was formed which was given the responsibility of health physics surveillance

in Trombay along with R&D work in general for health physics programs of DAE. I was made head of this Division. With this objective I tried to induct more R&D programs into the working of the division involving people at the grass root level and encouraging many to earn their post graduate degrees as an incentive while working on these problems. That, I believed was the satisfying development in trying to follow the footsteps of Dr. Ganguly.

Perhaps the most important development in terms of impact value to the DAE that evolved in this area was the development of aerial gamma spectrometry for emergency preparedness. Gopinath had carried out such an exercise in Kalpakkam using a hired aircraft generally used by AMD for uranium prospecting with a large volume NaI detector developed by Srihari of AMD. I along with my colleagues embarked on a program to use the microprocessor technology to design and construct a compact gamma spectrometer with novel features of recording the spectra in short intervals of time using large volume NaI detector to meet this requirement. Krishnamachari who had done pioneering work in multichannel analyzer for the whole body counting program under Somasundaram and had developed a Scanning pulse height analyzer (SCAMPHA) was prevailed upon to join the team with the initiative of Somasundaram. Pradeep Ganguly who was an excellent hand in electronics instrumentation was also inducted into the team subsequently. Incidentally Pradeep Ganguly was the son of Dr. Ganguly. He had also done pioneering work in the whole body counting program. This consolidation of experienced personnel was solely due to the initiatives of Somasundaram. By the time we happened to have a direct recruit to this team Sarangapani who turned out be another asset to this team. This team under the immediate supervision of Dr D N Sharma designed and developed a compact multi-channel analyzer system incorporating the microprocessor technology we had imbibed from the Indo German collaboration program which can be easily fitted on to an aircraft and flown. GPS technology was inducted into the system after getting consultation from TERLS, DOS in Trivandrum. The AGS operated on a storage battery power similar to the one available in aircrafts. It had in built features to store gamma spectra in 1024 channels in pre-set short times. The ADC required was incorporated with the expertise of Krishnamachari into the system. It had sufficient RAM memory to store spectra during a 3 hour flight every 3-5 minutes. And also an in built display to visually examine the spectra on board. The AGS system was mounted in a rack provided with shock absorbers to absorb any shocks expected during a flight. On a suggestion from Soman I used a condemned old jeep with no spring to test this equipment in rough roads around. We thought once the instrument stood this ride it will stand the ride in an aircraft. The instrument was first mounted in the hired aircraft first

over the RAPS reactor site and I along with Krishnamachari was in the aircraft flying at 400 feet tree top height, a nervous experience. The instrument worked admirably and even recorded some waste dumps on the ground. D N Sharma provided the overall guidance for the design and provided the system software support. I coordinated and allotted the job of development of software for on line data processing of the gamma spectra to convert it to Bq per m2 on the ground and display of the results superimposed over a terrain map to Abani, Suri and his group. The development was highly satisfying team effort with utmost sophistication and it was one of the key achievements of the division. The system was flown over RAPS from Jodhpur as base on the hired aircraft which AMD used for their uranium prospecting. I along with Krishnamachari was in the aircraft with some un-nerving experience of treetop flying. The flight path in a grid was chalked out earlier after discussion with the pilot so as to optimize coverage of the area. The maps of the terrain required were procured from the GSI. Later the system was flown in a defense helicopter from the Hendon airbase in Delhi. I did not realize the procedural complexities in arranging the helicopter until we finished it and the payment issues persisted with DOD and DAE for a long time.

Detailed in situ calibration experiment to convert the counts to activity concentration on the ground in collaboration with Defense Laboratory Jodhpur, with a large number of discrete iridium sources deployed on the ground in Jodhpur. An aircraft from the Defense Dept. was used for this purpose. The outcome of this exercise was indeed very satisfying and the systems were duplicated and made available for any NPP site which required aerial monitoring. The system architecture was such that it can be fitted in any aircraft within 30 minutes and operated using the battery power of the aircraft for facilitating its use in an emergency. Later I understood that the system was loaned to IAEA for detection of lost sources in Georgia and Krishnamachari was deputed to operate it. His help resulted in quickly trouble shooting an electronic problem with another system.

In 1993 I had an occasion to organize a conference on emergency preparedness for INS as convener to felicitate Dr. Gopinath on his retirement. The conference inaugurated by Dr. PK Iyengar was a success and it provided a platform for the first time to bring together various agencies involved in crisis management and emergency preparedness in the country to exchange their experiences. It was revealing for many that at that time the most effective channel of quick forewarning of natural disasters like cyclonic storms was effectively organized through the wide network of railway telegraphic connections to reach the interior villages despite it being rudimentary.

Another program initiated was automatic gamma dose transmission using VHF transmitters from environmental monitors deployed around the Trombay site and automatically transmitted the collected dose data to the emergency control center and displayed on a map of the site. This was an innovation which in principle could be used in emergency preparedness centers for NPP sites. Together with the met data processor the intention was to compute the possible source term under certain constraints in case of accidents and the necessary software were developed in the division. The prototype was demonstrated and the control room was the show piece to visiting delegations and VIPs for many years. This was the first demonstration of an emergency preparedness center in DAE. An attempt was also made to connect data transmission from emergency vehicles which can be used in case of an emergency.

Subsequent to my leaving for IAEA I gave a few suggestions to make wider impact of the monitoring systems. Some of these were a rail monitor to be developed with a GPS based environmental radiation monitor and the data recorded in RAM memory. After the train makes its journey the data can be downloaded. Thus with the wide network of trains the intention was to keep ready a system for emergency preparedness and location of rouge sources. This was successfully tried out as a feasibility project. On a suggestion given by me, miniaturized instruments were developed for mapping radiation fields in case of emergency using a remote controlled hobbyist aircrafts.

2.5.16 IAEA Assignment in Dept. of Nuclear Safeguards

I noticed an opening in IAEA safeguards department which exactly fitted my expertise and put in an application to Dr. UC Mishra who had become director of the group after Dr. Gopinath retired. Dr. Chidambaram, Chairman AEC had no problem in forwarding it. I was informed about my selection to the post without any interview as my work was by this time known to the Safeguards department of IAEA through my association with Dr. Ottmar and his group. Clearly the assignment was possible due to the pathways Dr. Ganguly created for me!

Thus started my stint with IAEA from 1994 to 1999. I noticed that the lessons learnt in BARC and the knowledge base built-up was in great use and admiration at IAEA particularly in the interpretation of the high resolution gamma spectra brought by inspectors from sensitive areas. I was put in charge as the task officer for the CANDU safeguards instruments of bundle counter and core discharge monitor. These were computer based unattended real time systems which generated and stored data on fuel discharge and movement for the PHWR on power re-fuelling reactors. The inspectors access the data

once in three months and account fuel movements. The project of upgrading these systems using PIN detectors were accomplished in collaboration with the fabricating company in Canada and all PHWR reactors around the word were retrofitted with these. I had occasion to visit PHWR reactors in many countries to evaluate the performance. The user friendliness of man-computer interfaces were got evaluated by IBM which was a revealing aspect for me which is often neglected in instrument design in our country. So I arranged for a talk in Trombay TC by the IBM expert once. I also served as an accredited inspector to the North Korean inspections which gave an in depth view of the safeguarding problems there. Some of the instruments designed by me for IAEA making use of the abundant experience in BARC were the design and installation of a reactor power monitor with neutron to gamma ratio for authentication and data transmission through internet, surveillance monitors using high sensitivity neutron counters to detect movement of fuel in reactors complexes. Along with Dragnev, former Safeguards Inspector, then an IAEA consultant whom I had already known from the 1975 safeguards symposium, I also was party to development of a novel innovative method for bulk Pu measurement using internally excited x-rays in Pu from the low intensity hard gammas from Pu isotopes and we carried out measurements at the ISPRA Euratom center.

2.5.17 AERB assignments

I have the satisfaction of serving AERB as Chairman of the accelerator safety committees for full 15 years post retirement. The lessons learnt from Dr. Ganguly in conducting meetings stood me well in these transactions. And the long experience in BARC helped me in identifying safety issues and their underlying principles which were generally over looked by regulatory people. The current assignment of a member of the Committee on Nuclear & Radiation Safety, ACNRS gives me opportunity for raising some regulatory policy issues.

2.5.18 Concluding remarks

The lessons Dr. Ganguly taught me and which stood the test of time from 1958 to 1978 till his retirement and from 1978 to a decade thereafter when he continued to influence me from outside was really a journey in innovation going around obstacles. Post retirement he was often anxious to enthuse scientific spirit in the organization he built up feeling his haplessness when once toward the end of his life he poetically remarked "it was like a dying man looking back at his decaying body unable to do anything." As if the words were a premonition he soon ended his epic journey in this world. I hope this treatise will help the newer generation, which may not have even remote idea of the how their foundation was laid, will serve as a case study to innovate and inculcate scientific spirit in all their endeavors.

2.6 Dr. Ganguly and laser method of enrichment of U235

Late Ramakoteswara Rao (interviewed by M R Iyer in 2008 and narrated)

Many in the present generation may not know that Dr. Ganguly initiated preliminary activities on laser separation of U 235 in BARC as early as 1972. In a related field, the "beads on a string model" proposed by Ganguly and Magee (Ganguly and Magee, J. Chem.Phys.25, 129, 1956) was generalized to allow Monte Carlo techniques to be used in calculating the influence of track structure on the yield of free radicals at early times following energy deposition by ionizing radiation in aqueous solutions. And during the discussions in AEET in sixties he used to mention this to some of us and suggested the possibility of using this principle to knock out U 235 from uranium matrix if higher energy radiation can be used. We must remember that such tunable lasers were not available still at that time. And people had only started thinking of this possibility. But for most of us this was something over our heads and we were engrossed in our own research problems, but those discussions now reveals how he was anxious to take up fascinating front line work and had a wide range of interests in science.

But Dr. Ganguly persisted on this idea and when he was made Director of Chemical Group of BARC in 1972, got an opportunity to initiate work on this. Dr. Ramakoteswara Rao who was working in the Spectroscopy Division went to meet Dr. Ganguly with proposals for new projects, as revealed to the editor who met him to share his reminiscences of Dr. Ganguly in 2008 prior to the passing away of Dr. Rao. One of the topics proposed by Rao was for studying selective absorption of molecules to radiation thinking that Dr. Ganguly might be interested since it may have application for quantification of pollution using such selective absorption. Rao remembers that Dr. Ganguly showed great interest in this for deeper reasons. This shows Dr. Ganguly's interest in identifying exciting branches of investigation which had practical application and which has not been touched by others even though it does not come strictly under his purview. However this made Dr. Ganguly remember his idea about possible use in U 235 enrichment.

He later identified Dr. Ramakoteswara Rao for this work who has been an excellent spectroscopist with intense scientific interest and he came up to the expectation of Dr. Ganguly. Further organizationally also this activity came under his ambit since Spectroscopy Division was also under him. So he started a group to undertake preliminary studies on this and he launched a section known appropriately as MDRS (Multi-Disciplinary Research Section). He put together a few people together, among them Dr. Mittal who had earlier pursued radiation chemistry at Dr. Ganguly's old school at Notre dame with Maggie.

Dr. Rao narrated that his collaboration with AKG began in 1972 and culminated in the formation of the first inter disciplinary activity gathering experts from different branches into a cohesive team called appropriately the Multi-disciplinary Research Section. Such bringing up of experts from different disciplines often crossing the boundary of watertight compartments of Divisions in the Centre enables to bring together scientific talents with the sole motive of achieving a goal and was not common in BARC.

The idea for the investigations on laser enrichment was sown in 1972, the MDRS was formed in 1974 and the first experiments started in 1977 and the first results of the investigations achieved in 1988. Dr. Ganguly had retired by then and passed away in 1988. Possibly he might have heard about the success of his initiative from Dr. Rao who was also a resident of Saras Baug where Ganguly spent his last days. Many parameters required to start a laser enrichment plant was established in those studies. In 1992 Dr. Rao also retired.

Dr. Rao mentioned a remarkable quality in Dr. Ganguly was that he gave full baking to his people in meeting the requirements and also did not insist that his suggestions must be followed in solving the problem. In fact this in general is one of the human fallacies of ego which stands in the way of achieving scientific targets. Many a scientific idea has been killed because of the personal ego problem. People at the helm of affairs sometime insists that they know better than those working under them and many a time insist on following their ideas though it may be the right one and in the process even kills their own project. Dr. Rao remarked that Dr. Ganguly was different and was a giant much above those considerations.

The interaction with Dr. Ganguly reveals one of the other qualities of AKG; that of giving full part for the people working around him in the discussion of the proposals with his equals and seniors in formulating the plans. Most other people try to keep the juniors in the background and try to take the credit of all initiatives to themselves. This nobility is rarely seen. Accepting the ideas and expertise of the people working with him and gently guiding them to the problem and of identifying the importance of such ideas was one of the reasons of his success.

2.7 T L Studies and evolution of Thermo luminescence School

2.7.1 Working with Dr. A K Ganguly: C M Sunta

2.7.1.1 Early Years of BARC

Dr. C M Sunta remembers how on September 27, 1957 he arrived in Mumbai from Nainital to join Atomic Energy Establishment Trombay (AEET), which was later named as Bhabha Atomic Research Centre (BARC) in memory of its

great founder and met Dr. Ganguly. The Head Quarters of the Department of Atomic Energy DAE was in a palatial building called Old Yacht Club (OYC) near Gateway of India in Colaba. The DAE was the only department of GOI with its Secretary's offices outside Delhi in those days. Even now it continues so. Sunta presented his call letter at the reception counter at the ground floor of the building. The gentleman there wrote on a small chit "A S Rao" and directed him to go to the upper floor where Sunta met another gentleman called Mr. Jayaraman sitting outside the cabin of A S Rao who in turn gave another chit scribbled "Dr. Ganguly". Eventually Sunta reached the office of Dr. Ganguly located at the TIFR building premises in Colaba by an official minibus. It was in one of the rooms in erstwhile naval barracks in Holiday camp Colaba. Dr. Ganguly asked a few questions about what Sunta had been doing before and pointed to another room where some more boys were waiting and simply chatting. Sunta mistakenly presumed Dr. Ganguly to be a medical doctor and others were waiting in that room to undergo medical examination, since the requirement of medical fitness had been mentioned in the earlier correspondence. When nothing seemed to progress, Sunta went back to Dr. Ganguly and asked him "how long should I remain here". He looked at Sunta and promptly said "as long as you like". This somewhat perplexed Sunta, but in hindsight it looked that he simply wanted to give Sunta freedom to leave early so that he could go for arranging accommodation, boarding, lodging, etc. Next day, while talking to others who had come before Sunta learnt that it was his working place and is called Health physics Division. The word Health Physics was new to Sunta and he was in a quandary as to what "health" has to do with "physics" and what Health Physics means and what he was supposed to do there. Sunta found that some of his colleagues were asked to fill-up the indent forms for tables, chairs and steel cupboards for their use and the rest were almost idle. So next day they were asked to go to the library of Tata Institute of Fundamental Research (TIFR) to study and find out what Health Physics was all about, which was at that time in the first floor hall of the O Y C building. While scanning through the various book shelves Sunta found a book on Atomic Energy which also explained what Health Physics means and gave him some satisfaction, but still there was no work to get a practical understanding of what they do in Health Physics. It was only some weeks later that he got an opportunity to visit some laboratories where radiation monitoring was being done routinely using the so called instruments, Survey Meters. It was then Sunta realized that radiation monitoring was one of the important jobs of a Health Physicist.

Sunta experienced in the very beginning that Dr. Ganguly gave full freedom to his staff to work wherever they wished. Once he asked Dr. Ganguly for

permission to apply for transfer to Spectroscopy Division, since his major subject in M. Sc. was Spectroscopy. He showed neither reservation nor annoyance and said that he could, but asked him to see Mr. A. S. Rao who was the Head of the HPD (Dr. Ganguly was Head of the RHC Section under him) for permission. When Sunta met A. S. Rao he advised him nonchalantly that "I would be better off in Health Physics Division and there would be enough opportunities to use spectroscopy in this Division too". In a cool manner he tried to convince Sunta by saying that he would be one among the many spectroscopy specialists in the Spectroscopy Division and would have lesser chances to work with freedom since they would have their fixed programs to pursue. In hindsight Sunta saw that Mr. Rao's advice was a good one, since Sunta and his colleagues later did use lot of spectroscopy to study thermo luminescence (TL) and as can be seen in this memoirs, led to many publications on TL. The editor notes that this perhaps was the experience of most of the early starters in the Health Physics Division which proved to be the nursery of any discipline one could choose under the sun. The outfit unlike other Divisions offered immense scope for one to work on any topic that ultimately was shown by Dr. Ganguly to be one way or other connected with Health Physics. This certainly was not possible in any other discipline in AEET or for that matter elsewhere in any scientific establishment or University. Thus by going through these memoirs one will realize that the Health Physics Division of yesteryears was the nursery for scientific innovation and freedom to grow, shift areas of work, invent and grow. And it was Dr. Ganguly's way of getting the best from his people and should be a lesson in scientific management for the younger generation. And in the editor's view the efficacy was 80 percent if not 100 per cent as a few could have misused this freedom!

Sunta found for himself that the scope of Health Physics is spread over a wide variety of subjects and Dr. Ganguly used to give full freedom for choosing a subject of one's interest and gave full backing and encouragement for the same. In fact for him there were no boundaries in science. Sunta himself had been the beneficiary of this independence of operation and he first worked on radiation shielding in innovating a slide rule, then dreamt of doing chemical dosimetry, then on to experimental study of capture gamma spectrometry of high energy photons in a reactor and finally landing in the area of Thermo luminescence dosimetry in which he and his team made substantial achievements and later even in internal dosimetry.

In Holiday Camp, Colaba, Sunta recounts, they had to shift from one location to other a number of times, since the old naval barracks were being demolished

one after other to make room for the TIFR main building and its annexes. We were located for some time on the unpaved dusty floor of the TIFR building under construction and some time on the third floor of that building. There were not even enough chairs or fans and one need to do musical chairs at times! Dr. Homi Bhabha was at that time Director of the TIFR as well as AEET and also Secretary DAE to GOI. These were the formative years of both these great organizations.

After about a year, the HPD moved from Colaba to Trombay, the main premises of AEET. This was still a temporary location in a large shed, roofed with AC sheets at the South side of the sprawling Complex at Trombay generally known as "South Site". The shed was partitioned into various compartments occupied by different teams of health physics division handling different R&D projects such as electronic instrumentation, dosimetry, and outfit generally known as "R&D group of AKG" in which a few of us including DV Gopinath, C M Sunta and myself (Editor) evolved. In the absence of brick walls the separation of workplace for each team was done using innovatively with steel cupboards used for storage of materials like electronic components, records. However on the four peripheries of the shed there were few proper rooms and cabins which were occupied by the Heads of the Divisions and Sections, radioactivity counting room and a lecture hall. One of those rooms was occupied by Dr. Ganguly. There was a mezzanine floor at one end which housed the divisional library. Other divisions such as Air Monitoring division, reactor control division, and nuclear waste management also shared this huge shed. The shed for most part of it was having no air conditioning and they all used pedestal fans to escape the sweltering heat in summer months. The inside of the shed was more heated due to the cement sheet roof than in the open sun! Noticing the plight of the staff someone thought of an innovative method of providing relief by cooling the roof with sprays of water and this did provide some relief. As this shed was required to house the Division of Purchase and Stores of AEET, after a few years the occupants of the this shed moved to another shed nearby which housed all the divisions under Mr. A S Rao under one roof (probably for the first time and last time! since later they all got split). This included the large Electronics Production division headed by V Ramarao churning out instruments for the research centre and this was branded as TEI (Trombay electronic instruments) and most of them were valve units in typical black panels. This was the outfit which later on evolved as Electronics Corporation of India and shifted to Hyderabad along with A S Rao. The various Divisions had to spend some years in this shed before getting permanent laboratory rooms in the newly constructed building named

Modular Laboratories in 1966. Sunta recollects that, except those few who were assigned radiation monitoring work in laboratories handling radioactive materials, many of the new entrants like himself were still not stabilized in any work in particular and were left free to study and to pick up any subject of one's interest and to start working on it. Dr. Ganguly gave a lot of encouragement to those who came with any proposal for work on their own.

2.7.1.2 Gama Shielding Calculator Slide Rule

Those were the times when computers were not available for use. Slide rules were still being used for many calculations along with electro mechanical calculators. Sunta happened to see a circular type of slide rule calculator from Harwell for calculation of shielding thicknesses for X and gamma radiations. This device caught his interest and he started to develop a shielding slide rule of a linear shape. A demo model in rigid PVC sheets was prepared and shown to Dr. Ganguly. He appreciated it and asked Sunta to get fabricated some pieces in a finished form. In this intervening period the CIRUS reactor was inaugurated in 1960. On this occasion Dr. Homi Bhabha invited renowned scientists from all over the world. Queen Elizabeth II was among the dignitaries invited for the occasion. Dr. Ganguly showed the slide rule shielding calculator to Dr. Bhabha who told him to prepare a good number of these and presented these to the foreign visitors as souvenir.

2.7.1.3 Deputation for Training Abroad

Meanwhile Sunta was nominated for a USAID fellowship for training in Health Physics at the University of Rochester, N. Y. The Medical School of the University used to run a course in Health Physics for those working particularly in US defense services and Public Health. Sunta was given an option by the hosts to join this course. Sunta wrote to Dr. Ganguly for getting his concurrence, which was readily given. Two of the doctors from AEET Medical Division namely Dr. Shah and Dr. Bombawale had just returned after training at Rochester, when Sunta arrived there. After completion of academic training at Rochester Sunta was given the option of visiting the various National Laboratories at Brookhaven, Argonne, and Oakridge to have practical experience for working as a Health Physicist. At Brookhaven he went through a more comprehensive training. It included also familiarization with waste management practices particularly the disposal of effluents. The training-In-charge showed that they use the dilute and disperse method. He took Sunta with a hand-held monitor to the area where the effluent is dispersed and showed the contamination level at various locations. This system of radioactive effluent disposal is reprehensible in today's context. On way back from Oakridge Sunta had a halt at Los Vegas where he participated in annual meeting of Health Physics Society.

Sunta returned with a Master of Science degree after about one and half year. The subjects in the course which he attended included radiation biology and genetics, subjects required to understand the short and long term effects of radiation on human body. On his return from US Sunta briefed Dr. Ganguly about the training including the courses at Rochester. He asked Sunta to give a course on Radiation Genetics in Health Physics Division. He himself attended this lecture series. This was his way of giving the encouragement.

2.7.1.4 Study of Neutron capture Gama Radiations

Dr. Ganguly assigned to Sunta work on neutron capture gamma radiations from reactor shielding materials such as steel lead and concrete. For this project an experimental set up was assembled at a tangential beam hole at the Apsara reactor by Sunta. The study required a gamma ray spectrometer consisting of NaI detector and a multichannel analyzer for measuring gamma spectra. The Electronics Division made available a very primitive vacuum tube based 100 channel analyzer for the purpose. It was about three and half feet tall and one and half feet wide. To record a spectrum one had to manually jot down the initial and final readings of each channel after a neutron beam exposure, subtract the initial from the final reading and plot the result of the experiment on a graph paper. And at times wait for the whim and fancy of the instrument itself! Such was the status of the technology available in those days. Nevertheless any result that came out from the experiment gave Sunta quite an excitement. Capture gammas being photons of high energy the single crystal spectrometer was not very effective and Sunta with the help of Electronics Division and a few persons who joined him started fabricating a Pair spectrometer using three NaI detectors. But the progress in this was somewhat slow.

2.7.1.5 Evolution of Thermo luminescence Dosimetry (TLD) in AEET

The seed for TLD work in AEET was sown in mid-nineteen sixties when Dr. Ganguly was on an IAEA assignment in Egypt and a letter was received from him. In that letter he suggested to Sunta and Nambi (who had joined the Division just then and looking for assignments) to take up work for developing thermo luminescence dosimeters for radiation monitoring. He had given a reference to a published paper at that time on the application of TL in radiation dosimeter. It was a new subject and there were no instruments commercially available to measure the thermo luminescence. Even published information was scanty on this topic. Later on after his return Dr. Ganguly discussed the topic with Nambi and Sunta pointing out the linearity of the TL with dosimeters for 6 or 7 decades and directed them to start investigations. The editor remarks that this led to India changing over its personal dosimetry program from the one based on Kodak film badges to a completely indigenous TL dosimetry system.

Today personal dosimetry service encompassing the whole country issues more than 50,000 TL dosimeters every month based on indigenously fabricated TL dosimeters. This is perhaps one of the largest dosimetry program anywhere in the world. TL dosimetry is used for personal radiation monitoring widely, but every country uses dosimeters supplied by commercial manufactures such as Harshaw Chemicals Co, whereas the Indian personal dosimetry program is a home grown one and uses indigenous components for this purpose. All these came out of the vision of Dr. Ganguly who initiated this program very early when the technique was not yet being applied.

Sunta has given a graphic account of the investigations on how investigations on TL took deep root in AEET under the guidance of Dr. Ganguly and an internationally recognized school evolved. Sunta along with Nambi got into the job of designing a TL reader in right earnest. They used the HPD workshop which was in operation for fabrication of various electronics instruments. Soon they designed and fabricated a light-tight enclosure with the photomultiplier assembly mounted inside for measuring even the faintest TL light. A major issue faced was how to make a resistance heater for the TL phosphor and to integrate it with the light measuring device. After trying different designs, such as a coil heater, a graphite plate, etc., they finally decided to use a Kanthal strip. A half inch wide and about two inches long strip with a central embossed depression to hold the chosen fixed quantity (about 5 mg) of the TL phosphor became the TL phosphor heater. In the beginning the power for the heater was tapped from a rheostat across which 220 V mains power was connected. The TL glow curve was recorded on a strip chart recorder in which the light glow from the photomultiplier working in the current output mode recorded the intensity versus time curve. This primitive arrangement could record the glow curve from room temperature to about 350 deg C. This system was sufficient for studying the radiation response of different TL phosphors and even for radiation monitoring applications.

2.7.1.6 The Monazite Project

Meanwhile Dr. Gopal-Ayengar, Director Bio-Medical Group (BMG) had initiated a WHO sponsored project to study the effect of high natural background radiation on the population living along the south west coast of Kerala where the beach sand has high concentration of Thorium bearing mineral monazite. The project was named Monazite project. The Chief Investigator for this was Dr. A. R. Gopal-Ayengar himself. His right hand man was Dr. K. Sundaram who later became Director BMG. He too had been deputed for training in Rochester Medical School when Sunta was already there. Both became friends and they returned at the same time. During a chance

meeting between them in Mod-Labs corridor Sundaram asked Sunta what he had been doing after return from Rochester. Sunta told him about his work on thermoluminescence dosimetry. Dr. Sundaram said they are looking for a group who can carry out dosimetry for the above stated project to correlate the effects of high background natural radiation. Sunta indicated to Dr. Sundaram that his group may be able to do the dosimetry. Later Sunta met Dr. Ganguly who readily agreed for the collaboration. Under this project the TLD group got additional technical manpower and funds to update the equipment. A spectrograph, and a micro photometer for studying the wavelength spectra of TL glow curves, a strip chart recorder, a temperature programmer, wires for thermocouples, and a bundle of Kanthal heater strips were imported under this program. Thermocouple wires and Kanthal strips were sufficient not only for their own use but also were liberally provided to many other researchers from BARC and other institutions in India.

Under the monazite project the TL measured radiation exposures integrated over a period of one month in about two thousand five hundred randomly selected residences and their occupants numbering about ten thousand were measured. The TL detector phosphor chosen for this project was the blue-green fluoride mineral powder, since it was available in abundance in India and was more sensitive as compared to the commonly used LiF TL phosphor which had to be imported from Harshaw Chemical Co. USA. The phosphor powder was deposited over the above 5 cm long and about 1.25 cm wide Kanthal strip using silicon resin. It was enclosed in a water proof and light impervious black polythene and attached to a chain so as to be worn as a necklace by the individuals chosen for this survey. By this innovative method the actual radiation dose received by the wearer could be recorded instead of depending on spot measurement of dose rates in the dwellings and estimated dwell times. The dosimetry data were used to correlate with possible long term health effects of high background radiation on the population. The gross health parameters chosen were malformations in new born children, abortions, fertility index, etc. No definite difference was found in these health parameter data of control population (living in normal background area along the Kerala coast) and that of the high background area. This was perhaps the first large scale dosimetric measurement in monazite areas of Kerala, though some mapping of dose rates using survey meters were undertaken by G H Vaze and his group as early as in 1957.

2.7.1.7 Basic Research

Apart from this major application, the group also undertook basic research on TL, in particular the TL characteristics of various TL sensitive materials. The

TL reader was further improved. The updated TL reader system of the TLD group has a thermocouple spot-welded underneath the Kanthal heater strip and a temperature programmer to control and program the heater temperature. A strip-chart recorder was used to record the glow curve in intensity versus temperature mode.

By this time thermo luminescence being a relatively low investment subject spread to many universities and Sunta and his groups provided support to them. The system developed by the TL Group was duplicated by a number of laboratories in University colleges in India. They were provided with the design and material support as well as training whoever requested for it. The academic institutions used this system in basic research.

Time came when Dr. Ganguly felt that the R&D in thermo luminescence dosimetry need to be separated from routine use of TL for personal dosimetry. He did exactly that and directed the TL group to give assistance to the Personal radiation monitoring group in the Division of Radiation Protection (DRP). This enabled the personal monitoring group in DRP to switch the personal dosimetry to TL from the Kotak film badges. This program took root under S J Supe and R. C. Bhatt. Main participants in this program were B. C. Bhatt, A. S. Pradhan, A R Lakshmanan and others joining them. They developed a TLD badge with appropriate filters to differentiate the type of radiations. This is one example how a home grown R&D program evolved into a national service. The TL group of Sunta and Nambi continued to concentrate on the TL research and explored various other applications of TL. The separation of the basic research and service activities was a model one for scientific research.

Subsequent to the Monazite project the TL group was assigned to work on an IAEA research contract for development of TL research. Dr. Ganguly who secured this contract was the chief investigator for this project. Using the resources available under this project additional equipment was acquired. A major piece among them was the scanning type grating monochromator for recording the TL spectra. Using this equipment they could avoid the tedious process of photographing and measuring wavelengths using a micro photometer. As a result of the IAEA project and the above stated Monazite project, the TL group built up in-house technical competence to develop and fabricate the required equipment and accessories.

Dr. Ganguly assigned additional scientific personnel to the TL research group from BARC training school graduates. This included V N Bapat, S P Kathuria and B D Bhasin. Each one of them contributed greatly to TL research. The

technical staff recruited for the WHO project included two scientific assistants M David and A S Basu, science graduates and D T Khatri an Electronics Engineer retired from Indian Air Force and A R Kamath, a Laboratory Assistant. This formed a self-sufficient team for various activities of the group which originally started as a two member team of Sunta and Nambi. Thus as a result of the research projects the group acquired in-house technical competence to develop and fabricate the required equipment and accessories and also sufficient manpower to take up large scale dosimetry projects.

Thanks to support and encouragement given by Dr. Ganguly the TL group became a center of attraction for many researchers of other Divisions. V K Jain and P N Maheshwari from Division of Radiological Protection (DRP) and S Muralidhara Rao from Technical Physics Division joined the group. Dr. Ganguly was always liberal in accepting persons when permitted by their parent Division. One Mohammed Ayad El-Kolaly from Egyptian Atomic Energy Commission also got trained in the group. Thus the group which started as a nucleus with Sunta and Nambi had now expanded. This became one of the pioneering TL groups in the world which carried out significant work in this area. Muralidhara Rao had good expertise in crystal growth. V K Jain used to work in personnel dosimetry in his parent Division and fitted well with the group's activities. Most members of the group earned their Ph. D and M Sc. degrees under Dr. Ganguly.

In 1970 an announcement appeared for holding the Third International Conference on Luminescence Dosimetry as a part of Solid State Dosimetry (SSD) Conferences series. Sunta prepared two abstracts for presentation at this Conference and sent them to the organizers with a letter stating that if the organizers could arrange for the presentation of these papers the full paper and the presentation slides would be sent, since Sunta did not expect to get funds for travel to Denmark the venue of the conference. Quick came the reply that the abstracts are interesting and offered to part finance the participation of Sunta to present the papers. A cheque of $ 5oo/ was attached with the letter with an offer that they would arrange for additional fund if required. Sunta showed the letter to Dr. Ganguly, who promptly took it to Director BARC and got his approval for Sunta's participation in the Conference. One of the papers dealt with the controversy about the super linear behavior of the intensity of the main TL peak called peak 5 in LiF TLD phosphor. Two hypotheses had been proposed by two groups of authors:

1) track interaction theory, which presumed that the irradiation produces tracks of ionization and the recombination during heating is within the track only

at low doses. As dose increases the individual tracks become close to each other with the result that recombination becomes possible also between the liberated electrons from one track with the holes on the neighboring tracks. This leads to increase in TL yield. Thus the TL intensity growth becomes more than linear with increasing dose.

2) The deep trap competition theory, which means there are traps at levels deeper than that of the peak 5. During irradiation the traps of peak 5 face competition from the deeper traps for capturing the free electrons. The hypothesis proposes that the deep traps are fewer in number and have higher cross section for electrons capture, so that they get saturated before the traps of peak 5. Thus after a initial linear growth the intensity of peak 5 starts increasing at more than a linear rate. This behavior is called supralinearity. The existence of deep traps was only a conjecture.

Neither the proponents of this hypothesis nor anyone else had detected the deep traps. One way of resolving was using the TL technique itself by extending glow curve recording to temperature region beyond that of peak 5 to look for any glow peaks from deeper traps. The difficulties in measuring TL peaks at higher temperatures arose due to interference from heat radiation. It was overcome by using a set of optical filters to block the infrared rays from reaching the light detector photomultiplier tube. In this way a number of glow peaks could be recorded in the temperature region between 200 and 5000 deg C including a strong peak at 4500 deg C. On recording the growth of this peak with increasing dose it was found that this peak does not saturate before that of peak No 5, on the contrary it continues to grow even beyond saturation temperature of peak 5. It thus disproved the deep trap competition hypothesis. Implicitly the track interaction theory remained in force. Dr. F. H. Attix while summarizing the Conference proceedings judged this paper the outstanding paper of the Conference.

2.7.1.8 Radiation Map of India

The TL group carried out the survey of background radiation levels all over India using the TLDs. For this survey the TLD detectors were placed in the weather stations of India Meteorological Department with their cooperation. The results of this survey for example showed that the natural radiation levels were higher in Ganga Yamuna basin than elsewhere in India except some hotspots for example along the south west coast due to monazite areas and uranium mining areas. A radioactivity map of India was prepared. Nambi and Sankaran prepared a colored version of this map with the help of Library and Information Division which became of very popular.

2.7.1.9 The Brazilian connection

In 1973 Sunta applied for study leave to avail an offer from the Brazilian Institute of Atomic Energy at Sao Paulo as a Visiting Scientist/ Researcher which after six months was converted to the position of IAEA field expert under request from the Brazilian host institute, since they already had the IAEA grant for this position. The Brazilian group became interested in further collaboration with Sunta. However Sunta could not stay more and he in turn suggested that his colleagues may continue this collaborative work. On his return he apprised Dr. Ganguly this proposal, who readily accepted it and got the necessary administrative sanction. The collaboration continued with three members of the TL group namely K S V Nambi, V N Bapat and S P Kathuria spending one year each at the Brazilian Institute during 1976-1980. They upgraded their R & D program on TL. This was the materialization of a very fruitful international co-operation.

In 1975 Dr. Ganguly was promoted to the position of Group Director and Shri S D Soman became the Head of the Health Physics Division. He gave full support to the activities of the TL group. The group ventured into the field of application of TL technique in dating of Archaeological and Geological samples. Sunta and K S V Nambi participated in the Dating conferences at Oxford University. Prof. M. J. Aitken who had earlier visited TL Laboratory and appreciated the work of the group provided the funds for participation at these conferences. The editor notes that it was at this time that Mr. Paramasivam, who had retired from the Archaeological department Chennai and who had taken deep interest in getting the artifacts estimated for their age, approached Dr. Ganguly and had interesting discussions how the TL dating technique can be used in his passion for dating such artifacts. A few samples were analyzed for him by Nambi. And the TL group offered to supply equipment for them to continue the work. It was a sight to see the fervent scientific pursuits of two veterans. Paramasivam who was advanced in age used to come down to BARC with a shoulder bag full of photos and some samples of the artifacts.

2.7.1.10 Organizational changes

After the retirement of Dr. Ganguly, some organizational changes took place. V. N. Meckoni became Group Director and in 1980 Sunta was assigned to head a new section called Internal Dosimetry section. He continued in this position for about ten years. The Whole Body counting and the Bioassay programs of this Section had already been well established with R C Sharma and Kamala Rudran as the respective group leaders. The program initiated by H S Dang on elemental analysis of biological samples under Somasundaram was strengthened by Sunta with activation analysis of Biological samples. One

of interesting findings of this program was the analysis of blood samples of personnel working in the Thorium plant in BARC. Blood samples were collected from three groups of personnel working in this plant. - persons working inside the plant, peripheral workers of the plant and office staff. The level of Thorium contamination, though below the permissible levels, was highest in the occupationally exposed groups. The contamination level could differentiate between the plant workers and the peripheral workers. The office staff was the control group.

In 1990 Sunta was transferred to Atomic Energy Regulatory Board (AERB) as Director of Radiation Safety Division, from where he retired on superannuation in early 1992. He was continuing to work in AERB as a consultant, when a letter was received from the organizers of the International Conference on Measurement of on low levels of Radioactivity in Biological and Environmental Samples to be held at Rio de Janeiro Brazil. Being a member of the organizing committee of that series of conferences he could get the necessary funds for travel to Rio de Janeiro. He also got an offer from the Institute of Physics University of Sao Paulo (USP) for Visiting Research Fellowship to be availed post-Conference. Sunta remembers that Mr. S D Soman who was then Chairman of AERB helped him to get the necessary approvals to travel to Brazil for the above purposes.

2.7.1.11 Post Retirement activity

This was the beginning of a new chapter in Sunta's academic career and international collaboration in TL studies. Initially he worked with Prof. Emico Okuno of Dosimetry Unit of USP, Sao Paulo for over one year and returned to India. Later he received a letter from Prof. Shigueo Watanabe with whom he had contacts since 1973 when Sunta was with him as IAEA Field Expert. On Prof. Shigueo's invitation Sunta now established himself in his Laboratory as visiting scientist. For two years he was in the faculty of the University as well as a "Professor Collaborator".

He continued to work at USP as visiting Professor/Researcher until April 2004 with in-between breaks. While studying the theoretical aspects of thermoluminescence at USP, Sunta found certain deficiencies and anomalies in the existing theories and published his findings in international journals of repute. Based on this work he later authored a book on Thermo luminescence" published by Springer India. Needless to say that in this book Sunta has profusely acknowledged and paid his deepest gratitude to Dr. Ganguly, his teacher.

2.7.1.12 Dr. Ganguly, a social giant.

The Health Physics Division under Dr. Ganguly used to arrange annual picnic of HPD staff members and their families. He always joined and enjoyed the fun in the activity. Initially the picnics were held in places close to Mumbai city in places like Powai-Vihar lake areas. Later these got extended to far off locations like Matheran and Mahabaleshwar with overnight stay in a hotel. We had such a picnic also to Tarapur and the accommodation was arranged in the Guest House of the Tarapur Atomic Power Station. In these outdoor activities he was like a patriarch for us as well as a usual picnicker among us freely sharing the fun and light moments with all of us. Once in Mahabaleshwar, our entire group of picnickers had gathered in the dining hall of the hotel for dinner. Thalis and spoons were already laid on the tables. We were waiting for the food to be served, but apparently waiting became a bit too long. Someone among us started to beat his thali with the spoon. Soon others too joined. We rejoiced to see that Dr. Ganguly too joined in this noisy activity. The restaurant manager came and bowed to Dr. Ganguly, but at the same time said "Aap bhee ismem shamil!!". Dr. Ganguly smiled in return. The food was soon served.

2.7.1.13 Dr. Ganguly and his Empathy

Dr. Ganguly was a person abundant with human kindness and used to look at his subordinate's problems with sympathy. Sunta recalls once, a colleague who was sent abroad for initiating work on a new scientific topic and training for six months, returned in just two weeks' time. He could not adjust to the foreign environment, lost sleep, felt difficulty in finding suitable vegetarian food compounded with social problems and became nervous. Frustrated and in dilapidated health, he returned. His colleagues, including some seniors ridiculed and admonished him. Sunta asked him to meet Dr. Ganguly and asked his forgiveness and expressed to him that he was extremely sorry for his behavior. Dr. Ganguly saw at his nervous condition and told him "on the contrary I am sorry for you that you lost a good opportunity given to you". Dr. Ganguly reconciled the person and advised him to take leave for some days, spend time with his family and then resume his work. Such a sympathetic attitude for a subordinate person may be rare to find in a hierarchical organization. Earlir the person concerned had been reprimanded by his senior and was seen coming out of the chamber weeping, but he was still in more tears sobbing after getting advice from Dr. Ganguly due to a deep sense of remorse!

Another instance of his empathy which was noticed by the editor was in the case of a vegetable vendor half-clad and half hungry who used to peddle vegetables at Dr. Ganguly's house in Ghatkopar. He was so impoverished that Ganguly offered him a daily wage job for collecting samples, etc. in HPD in

BARC. He in due course became very popular under the name of Ramkaran and became a peon at Ganguly's office. Ramkaran was a close observer of men and matters and learned the practices and daily routine of Dr. Ganguly and used to serve him with water, tea, etc. at the appropriate times and also offer him his usual dose of pan apart from cautioning people waiting to see Ganguly that Saab is busy and they can try later. Because of his typical behavior became very popular in the Division. I often used to feel that had he been educated he could have well ended up in a scientific worker. But in the end he became a nuisance to Dr. Ganguly when he started controlling his visitors. Finally Dr. Ganguly got rid of him by transferring him to Mr. Vaze who was Head of the Electronics Division.

Another anecdote shared with the Editor by M S Kulkarni, Secretary IARP demonstrates the empathic nature of Dr. Ganguly. Once a junior person approached Dr. Ganguly for recommendation for out-of-turn allotment of office quarters due to his personal problems. Dr. Ganguly patiently listened and asked him what was his father and on being told that he was a teacher. Dr. Ganguly at once recommended remarking that a teacher's son should oblige another teacher's son!

2.7.2 Evolution of thermo luminescence investigations and Dr. K S V Nambi's contributions under Dr. Ganguly.

2.7.2.1 Narrated by M R Iyer

K S V Nambi joined AEET in 1962 and was allotted work in Health Physics division under Dr. Ganguly. He had a DAE fellowship during his postgraduate course in St Joseph's College, Tiruchirapalli and in that context had encounters with BARC scientists even before joining AEET. He seemed to have been interviewed by Dr. P K Iyengar for this fellowship. Once Nambi revealed to L V Krishnan that he was keen to join the Nuclear Physics group in BARC. Since he had already met Dr. Iyengar in his college days, he approached Dr. Iyengar in this context. PKI seems to have remarked that it would be wise for Nambi to remain with AKG as he is the kind of person who was capable of identifying research topics in whatever work he undertook. That was indeed a true assessment of Dr. Ganguly. It is a tribute from another person with a similar spirit of inquiry and sums up the vast scientific interest Dr. Ganguly had.

K S V Nambi was allotted to work in the loosely knit R&D group with Gopinath. While he was looking for a problem to work on, Dr. Ganguly introduced him to the topic of Thermo luminescence which was just emerging as a versatile potential solid state radiation dosimeter. On his return from

attending a conference Dr. Ganguly assembled a few people and showed them a paper which was presented at the conference and the editor was a bystander at this "historic event". Dr. Ganguly said that this is possibly a dosimeter of the future with astounding linearity over 6 or 7 decades. And looking at Nambi he suggested to him, as he had not yet homed on to a problem, to go through the paper and see what can be done. Nambi thus started his career with work on thermo luminescence allotted by Dr. Ganguly to him and Sunta. The work on TL progressed quickly inviting international attention and leading to the largest TL dosimetry services developed indigenously in the world. The "Ganguly School" thus evolved a "department of Thermo luminescence" which carried out pioneering work on TL phenomenon and measurement methodologies. Sunta also gravitated toward the subject as his efforts with capture gamma Spectrometry was making slow progress and thermo luminescence was a new field with scope for many workers and formed a dosimetry group.

The work on TL was growing from strength to strength with many people joining the group as mentioned by Sunta in his memoirs. It also led to an extensive mapping of radiation exposures by the public in the monazite areas in Kerala as part of a BARC-WHO project under Dr. Gopal-Ayengar. Later the mapping of radiation dose throughout India, an ambitious project, was undertaken by Nambi which resulted in the Radiation map of India and acclaimed by IAEA. These are described in details in the paper by Nambi reproduced below and also contained in the memoirs of Sunta. On Dr. Ganguly's suggestions, the knowhow for inducting TL dosimeters for personal monitoring by the personal monitoring group in RPAD, was provided by Nambi and his group. Thus the TL personal monitoring program was based on indigenous developments. And is now one of the biggest service providers of TL personal dosimeters in the world handling around 50,000 dosimeters each month in India. Nambi had a stint of working in Japan on the topic when Dr. Ganguly deputed him under a fellowship in 1978. In 1980, Nambi took charge of the TL group after Dr. Sunta was given the responsibility of internal dosimetry section in HPD. In later years Dr. Nambi also spend one year in Brazil as an expert and guided research there and published many papers on TL.

The accomplishments of the Ganguly School on TL is contained in the paper authored by Dr. Nambi "Dr. Ganguly's scientific contributions: Thermo luminescence research and its applications" sent to me by Nambi a few months prior to his sad demise, as he expressed his inability to prepare a separate memoir for this compendium, having been riddled with medical problems. So I was postponing getting a few details on his career from him and as I was planning to send him a draft of my narration of his career, news reached

about his sad demise in April 2017. Another member of Ganguly School was gone! The paper is annexed below.

2.7.2.2 Dr. A. K. Ganguly's scientific contributions: Thermo luminescence Research and applications (Reproduced from a publication by late KSV Nambi)

In the early sixties during one of the international conferences on Radiation Dosimetry attended by Dr. Ganguly, thermo luminescence dosimeter (TLD) was announced as the most promising new detector in Radiation Dosimetry with unsurpassed linear range, energy independence, negligible fading and great sensitivity. On his return, development of such a TLD indigenously for use in the Department of Atomic Energy was assigned to the Dosimetry Group in the Health Physics Division of BARC (then known as AEET). "Indigenization" both at the material level and electronic instrumentation level was the guiding principle to be followed. This principle was strictly adhered to for more than three decades and to-day BARC is reckoned as a Leader in this area of study and application. A significant move made by AKG was to convene the First National Symposium on TL and Applications which was held in 1975 at the Reactor Research Centre (presently known as Indira Gandhi Centre for Advanced Research), Kalpakkam, Tamil Nadu. This was a well-attended meeting of TL workers from various universities all over India and helped to galvanize meaningful activities in this field at a national level. A bibliography of all the research publications and theses produced in India was published along with the Proceedings of the Symposium and this volume was most sought-after world-wide.

Devotion of Dr. Ganguly to the new area of study was total and in spite of his heavy administrative work load as Director of the largest Group in BARC, he spent at least a couple of hours every day in the TL laboratory outside official business time. He discussed with equal ease with every worker in the laboratory irrespective of the age or the official status of the person in the organization. He became the most loved teacher-guide to all the eight member-scientists of the TL group who were registered for their Ph.D./M.Sc. degrees. There was also a Ph.D. scholar from Egypt who joined this group and worked under the guidance of AKG. The various topics covering his interests are discussed briefly below.

1. Indigenous development of phosphors and instruments.

The first international announcement about a useful TLD phosphor was concerning CaF2: Mn. This became the starting point to make attempts in the laboratory. Co-precipitation and firing techniques were employed and the first

successful results were presented at the Health Physics Society meeting held in USA during 1966. Progressively a crystal Growth Facility was established and single crystals of CaF2 and LiF with different dopants such as the 14 rare earth elements, Mg, Mn, U, etc., could be grown with remarkable success. In fact when these single crystals (each nearly 6 cm long with 6mm dia.) were exhibited during the Fifth International Conference on Luminescence Dosimetry held in Sao Paulo during 1977, Dr. Lucas from Harshaw Chemicals (who had the world monopoly for selling commercially TL phosphors) commented that BARC might even throw them out of business in the near future! Equally important was the success achieved in making TL glow curve recorders with linear heating, dosimeter reader with fast heating, TL spectral analyzer with isothermal hold facility, adaptability to record TL from liquid Nitrogen temperature to high temperatures.

2. Environmental Radiation Monitoring Around Nuclear Power Stations:

Due to the foresightedness of AKG, establishment of an Environmental Survey Laboratory even before a Nuclear Power Plant is put up, was made mandatory in India. This became a role model to be strongly recommended to all member nations by the IAEA. One of the functions of this ESL is to monitor regularly the environmental radiation levels in the vicinity of the Power Station using TLDs and that should be initiated at the pre-operational stage itself. Such a program was initiated in India in the vicinities of TAPS, RAPS and MAPS during the late sixties itself. The environs of BARC were also included in this program. As years passed, all the DAE facilities have been covered by this program of environmental monitoring centrally organized by the Environmental Assessment Division of BARC. Quality maintenance of the data routinely generated was given top priority right from the word, 'go' and AKG was uncompromising on this. BARC continuously participated in all International Programs of Inter comparison of Radiation Dosimeters. To-day, BARC can boast to be a proud owner of a large body of quality data be it environmental or personnel radiation monitoring covering decades of DAE operations.

3. Large-scale Population Radiation Dosimetry in Monazite Areas:

One of the earliest and bold attempts by AKG was to commit to a large scale population radiation Dosimetry along the monazite-bearing coastal areas of thickly populated Kerala state at a time when TL dosimetric applications of this size was not on the cards anywhere in the world. That this was to be done wholly indigenously was the most attractive and surprising feature of this WHO Project study as expressed by the international representative who visited BARC at the start of the project. Nearly 20000 personal dose measurements

were made over a period of about 2 years and each dosimeter was handmade! Without the unstinted and spirited support of AKG this would not have been possible at all and it adds to the greatness of this selfless man that he declined to be one of the authors of the first report on this project presented during a Geneva Conference on Peaceful Uses of Atomic Energy; he contended that he had only provided support and not soiled his hands during the project study! The dosimetric data quality of this project study was specifically praised by Dr. K. S. B. Rose in his review article on studies carried out in monazite areas of Kerala [Nucl.Energy 21,399-408(1982)].

4. Study of Minerals and applications in Geology:

During a routine checkup of all available brands of CaF_2 powder in various laboratories, it was discovered that the natural CaF_2 powder traditionally used as a catalytic agent in Uranium Extraction from the ore, exhibited the highest TL sensitivity. This aroused the curiosity of AKG who encouraged us to go after minerals and study their TL characteristics. He played a key role in getting an IAEA project award for such investigations. He initiated the entire group into the basic tenets of Geology by inviting a Professor from IIT, Kharagpur as a Visiting Scientist in the TL group. AKG had a special love for mineral Quartz and a well-knit study on various aspects of its TL behavior was carried out and a series of papers were published in the Indian Journal of Pure and Applied Physics. Quite a number of useful research papers came out of these efforts which culminated in the publication of a very popular review article.

5. UV Dosimetry and applications in Pharmaceutical Industry:

Sensitivity to light of the natural CaF_2 TL phosphor always fascinated AKG who egged us on to get deeper into the phenomenon. It was a very significant observation that the UV photons could selectively depopulate filled deep traps and repopulate the shallow traps in the same phosphor giving rise to the observed light sensitivity. A TLD application for UV Dosimetry could be successfully proposed. The observation made in CaF_2 could be repeated in almost all other phosphors to various degrees of sensitivity. The importance of UV Dosimetry in Medical Applications did not escape the attention of AKG who initiated a field measurement to be carried out in the CIBA Pharmaceutical industry to check the effectiveness of the Germicidal UV Lamps used by them.

6. Neutron Dosimetry:

Assessment of doses due to neutrons has always been a challenging task in Atomic Energy Installations. Dr. Ganguly desired very much that a convenient TLD system be put in place for neutron Dosimetry. The natural CaF2 TLD used very successfully in Gamma Dose measurements does have some

sensitivity for thermal neutrons because of the rare-earth impurities naturally present in the fluorites; however it does not have any sensitivity for fast neutrons for lack of any significant reactions. A novel method was devised to use a sandwich of CaF2 powder in intimate contact with polyethylene sheets so that the recoil protons from the fast neutron reactions with hydrogen could deposit energy in the TL phosphor. The findings of this study created lot of interested during an IAEA organized international meet. This study was carried forward to Institute of Atomic Energy, Sao Paulo, Brazil with which a collaborative visiting program materialized; herein hydrogen doping was achieved in various TL phosphors and the fast neutron response could be increased.

7. TL below room temp. as well as the highest possible temp.:

Yet another curiosity of Dr. Ganguly was to extend the temperature record of the TL glow curve to as much as possible on either side. Hence a two-pronged attack was made on the instrumentation side: (i) a cooling jacket for the sample-cum-photomultiplier housing assembly of the TL Reader and, (ii) increasing the capability of the heater to withstand high temperature and to provide suitable mechanism to reduce thermal noise recording. A full TL glow curve covering a wide range of temperature - from about 200K to nearly 9000K was reproduced as a tribute to Dr. AKG's all-round efforts in widening the scope of TL research. Recording of high temperature TL peaks above about 5000K was a great challenge; this was uniquely surmounted by choosing a proper combination of a fast heating rate and recording rate

8. Applications to Dating in Archaeology:

AKG's interest in Archaeology was aroused by a retired Chemist (late Dr. Paramasivam) from Chennai who in his seventies wrote out a voluminous Treatise on Nuclear Techniques for betterment of Indian Archaeology and requested Dr. Ganguly to help its cause. TL dating exercise was immediately assigned to the TL group in Health Physics Division and the very first report was presented during the first National Symposium on TL and applications in presence of Dr. Paramasivam and Dr. Thapar, then Director General of Archaeology. AKG extracted a promise from the DGA an invitation to a TL scientist to participate in an excavation and collect pottery samples as per the stringent requirements of TL dating methodology. This also happened in two excavations one at Mathura and other at Panipet and a report of the dating results was communicated to the Dept. of Archaeology. A bonus that got accrued due to the involvement of radiation dosimetry scientists in dating applications was the culmination later in a standard publication giving most accurate dose conversion factors useful in dating. After standardizing the TL

dating technique and helping a couple of other national institutes to enter into routine dating, BARC almost withdrew from these studies due to other pressing engagements directly relevant to Atomic Energy. The initial results obtained at BARC on a variety of materials such as potteries, kankar nodules, beach sands, etc., will stand for ever as testimony to the pioneering effort primarily initiated by AKG. Of significance was the concordance obtained for the age of kankar nodules from the Narmada River Valley with C-14 age estimates by Oxford University for pollens retrieved from the same site.

9. Spectral Characteristics of TL emissions:

While there was a keen race going on in the world to develop a convenient and sensitive TL dosimeter, AKG was also curious to know the spectral nature of TL light although it was a demanding experiment to think at that point of time (in the sixties). Since TL emission is of a transient nature as the material is being heated. He insisted on 'flashing' one by one a large number of samples of exactly the same weight and irradiated to the same dose, in front of a monochromator with the wavelength selector being advanced in intervals of 2.5 nm over the whole range of the spectrum viz.300 to 1000 nm. This laborious exercise was fondly called by AKG as "Donkey's Experiment"! He was also very particular of evaluating the quantum efficiency of the TL emission. For this, he persuaded that the monochromator be evaluated for the overall detection efficiency making use of Standard of Irradiance of known color temperature and corrections for deviation from an absolute black body radiation source. All these were painstakingly done and results published.

10. Correlation Studies:

Dr. Ganguly was instrumental in bringing to the attention of his students to look for information which can be gleaned from experiments on TL in correlation with other properties such as optical absorption, electron spin resonance, photoluminescence, thermally stimulated exo-electron emission, electrical conductivity, etc. The first major breakthrough was obtained in CaSO4(RE) phosphors where ESR measurements gave clues to the host-lattice-related trapping sites and the emission spectrum on electron traps in conjunction with recombination centers.

11. Damage of TL sensitivity:

Dr. Ganguly strongly believed that an insight into the TL process in a phosphor could be had by trying to "kill" the TL sensitivity of the phosphor by some laboratory treatment. Such apparently 'negative' thoughts could occur only to people like the genius of AKG and he was invariably right in his instinct. Killing of TL by "wacking" doses of radiation or by thermal treatments were

the laboratory operations tried to varying degrees of success and the findings did help to understand more the underlying processes in the phenomenon of TL. Yet another idea of AKG was to mimic the natural alpha self-irradiation in minerals over geological periods. Uranium doped CaF_2 crystals were grown in the laboratory and indeed the alpha ray induced damage of the TL sensitivity could be readily seen. Gamma radiation induced damage could be readily observed in the TL of LiF phosphors.

12. Models for TL processes:

CaF_2(RE), $CaSO_4$(RE), LiF (Mg, Ti) and mineral Quartz are the materials in which the TL processes could be modeled under AKG's intuitive guidance. The efficient role of rare-earth impurities in the TL of CaF_2 and $CaSO_4$, the crucial role of the deep traps in the TL of LiF and the relationship of the crystallographic phase changes with the TL of Quartz are some of the salient features in the modeling of the TL processes in these materials. The various intriguing aspects of TL very often discussed by AKG were presented in an International Conference which was widely appreciated.

2.7.2.3 The Second phase of contributions from Dr. K S V Nambi Narrated by M R Iyer

Having contributed significantly in TL after retirement of Dr. Ganguly from BARC in 1978, there was a need to re orient the work to broader goals as it happened in many other cases and gradually under Soman's suggestion Nambi started working on epidemiology and carried out significant work on analyzing the personnel exposures and medical effects in amongst radiation workers in DAE. He along with Soman was one of the first to investigate and publish a paper on hormesis hypothesis on the effect of low level radiation on man, which widely attracted attention. Nambi was a person who will make his mark felt in any field he is allotted to work and he published several papers on the epidemiological investigations on the radiation workers in BARC contributing significantly to analyzing these effects. This helped in DAE to effectively contest the media reports by anti-nuclear groups to suggest possible radiation effects amongst radiation workers in DAE.

Dr. Nambi found great company with Dr. Gopinath when he took over as Director of the Health and Safety group. As noted elsewhere in this volume, Dr. Gopinath made several re-organizations in the Health and Safety Group of BARC from 1990 to 1993. Gopinath was anxious to give importance to the field of environmental sciences being the prime concern of his guru, Dr. Ganguly and implemented this in his reorganization in BARC. Thus the Health and Safety Group became Health Safety and Environment group and Dr. Nambi was made Head of a new division Environmental Assessment Division. At

that time he was heading the Air Monitoring Section of the HPD, after Dr. U C. Misra who was heading this section was shifted to head the BARC Training Division with wider responsibilities.

Once given the responsibilities of environmental studies, Nambi initiated a program of setting up a network of radiation monitoring countrywide which led to the Iermon program. The editor remembers how the sensitive environmental monitors developed by him earlier for radiation background measurements around NPPs were the incentive to refine those to serve as standalone monitors countrywide. In this process, Nambi also carried out investigations on the dose response of plastic scintillators to background radiation as this was thought to be an alternative to high sensitive GM counters which were used in the original environmental monitors. Some environmental laboratories like those in UCIL Jaduguda came under EAD, as Nambi had earlier initiated a fairly large program on environmental radon monitoring in dwellings and he had innovated radon monitors and calibration aids for this purpose. But the bulk of the ESLs rightly continued with the Health Physics division. I am annexing the memoirs from Dr. Mayya who worked with Nambi and was a major player in Nambi's work on epidemiology.

2.7.2.4 K. S. V. Nambi: Memoirs for the period 1988-1998
By Y S Mayya

The Post 1985 contributions of Dr. K. S. V Nambi represent his forays into diverse fields and ambitious programs. Radiation epidemiology was an outstanding program initiated by Nambi along with Soman in mid-eighties. This can be seen as a corollary of his work on population radiation exposure studies in the monazite project under the direction of Dr. Ganguly. After becoming Head of Environmental Assessment Division, Nambi gave great impetus to research on Air pollution studies in relation to human health, Nuclear Aerosol experimental program, development of passive Radon monitors and luminescence application to Archaeology. I was involved with him in the areas of epidemiology, aerosols and radon, Dr. M. P. Chougaonkar on Archaeology and Dr. Khandekar's group on air pollution studies. In order to do justice for these contributions I felt it necessary to take help from Dr. Munish Kumar (on luminescence and archaeology) and Dr. A. Vinod Kumar (on air pollution studies), who are our younger colleagues actively pursuing luminescence and environmental radiation studies in BARC now.

2.7.2.5 Epidemiological Studies.

Dr. Nambi and Mr. Soman had been pursuing these studies by correlating the cancer rates recorded in Indian urban registries with gamma radiation levels in

the region. Their findings of negative correlations between background radiation levels and cancer death rates were in consonance with the concept of radiation hormesis, vigorously pursued by certain investigators to counter the well-known "Linear-No-Threshold" (LNT) hypothesis used by ICRP for establishing dose limits. However, Nambi and Soman faced the criticism that ecological studies are not fundamentally sound as they do not take confounding and several other factors into account. The correct approach to understand the effects of low levels of radiation is to perform epidemiological studies based on the well-established cohort or case-control design. This formed the genesis of two major programs (i) Establishment of a cancer registry in Karunagappally to pursue cancer epidemiology in HBRAs, (ii) institution of studies on cancer occurrences among Atomic Energy Workers. The former program, originally headed by eminent cancer surgeon Dr. Krishnan Nair and epidemiologist Dr. Gangadharan, continues even today. In contrast, the DAE cancer study program using time aggregated cancer mortality data, fell dormant after the retirement of Dr. Nambi. Instead, several cross-sectional study programs were sponsored by NPC in collaboration with TMH, which were more in the nature of public awareness programs, rather than systematic cohort studies. An Indian Registry of Radiation Workers (IRRW) in 2009 as a part of the National Occupational Dose Registry System (NODRS) with Dr. B. K. Sapra in RP&AD to collate Radiation Worker database, including those in the public domain, is initiated as a follow up to eventually enable the building of radiation cohort for epidemiological studies.

I was transferred to Dr. Nambi's group in 1988 after about 10 years of experience of working on aerosols and radon with Dr. Kotrappa and further 3 years of pursuing and publishing theoretical papers on aerosol fractals, a then emerging subject on aggregation phenomena. I was assigned to work on the topic of epidemiology of cancer among atomic energy workers. Within a few days of interaction, Nambi realized that I had a genuine interest in theory and gave me an offer: "devote 60% of your time on epidemiology and pursue your theoretical interests for the remaining time". This was the beginning of a saga of our dynamical partnership that grew from strength to strength for the next 10 years. Within about a year, we submitted our first Journal paper to Indian Journal of Cancer on "A cancer mortality study in Bombay-Based Atomic Energy Community: 1975-1987". We employed a "Person-Year-at-Risk" method, which, Nambi used to refer to as "PYAR" method. This study, evaluated the Standardized Mortality Ratio for Bombay based workers and their families with respect to the national baseline cancer mortality rates constructed by pooling data from major urban registries. This also provides the rationale for pursuing R&D programs at developing techniques to lower the detection

limits well below the regulatory limits. As a large database accrued over the years including the low dose groups existed in DAE, it will have the potential to throw light on low dose radiation risks present in Indian populations and help assess inherent safety margins present our regulatory limits.

The Bombay study was followed by similar studies for Tarapur, Kalpakkam, NFC Hyderabad and IRE Alwaye, and these were made possible by the support from the then local Health and Safety authorities like Dr. LV Krishnan, AG Hegde, S. Viswanathan and AC Paul. A combined five unit analysis was also conducted. The activity also saw several critical reviews and risk projection modeling using the revised of 1990 ICRP risk coefficients, most important one being pointing out quantitative errors in ICRP-60 Appendices. Coincidentally this was also the period when large scale epidemiological studies in UK and US were gaining attention. In particular the Sella-field study by Gardner et al., on the association between childhood leukemia and paternal exposure had made great a wave and Nambi deputed me to present the implications of this study in various fora. Although Gardner hypothesis was discarded subsequently as an isolated finding not reproduced in any other nuclear installation, it became a fine pedagogical example of case-control study design in radiation epidemiology.

Dr. Nambi contemplated, in the long term interest of transparency for DAE, that our radiation worker data should form a part of the pooled epidemiological study program of International Agency for Research on Cancer (IARC), then pursued vigorously by Elisabeth Cardis. She had visited BARC in 1994 and I was asked to participate in one of her meetings in Leon, France, during the period when I was under deputation to Germany. It may be recalled that her publications of 2005-2007 involving pooled data from several western countries, can said to be the first effort at providing direct evidence on low dose radiation risks. Although these papers became controversial, they demonstrated that there is no other way to examine the scientific question of low dose radiation risks other than by a pooled analysis of systematically constructed radiation cohorts.

2.7.2.6 Nuclear Aerosol Project:

The Chernobyl accident was a clear demonstration of the fact that ultimate public impact of a nuclear accident occurs through the dispersion of radioactive aerosols. That was the time when reactor engineers were formulating the defense-in-depth philosophy by including an assessment of the environmental consequences of the Beyond-Design Based accidents. Motivated by these factors, Dr. Nambi, in association with Dr. PVN Nair (who was in charge of

aerosol research in EAD) and Shri S. K. Mehta (then Head/Director of Reactor Engineering Division), organized the first brainstorming meeting on Nuclear Aerosol source term assessment, sometime in 1991. Subsequently, a proposal was put up under 8th plan, which unfortunately did not come through. Later, Nambi approached Dr. Kakodkar, then Director BARC, seeking separate funds to establish a Nuclear Aerosol Test facility and it was approved. Although Dr. Nambi retired before the facility came up, most of the ground work such as the choice of the site, the test vessel, the team identification from various other Divisions such as Reactor Safety Division and Plasma Technology Division, was already done during his time. Myself, P. V. Joshi and B. K. Sapra, from EAD, SG Markandeya and Sunil Ganju from Reactor Safety Division and Sree Kumar from Plasma Technology were the core members of the working team. For me, it was coming back to aerosols after a decade of hibernation. I must add that Dr. Nambi always encouraged my association with theoretical stalwarts, especially with my Ph.D. Guide, Dr. D. C. Sahni. In fact, it goes to the credit of then prevailing informal spirit of BARC that a neutron transport theorist like Dr. D. C. Sahni made path-breaking contribution on droplet evaporation and aerosol coagulation, which is remembered and admired by international aerosol community even today.

A. Kakodkar and H. S. Kushwaha gave unstinting support to this program which generated aerosol behavior data for validating nuclear safety codes, with several publications during 2002-2012. This activity has now got ramified into an inter-institutional project between BARC and IIT Kanpur under Prof. S. N. Tripathi, with a major test facility scheduled to be commissioned in IITK in 2017.

2.7.2.7 Indoor Radon CRP

With the establishment of a BRNS sponsored Cancer Registry in High Background Radiation Areas of Kerala and the initiation of Epidemiological studies, it became imperative for BARC to provide dosimetric support to the program. Nambi's experience on large scale population dosimetry made it largely a smooth affair in so far as external gamma dosimetry was concerned. However, Nambi was ambitious, he argued that inhalation doses due to radon and especially thoron might be substantially higher and should be assessed on a house-to-house basis for the success of the study. Retrospectively speaking, this was a visionary step since, until about 2005, internationally, thoron was never included in population surveys of residential radon studies. Dedicated effort was put to develop the now famous twin-cup radon thoron discriminating dosimeter using LR-115 Nuclear track detectors. Nambi also started a major CRP on indoor radon involving K. P. Eappen and TV Ramachandran from EAD and about 20 professors from the Universities as collaborative partners, to construct the

Radon-thoron map of India. One important achievement of these efforts was the systematization of radon, thoron measurements. Secondly, it catalyzed several basic and applied studies on radon and thoron and eventually led to the building of an internationally visible group in HSEG since the year 2008.

2.7.2.8 IERMON program

Vinod Kumar

After the Chernobyl accident, Dr. Nambi proactively initiated the countrywide atmospheric gamma radiation program. Systems with state of the art communication device were developed and installed at geographically distributed locations in the country. This network provided feed back to the Global Environmental Radiation Monitoring Network (GERMON). The data comprising of gross alpha, gross beta and gross gamma were shared with international community to work as early warning system to track transboundary migration of radioactivity coming into the country or going out of the country due to a nuclear accident. The network was renamed as "Indian Environmental Radiation Monitoring Network (IERMON)", and is currently working with about 500 units spread all over the country. Dr. Nambi's vision of having a countrywide network was immensely useful at the time of the Fukushima accident to instill confidence among the public and policy makers that no radioactivity has reached the Indian region.

The capability of trace and ultra-trace level estimation of heavy metals in EAD were diversified to various fields of heavy metal contamination in food, medicines, herbal preparation, etc. Dr. Nambi steered one group to exclusively work on atmospheric concentration of lead and its impact on the concentration of lead in blood of population residing in that area. This was a relevant study during the period, when lead was being added to gasoline as an anti-knocking agent. The long term study, spread over years, was recognized and used by government agencies to impose reduction of lead addition to the gasoline.

Dr. Nambi also led the work on the quantification of heavy metals in various herbal medicines. It was found in one of the studies that although trace metals in a herbal preparation were very high, it was not reflected in the blood samples. This was a bold statement, specifically during the period when there were several objections worldwide on certain Indian herbal preparations due to its high heavy metal contents.

His intense engagement with heavy metal studies in relation to human health continued. His team established the buildup of Aluminum level in the patients undergoing Dialysis. This led to changing many components and techniques of

dialysis. Studies on blood Selenium levels in patients undergoing treatment for depression was another field which helped doctors in controlling the dosage given to the patients. These and several other studies led to the starting up of a new facility at Bombay Hospital to treat patients with heavy metal poisoning.

In the nineties, Nambi catalyzed the development of standalone and rugged continuous air particulate and gaseous monitoring equipment for conventional pollutants and long term monitoring were carried. For the first time, a major study, involving more than a dozen types of measurements (solar radiation, Ozone, SOx, NOx, organic pollutants, heavy metals, aerosol number and mass concentrations, etc.) were organized to understand the effects of the solar eclipse (October 1995) on air pollution and the post relaxation response of the environment. This showcased not only the comprehensive expertise that existed in EAD at that time, but also the team spirit of the division.

Nambi's efforts at integrating measurements with modeling saw applications in identifying the sources of conventional pollutants in nuclear power plant areas like Tarapur where there are large numbers of secondary industries, mainly to differentiate the contribution from nuclear and non-nuclear industry. In this context the editor remembers Dr. Ganguly's suggestions of identifying source of pollution from monitoring results of pollutants from multiple sources many years earlier. The findings and conclusions were published in various peer reviewed journals and are widely referred to. A "National Symposium on Environment" sponsored by BRNS was initiated by Dr. Nambi in the early 90's and still continues as a monument of the great guru and one of his notable products.

2.8 Internal dosimetry and trace element analysis
- 2.8.1. S. Somasundaram
- 2.8.2. Kamala Rudran
- 2.8.3. S Somasundaram
- 2.8.4. A R Reddy

2.8 Internal dosimetry & Trace element analysis

2.8.1.1 Evolution of Body burden measurement in AEET

Somasundaram

While the CIR reactor was being constructed, the Canadians inquired about the availability of whole body counting for internal dosimetry of workers from possible intake of radionuclides once the reactor starts working. As a sequel to this, a separate section called Body Burden Measurements Section was organized in the Health Physics Division and A S Chhabra was asked to develop the necessary infra-structure before CIR went into operation. Following the trends in other countries it was decided to set up a total shield whole body counter

for assessing the internal deposition of various radio nuclides in human body using a large volume NaI detector housed in steel shield. Accordingly a 40 ton steel hut was setup at a location away from the reactor environment in order to reduce the radiation background, at the OYC DAE offices 20 km away. The initial team for this consisted of Hukkoo, an alumnus from AEET training school and Katoch, a physics graduate recruit. Vaidya another alumni from AEET training school was given the assignment to design the electronics system for the whole body counter. To assist him there were two electronic specialists Ravetkar and Ghatikar. 200 tons of special virgin steel free from any radioactive contamination was procured and the Central Workshop, AEET designed the steel hut with a steel door. (Industrial steel is likely to be at times contaminated with Co-60 which is a tracer used in blast furnaces for steel production).

The inner side of the steel room was lined with lead to further shield the detector from the backscattered background radiation. The tilting chair geometry was used for locating the subjects for counting. The penetration of cables into the steel room was such as to avoid any direct streaming of background radiation. Vaidya and his team developed the electronics including a pulse height multichannel analyzer required for operating the NaI detector and Hukkoo created a pressed wood phantom simulating the human body torso to carry out calibration using standard Cs-137 and Co-60 sources and the whole body counter was made functional in time.

ICRP at that time suggested Ra-226 as reference radioisotope for body counting because of extensive toxicological studies available from dial painters, uranium mines and elevated natural radioactivity areas. A few recruits joined the team who took up studies of Ra-226 from environmental samples after radiochemical separation. The workforce was greatly augmented by alumni from AEET training school - RC Sharma, M R Sachdev, S P Garg and H S Dang. Unnikrishnan joined Vaidya's team. Chhabra got his Ph.D. on his work with Ra-226.

On Chhabra's resignation in 1960 Dr. Ganguly appointed Hukkoo as the head of BBM Section. Prompted by Dr. Ganguly he developed a light weight shadow shield body counter. Made of steel sheets of different sizes and shapes for shielding the NaI detector while it views the body of the subject lying on a couch. This could be easily disassembled and transported and set up in any location and was ideal for scanning radiation workers for intake of gamma emitters like Cs-137, Co-60, etc. Dr. Ganguly directed this to be set up at the basement of the Modular Labs since at this location it was not found to be affected by a higher radiation background from the Ar-41 plume released

through the stack of the CIR reactor. Air which contains natural Argon was used in the reactor to cool the shields. Katoch and colleagues used shadow shield counter to scan the radiation from CIR, Radio chemistry division and Isotope division for internal dosimetry workers.

Somasundaram was on an IAEA assignment for four years till mid-1969. On his return, Dr. Ganguly asked him to take over the BBM section as its Head. This was a surprise for Somasundaram since he was associated with organizing the health physics operations for RAPS before his departure to Vienna in 1965. By the time he returned RAPS health physics operation was already being organized by BML Sah and V K Gupta. Dr. Ganguly decided on this assignment in preference to his continuing in his earlier tryst with operational health Physics due to his extensive hands on experience with organizing and application of whole body counters while he was in IAEA. SS reminiscences that during his tenure at IAEA, he had visited several countries, compiled a directory of whole-body counters and collated body burden measurement data. While in IAEA he had also associated with the application of body counting in radiation medicine and compiled and reviewed data on radiation exposure of radium dial workers. In every assignment, Somasundaram showed his mettle for organizational and documentation skill and always put his heart into it which was noticed by Dr. Ganguly.

Soon after A S Rao in recognition of his organizational skill gave Somasundaram an important assignment on the directive from Sarabhai to act as Secretary of the First national conference on electronics during February to August 1970. This important conference was sponsored jointly by DAE and DOE. The services of SS in conducting this conference was well appreciated by all including Sarabhai. SS remembers that Sarabhai once showed him a communication in which PM Indira Gandhi had commended the role played by Somasundaram. Somasundaram was also perhaps tipped as the Secretary to the Electronics Commission which was being set up. At the end of these tasks Somasundaram perhaps preferred his assignment with BARC and took control of the BBMS. At this time SS had also a two month assignment on Radiation protection from IAEA and visited several south East Asian countries and made recommendations to IAEA on their programs. He thus got again an opportunity to demonstrate his organizational skill on any scientific assignments. Somasundaram expresses his gratitude of support from his colleagues in BBMS in these assignments and also for carrying on the day-to-day responsibilities of the Section during his absence. SS plunged back into his assignments on building up the body burden measurement activities by end of 1970.

After in-depth discussions with his colleagues SS submitted a proposal for an action plan to revamp the activities on Body Burden Measurement Section in the following areas:

- Development of shadow shield counters and its deployment in various DAE sites and expanding its applications
- In vivo measurement of Pu-239 and other actinides using low energy gamma spectrometry.
- In vitro analysis of human body tissues and body fluids for estimation of trace elements.
- Innovated use of shadow shield counters for radiation medicine applications using radioactive tracers to study body function and in diagnostic medicine
- Use of body counters for distribution of K-40 in children

Dr. Ganguly not only gave whole hearted support for these plans but also suggested innovations.

Shadow shield counters were installed in various locations at the Trombay plutonium plant, Tarapur reprocessing plant, at IRE Alwaye and at the various NPP sites. BBMS oversaw the installation, quality control and calibration and provided phantom and standard sources for calibration and looked after the maintenance. These were however operated by the respective health physics units. An illustrated user manual was prepared for guidance in the operation of these systems. Dr. Ganguly suggested the setting up of shadow shield counters in the ESLs which were being set up at all DAE industrial units. P R Kamath had produced a design document for these ESLs with all details of civil construction, instrumentation, auxiliary facilities and the man power required and this became a blue print. This document was accepted and appreciated by IAEA and WHO. On the suggestion of Dr. Ganguly, Shadow shield counters were included in this. The locations were ideal for operating shadow shield counters, since the ESLs on Dr. Ganguly's initiative were located in low background areas at the DAE Townships away from the nuclear plants to facilitate low level counting. These were used to monitor the workers in the plants for any intake of radio nuclides and assessment of the internal dose. Selected members of the public in the immediate vicinity of the plant were also scanned to ensure that they do not have any intake of radionuclides from the operation of the power station. The nuclear power stations at Tarapur, Kalpakkam, Narora, Kakrapara, and Kaiga, and front end facilities at IRE Alwaye and UCIL Jaduguda were all provided with this facility and enabled the Health Physics units to control and assess the internal dose of the radiation workers. A steel room was erected at NFC Hyderabad. The local building

materials were found to contain unacceptable amount of natural uranium daughter products which could hamper the body burden measures and hence the materials were transported from Mumbai.

Such a shadow shield counter with advanced features was also provided to Philippines with whom India had a collaboration program under an IAEA contract. Advanced features were incorporated in this unit such as adjustable slit collimator, radioactivity profile studies, segmented scanning of internal organs, etc. with possibility of using in medical diagnostic applications as well. Reactor control section provided engineering design. The system fabricated and tested in Trombay was airlifted and re installed by the BBMS staff members at Manila. For aiding the operation and calibration, users were provided with manuals, pressed wood phantom and standard sources. A working model of the body counter was also exhibited at the Delhi exhibition which educated the public how radio tracers can be used to evaluate the performance of organs and diagnose malfunctioning. It also provided educative fun for children to locate radioactive sources.

At the international symposium on radioactive internal contamination held in Sweden in 1975 Somasundaram gave the keynote address and chaired the panel discussion. Panelists included pioneers like Dr. Morgan. The conference enabled SS to highlight the pioneering work done in India. A few papers from India were also presented at the conference. Dunster and Newton were present the conference. Newton had in later years made many visits to India and contributed to the various programs of the BBM section.

In vivo counting of transuranics using low energy photons to measure pulmonary deposit of inhaled Pu posed challenges due to the very low energy x-rays emitted by these isotopes and its very low limits of body burden. The varying attenuation by the chest wall of the subjects was also challenging. Somasundaram and his team had done pioneering work in the development of special detectors and adaptation of methodologies for these measurements. Gas ionization, gas scintillation, thin NaI detector. NaI CsI phoswich combination, etc., were tried out for this purpose. Somasundaram put his team consisting of RC Sharma, Unnikrishnan and Garg on this work. He also proposed to carry out Monte Carlo computations to corroborate the experimental results using these detectors published by Dr. Lindenberg. The team accordingly developed computer codes for CDC 3600 computer at TIFR and published a paper on the response of thin NaI detectors for low energy photons below 100 key. Not only the paper was accepted without modification in Nucl. Instr. and Methods but its editor Siegbahn commended the work. Kai Siegbahn got his Nobel Prize later in 1981 for his work on nuclear spectrometry. His book on

alpha, beta and gamma spectrometry was a bible on the topic for us in those days! Chemical Engineering Division had initiated work on preparing NaI detectors, and BBMS provided the testing of these detectors for low energy gamma rays. The expertise of the team on gamma spectrometry was useful to evaluate their detector development programs. A paper in Nucl. Instr. and Methods was published on the modified low energy gamma spectra from radioactive nuclei present in tissue equivalent media. These were accepted internationally with Prof. Turbey requesting for the code developed in BBMS for inclusion in the Code Library. This was provided to him after Dr. Ganguly got necessary clearance from DAE.

At this point of time phoswich detectors were being developed in UK and SS imported one such large area detector and put Krishnamachari on developing the necessary pulse shape discrimination circuits in which he became an expert. ABS Sweden requested the services of R C Sharma for low energy photon spectrometry under the technical cooperation with Sweden. Dr. Ganguly obtained the permission of DAE for this participation and R C Sharma worked as an expert at this institute. RC Sharma participated in a symposium on radioactive contamination in human body and presented his work which attracted the attention of Benson. This led to collaborative programs with Dr. Newton of AERE Harwell. These collaborations were very useful and Garg from BBMS worked with Newton in UK for some time and as part of a bi lateral collaboration between AERE Harwell, UK and BARC in this area. Under this Newton visited BBMS and had very useful interaction with SS and his colleagues. He suggested use of short-lived radio isotope Pd-109 for calibration of phoswich detectors to simulate Pu-239 x rays. Kotrappa who was by then doing pioneering work on aerosol physics had developed polystyrene aerosols generators and he tagged these with Pd-109 which enabled this to be used as tracer in volunteer subjects. SS volunteered to inhale these which resulted only a very minute dose and enabled him to carry out very useful research in using this method to calibrate phoswich detectors. This was carried out under the bilateral program with same subjects being counted in Harwell as well as in BARC and produced very useful results. This resulted in a paper in Health Physics journal on x ray detection efficiencies for Pd-109 data from the two laboratories. These measurements led to exchange of information between BARC and Livermore laboratories in USA. This also resulted in IAEA mooting to initiate a coordinated research program on using Pd-109 for these investigations but later had reservations about the ethical implications of subjects voluntarily inhaling radioactive aerosols. So they instead initiated a program with Lawrence Livermore laboratory offering

to provide a realistic chest phantom with known amount of impregnated Pu-239. BBMS participated in this program with Somasundaram as leader. This resulted in an important contribution from India and was published as a report. Dr. Turbey commended the contribution of BBMS section in this area. Dr. Ganguly played a prominent role in patronizing these ventures.

2.8.1.2 Low Level Radioactivity Counting Laboratory at BARC Hospital Somasundaram

Somasundaram took a prominent role in the setting up of the Low level counting laboratories at the ground floor of the BARC Hospital building in Anushakti Nagar which was taking shape in 1975. Dr. Bhabha had in his visionary conception envisaged this huge hospital complex for the DAE fraternity, which turned out to be a boon to generations of BARC employees and retirees along with their families. Dr. Ganguly in turn had facilitated LLRCL project while the BARC hospital complex was being constructed in 1971 and envisaged the special laboratory in view of the need for locating these away from the BARC premises to enable efficient functioning due to consideration of the possible higher background in the vicinity of the nuclear facilities in Trombay. An Emergency Control Centre was also to be a part of this complex. This was analogous to the locating ESLs in township in DAE nuclear power sites. The proposal was approved by DAE and necessary provisions were made in the blueprint.

The following laboratories were envisaged in the new location

1. Relocation of existing whole body counting facilities at OYC location of the BBMS Section
2. Environmental sample analysis laboratory, the AAS laboratory, etc. of the RHC Section
3. Low level counting laboratories of the Air Monitoring Section requiring low backgrounds
4. Aerosol Physics Laboratory conceived by Dr. Kotrappa

Dr. Ganguly appointed Somasundaram as the liaison officer to implement this project known as LLCL project. The plans included the design and construction of a world class Whole Body counting laboratory with features involving the setting up of a steel room with 100 tons of steel much bigger than the steel hut of 40 tons at OYC. This was to be located at the basement of the Hospital building to take care of load bearing. The steel room design comprised of two compartments: one locating phoswich detector to routinely carry out lung counting of the Plutonium plant workers. And another compartment was meant for use in investigations and research of new type of detectors and methodology.

Both the compartments had massive steel doors electrically operable from a control desk which had also the electronics for counting and spectrometer systems which were all located in the hall outside the steel room. The steel shield of the first compartment was provided with additional lead and also graded shields consisting of lead, cadmium and electrolytic copper to shield the detector from low energy photons from the interaction of background photons in steel and lead. Special conduits and penetrations were provided for leading the cables to avoid any streaming of background radiation inside the room. The steel room was also provided two way in circuit TV and soft music to provide a pleasant atmosphere for the subjects being counted for long times of 45 minutes.

Bath room and change room were provided for the subjects to be ensured free form any external contamination before counting. The radiochemical laboratory for preparation of samples and standards connected to body counting was also provided. The existing workshop at OYC was upgraded to take care of setting up of this new facility. On request from Dr. Gopinath the existing steel room at OYC was to be shifted to Kalpakkam SRL to cater to the needs of the Fast Reactor Centre including lung counting of workers from plutonium handling facilities there. Dr. Ganguly approved these proposals. The need of an engineer was felt and NPN Shetty from RHC section was transferred to BBMS.

The laboratories were located in the ground and first floors of this wing of the hospital. The basement posed some problem of possible flooding due to rains. This portion of the basement was 3 feet lower than the rest of the basement. This was taken up with the civil engineering division and they provided additional protections. The central workshop provided the engineering support for setting up the steel room with it massive doors and the Reactor Control division designed the control system for operating the steel room. Thus a thoroughly revamped Steel room and new laboratories were successfully commissioned.

While transporting the Whole body counter auxiliaries from OYC started, stocks taking showed some platinum crucible in the chemistry lab were missing and this led to investigations and follow-up. In spite of these distractions and unsavory incidents, Somasundaram and his team put their heart to the scientific assignments and brought up successfully the whole body counter system at the LLCL. The momentum of the project continued. Haridasan studied the chest wall thickness of subjects using the 3 D ultra-sonic scanner available with the BARC Hospital and developed correlation equations which

was different from that used internationally by Lund. This was required for correction of low energy photons emitted from imbibed Pu in subjects. He also got his Ph.D. on his work using phoswich detectors.

Vaidya and G Krishnamachari developed two 100 channel analyzers, one of these was later used in the PNE experiment. BBM section imported a mini computer and with end use controls. But it looked absurd since a private company under agreement with Digital Corporation with no restrictions started manufacturing it and was available in the Indian market. This computer was used by Vaidya and his group in the whole body counting console effectively.

2.8.1.3 Application of shadow shield counters for applications in medicine

S Somasundaram

Somasundaram got involved with the use of shadow shield body counters for clinical applications during his tenure in IAEA and took interest in these. He thus initiated this program in the BBM Section extensively. Due to Somasundaram's efforts, the doctors in GS Medical College got interested in studying the uptake of vitamin B_{12} in patients by using a radioactive tracer and following up using the shadow shield counter. This encouraged SS to pursue the proposal and he facilitated the approval of BARC with the support of Dr. Ganguly. H N Sethna, Director BARC not only gave the necessary permission but directed that the hospital should be given all support to pursue this line of research. Consequently shadow shield counters for medical applications were installed by BBMS at the GS Medical college and then at Grant Medical college. The service of Mehta was provided to G S medical college and he pursued this line of research and obtained his Ph.D. degree creditably. Mehta was subsequently transferred to Grand Medical College. Jeevanram who took Ph.D. in these studies later was transferred to RMC and replaced by Raghavendra Rao who looked after the shadow shield body counter at the Mod Labs. Katoch who was carrying out these duties participated in a study of Mg in cardio vascular studies using Shadow shield counters and got his degree.

Dr. Baker, an Australian Missionary working in Vellore Hospital requested Dr. Dudley head of the Life Sciences at IAEA support for his studies on B_{12} in tropical pulmonary studies. IAEA in turn forwarded it to BBMs and finally his request was approved in BARC. A scanning bed shadow shield counter was supplied to Vellore hospital and this was commended by Dr. Ramanna, Director BARC. A shadow shield counter was also to be supplied to Zonal Centre for Nutrition Studies, Hyderabad on using body sodium for medical studies. Though Dr. Ramanna and Dr. Gopal-Ayengar were appreciative during a review, the collaboration could not be pursued. Thus, the use of body

counting and tracers became well spread in the medical institutions in India due to the perseverance of Somasundaram and the patronage of Dr. Ganguly.

Somasundaram considers his career with Dr. Ganguly in meeting his goals in the areas of body burden measurements and the applications of shadow shield counter in the areas of medical research as the most productive periods in his career. The vicissitudes of life again came rolling and Somasundaram found himself in the midst of his earlier role as an excellent operational health physics organizer when he was transferred to head the RHC Section in 1980. He later concentrated on his organizational capability in his role in the regulatory body toward the end of this professional career. He has such a rebounding capacity and post retirement he yet played another prosperous role in his personal life as a financial consultant in USA in which he used the lessons he learnt in his scientific career. Somasundaram took the trouble of sharing his extensive memoirs and private recollections with the editor of his exciting tryst with the health physics program in India, in his own "typical" handwriting that is familiar to many old timers, in spite of his "failing faculties", from his retirement habitat in USA

2.8.2 Evolution of Internal dosimetry – Bioassay and Excretion Analysis. Kamala Rudran

When one attempts to record the evolution of the development of body burden measurement of radiation workers through excretion analysis, one cannot but recollect the major role played in this area by Dr. Kamala Rudran and her team. This program grew complementary to and with excellent coordination of the whole body measurement activities started by Dr. Chhabra in which Somasundaram played a major role after 1964 in developing techniques and setting up whole body counters and scanners along with his team many of whom became international experts.

The activities on Bioassay were evolved centered in a small chemical laboratory of 200 square feet at a naval barrack shed at TIFR campus Colaba, with its makeshift linoleum covered floor, developing techniques for analysis of excreta samples for assessing the internal dose to radiation workers from intake of various radio isotopes. Initially the activities started with analysis of urine samples from radiation workers. SD Soman was directing the newly joined recruits A Ramamurthy Jr. and others in these activities. PR Kamath was overseeing the environmental sample analysis in another shed when KC Pillai and IS Bhat joined him. Later on PR Kamath took over charge of the bioassay development activities also. These laboratories were shifted to a shed behind the "Electronics Shed" at the South site at Trombay in 1959. Subsequently when construction

of Modular Laboratories was completed in 1966 the laboratories were shifted to the III floor of this unique building. Kamala Rudran recalls how after joining the Health Physics Division and reporting to Dr. Ganguly she came to be associated with bioassay activities. The bioassay labs had by then already shifted to the Electronics shed.

In those days, probable rough estimates of radioactivity intakes were arrived at from air concentration measurements in the workplace. Body radioactivity measurement leading to internal dose assessment was accomplished by measurement of radioactivity in urine samples and extrapolation using known excretion patterns for workers in areas where air activity measurement suggested the same. A ready reckoner AEET/H P/BA/I was published in1958, under the able initiative of Dr. Ganguly by S D Soman and P R Kamath to arrive at the body burden.

A reasonably good chemistry laboratory for radiochemical separations, a counting room with Zns(Ag) scintillation counter for alpha and GM counter for beta, a spectrophotometer and a fluorimeter with accessories, took care of measurement of thorium, natural uranium, alpha and beta emitters. The counting room support was ably organized by LH Peshori who also took care of all instrumentations support for radiation monitoring in the various plants. A number of innovations were inducted in this area as well. The assessment of tritium which was initially accomplished by gas phase counting and called for simpler more efficient liquid scintillation counting. A separate program for this was taking shape under the direction of S D Soman and Dr. Ganguly who realized the importance of this in view of the large scale PHWR program that was envisaged. T. Sesha Iyengar specialized in this area and had established one of the best tritium labs and inter alia carried out many basic uptake studies on Tritium. He was even known as Tritium Iyengar. Sadarangani, Vaze and Sahasrabudhe were some of the scientists who contributed in this field along with Iyengar and Soman. They carried out study of biological half-life of tritium after ingestion by volunteers.

Kamala Rudran reminiscences that in college each student had to bring their own tiny platinum wire. Here right up to crucibles were available not under lock and key, but under individual responsibility. Urine collection protocols were established along with instruction for collection of urine samples. Workers were instructed to take a bath to avoid external contamination and to collect urine voided in the 16 hours at home. She notes how the collection program was a success with co-operation from the workers, local health physicists and a person for sample collection, Mustapha, who went around the laboratories

with specially selected plastic bottles encased in a khaki bag so that the radiation workers could carry it without inhibition to their homes for collection of samples and return it the next day. Though these might look trivial, the practices were firmly established and contributed to the success of the program. The program started with collection of samples for internal exposure cases from Indian Rare Earths factory, Uranium Metal Plant, FAGGOTS, the fuel fabrication plant, Radiochemical and Isotope Laboratories and later extended to the CIR reactor and the Trombay Plutonium Plant. Later on the service was extended to other DAE units like IRE Alwaye, NFC Hyderabad, UCIL Jaduguda, till their own monitoring programs were initiated and to outside units like radioactivity labeled luminous paint factories at Bombay and Bangalore which didn't have monitoring program of their own.

Analyses were started for uranium, thorium, plutonium, gross alpha, gross beta and tritium to begin with. The first development assignment allotted to Kamala was on the use of silver chloride for adsorption of Iodine - 131 from aqueous samples like urine and environmental water samples. P R Kamath on being suggested by Dr. Ganguly asked Kamala to look into this. That beginning finally led to use of silver chloride as a concentrating matrix for radioiodine, with potassium iodide as added carrier, followed by separation of silver iodide for beta counting. Efficiency for recovery was established to evolve correction factors. Next to this, similar methods for concentration of radio cesium using canary yellow powder of ammonium phosphomolybdate was standardized. Radiochemical separation technique for Cobalt-60, removing zirconium impurities as phosphate followed by purification on anion exchange column, reduction with sodium sulfite and precipitation as oxalate was also developed. A Ramamurthy Jr. on guidance from Dr. Ganguly developed electroplating techniques initially for preparation of alpha standard sources which was then applied for preparing samples for alpha spectrometry for environmental samples also. He earned his M.Sc degree and later Dr. Ganguly facilitated his doctoral program at McGill University, but he left soon afterward. He had trained Mitragotri in the electroplating techniques by the time he left. Radiochemical separation using ion exchange columns followed by co-precipitation on ferric hydroxide for alpha counting for actinides and by spectrophotometry for thorium was subsequently developed. This resulted in elimination of alpha background due to traces of thorium present in lanthanum carrier used in the earlier procedure and facilitated sequential separation and estimation of plutonium, americium, thorium and uranium. Sometime before 1967, procedures for estimation of Carbon-14, and Ruthenium-106 in urine were developed as and when necessity arose. By this time, under the overall directions of Dr. Ganguly PR Kamath had

organized a good work force for bioassay and Kamala was heading this group. This was a unique group which was dominated by women scientists. Elizabeth Mathew, Urmila Kantak, Vasanti Matkar, Jyoti Sawant, Somasundari Thampan, Vasanthi Bangera, Vijaya Pullat, Lalita Barde were some of the stalwarts of the early years. Many of them along with Kamala earned their Ph.D. degrees in that process. The team was then called by some as "Kamath and his girls!". Many people who got experience in these programs were then deployed to various other environmental laboratories around the country in the national atomic energy program. Thus Dr. I S Bhatt was asked to head the first environmental survey laboratory at Tarapur Atomic Power Station, MAR Iyengar, Raghavayya, and Markose went to UCIL Jaduguda, R P Gurg and Dube to Kota, Sebastian to Kakrapara and Paul to IRE Alwaye. MAR Iyengar who had left the group for UCIL later was posted at ESL Kalpakkam to manage the environmental and internal dosimetry unit at MAPS. Thus, the environmental and bioassay labs at Trombay was the nursery for the environmental scientists all over the country who were trained and ably guided by Dr. Ganguly.

In 1962, AKG had organized another activity on environmental radioactivity investigations with the initiation of the Project Marina which was funded by IAEA. Dr. R Viswanathan, Dr. T. P. Sarma, Dr. Y. M Bhatt, Dr. B Patel and Dr. Mrs. Patel were the experienced trained scientists with doctoral degrees who were imbibed into the program and Dr. Ganguly thus initiated the marine ecology and oceanographic program of the center at Trombay. Some of them had participated in the prestigious Sagar Kanya expeditions to the Antarctica.

The internal dosimetry program advanced further and one of the best teams anywhere in the world took shape. Developments centered around bioassay part of internal dosimetry were on radiochemical analytical techniques, study of excretion and retention patterns, deposition and clearance from organs by following excretion patterns, in vitro studies and radiation dose computation to match ICRP standards. These were amply augmented with whole body counting. Internal dose estimation and apportionment in case of plutonium was a challenge with its very low body burden limits and low intensity low energy photon emissions. The combined work of the whole body lung counting ably developed under the directions of Somasundaram and Dr. R C Sharma and the plutonium excretion analysis by bioassay by Kamala and her team was a great feat of achievement in meeting the challenging program of assessing internal exposure in the fuel reprocessing program of the country.

In 1967, Kamala was sent to AERE, Harwell, UK for training in internal dosimetry. Dr. Ganguly had sent letters of introduction to Dr. Lister and

Dr. Stewart who were international stalwarts in radiation protection. Dr. Ganguly had earlier arranged a lecture series in AEET by Stewart for a couple of weeks which benefitted the early entrants to the Health Physic Division. At Harwell Kamala had the opportunity to work with Dr. Z Morgan, John Eakins and A Lally on radiochemical techniques and developed a comparatively easy, efficient and economic method for electro deposition of actinides from aqueous ammonium sulfate on to stainless steel planchettes. The procedure has been subsequently in use at Trombay as well as at Harwell. This work was brought out as a Harwell publication in 1969. She recalls the importance given at Harwell to fecal analysis in estimating intakes of sparingly soluble radioactive substances and this was introduced later at Trombay. Wide mouthed plastic bottles with a plastic cover inside to collect the fecal voidings wrapped in purple cloth bags were supplied for the same. One of the things noted by Kamala during her stint abroad for training was that the chemical methods intuitively developed at the start of the program in India were also the same process in other countries. By the time Kamala left Harwell after getting training from Dr. Beach, she had imbibed the metabolic diagram for uptake of radionuclides in the organs and the method of computation of internal dose from body and organ intake of radioactivity. On return to Trombay in 1968, the concepts she learnt were introduced at Trombay and also in evaluation of dose from acute intakes. The entire dose, infinite time integral from an intake, was allotted to the dose for the year, unlike the 50 year committed dose allotment adopted by ICRP later on. But for Plutonium, annual dose evaluation and apportionment posed challenges due to its long biological half-life and were finally sorted out much later when the editor happened to head the Radiation Safety System Division during 1991-1994. Krishnamony contributed significantly to resolving the issue.

Kamala Rudran and K N Kirthi published a research paper in 1983 on basic limits for control of internal dose along with Annual Limit of Intake and metabolic pathways and other parameters observed at Trombay for computation of dose from the intakes of tritium as tritiated water. Three-tenth and one-tenth of limiting values which were termed reference levels were worked out and recommended as investigation and recording levels for acute exposure. Corresponding derived levels in urine and air were also computed and published mainly to make similar computations for specific radioactive compounds where general formulations did not suffice.

The internal dose evaluation program also led to many basic studies over the years:

1. The establishment of biological half-life of tritium, sulfur, strontium, cobalt, iodine, cesium, polonium, uranium, and plutonium in Indian

subjects, some of which were significantly different from that reported in western subjects.

2. The necessity to differentiate between tritium as tritium gas, tritiated water and labeled paint for dose evaluation.
3. In vivo organic binding of tritium, strontium, uranium and plutonium and its effect on total radiation dose.
4. Establishment of behavior of cesium as W class aerosols (moderately soluble) and D class (highly soluble).
5. Method of evaporating urine and blood to water free organic matter at room temperature was developed for the evaluation of organically bound radioactivity. The method was subsequently used for estimation of tritium, Pu, Sr-90 and uranium in cells and plasma,
6. Establishment of fecal to urine excretion ratios of various radio isotopes
7. Investigation excretion patterns of plutonium following exposure by inhalation and absorption through skin in some burn incidences
8. Periodical confirmation of accuracy of analytical procedures by participation in International Inter-comparisons conducted by International Reference Centre, WHO

2.8.3 In vitro analysis of trace elements in human body
Somasundaram

Somasundaram's interest in this topic evolved as a result of his earlier work on the Indian Standard Man. The evolution of Atomic Absorption Spectrometric analysis program is already mentioned.

During his training in USA, SS had spent the summer of 1960 in Argonne National Laboratory from May to August 1960. A team consisting of Hurst, Richter and Auxier had just then returned from Yugoslavia where a criticality accident took place. They went there to conceptually recreate the accident and to assess the dose received by the victims. SS learned that they used neutron activation methods and Monte Carlo methods to determine the dose received by the victims.

Somasundaram after his return in 1966 suggested to K N Kirthi to take up study of activation analysis on blood samples for elements like Cl, Na and S for application in accident dosimetry. The blood samples were provided by Dr. Shah of Medical Division.

During his IAEA assignment for 4 years from August 1965, the Indian standard man activities came to a halt with Venkataraman resigning and Raghunath given other assignments. After his return in 1969, SS took up the study of trace

element in human body by neutron activation analysis. H S Dang in BBMS pursued this study using the newly constituted laboratory facilities in the BARC hospital. Dang got training on this in the analytical chemistry division under Shankar Das. He took up a study of trace elements in Ayurvedic medicines in which Podar Medical College was interested. A systematic study was also initiated by Post graduate Institute at Chandigarh

Under the initiative of Somasundaram this led to BBMS participating in an IAEA coordinated research program on neutron activation analysis in life sciences with Analytical Chemistry Division and Radiation Medicine Centre under Ganatra. That led to considerable research on pediatric medicine and a committee was formed to coordinate the efforts. The committee decided to work on:

- Constituents of human milk by neutron activation analysis
- The study encompassed not only the nutrients but also trace elements like as Hg, etc., to study hormesis theory
- HS Dong and Jaiswal were involved in these studies
- Clean room facility was used to avoid any post irradiation contamination.
- IAEA was requested to provide standards for the estimations

Dr. Ganguly provided necessary guidance for this team which met periodically to review the work. This is yet another area where SS was able to organize a multi-disciplinary team for activation analysis and brought scientists from different areas including life sciences and made them aware of the potential of analysis tools like activation analysis and body scanners. SS recalls M R Iyer providing training to Dang in high resolution gamma spectrometry available in his lab. The 3 years coordination program led to publication of several papers on the topic.

The major findings of this study were:

- For the first time yielded data on Mo in human milk which is component of growth hormone
- Concentration of Mn was lower than in that indicated in NBS standards who accepted the findings
- The recommended daily allowance of Mg is probably lower than that adopted by WHO
- Indicated adequate level of trace elements up to 4 months post-partum and showed the need for supplements beyond that.
- The study did not support hormesis of toxic elements like Hg and As

Thus the multidisciplinary team initiated by Somasundaram under the guidance of Dr. Ganguly delivered significant findings. Dr. R M Par of IAEA was

the coordinator for this project and he took deep interest in the work and made several visits to India. IAEA extended the project by 3 years. R M Par suggested fine resolution PIXIE analysis for further studying the trace element distribution in human tissue. At this point of time SS was called upon to take charge of RHCS leaving his stint with BBMS. With SS being shifted from BBMS and Dr. DeCosta leaving RMC the project went into Limbo and was not pursued. SS dedicates this work on trace elements to Dr. Ganguly whose unstinted guidance enabled this work to have impact in several countries in addition to its impact on medical circles in India.

2.8.4 Dosimetry of Internal Emitters in Nuclear Medicine

A. R. Reddy

In the first NSRP conference during 24-27 November 1970, which was organized under the convener ship of Dr. A. K. Ganguly, I was one of the invited speakers. I spoke on Dosimetry of Internal Emitters. Dr. Ganguly, in concluding session while summarizing the proceedings, said "In dosimetric techniques as applied to life sciences there is scope for further improvements in precision of the existing methods. But fundamental developments in this area of applied radiation physics, perhaps, have to come from the concept of microdosimetry as brought out by Dr. Reddy." Today, nearly 37 years afterward, I wish to dwell on the same topic of Dosimetry of Internal Emitters to bring out the developments that have taken place over these years and try to examine whether the prediction of Dr. Ganguly has been realized.

Dosimetry of internal emitters deals with the quantification of the amount of energy imparted to a target in a biological system due to different types of radiation emitted from a radionuclide distributed in it or elsewhere in the system. It also is concerned with the spatial and temporal distribution of this imparted radiation energy in the target. The target in nuclear medicine procedures could be whole body, or an organ, or a tissue, or a cell or a sub-cellular structure. The energy imparted to the target is converted to the absorbed dose. Internal dose computations are done not only in medicine but also for radiation safety and radiobiological issues. The dosimetry of internal emitters is generally presented at 4 different Levels.

Level-1: Generic Dose Estimation in Diagnostic Nuclear Medicine:

The internal dose estimation utilizes age- and sex-specific reference data for human anatomy and body composition. In the diagnostic use of a radionuclide the associated risk due to radiation dose far outweighs the diagnostic information derived for the benefit of the patient. Hence estimation of an

average dose assuming uniform distribution of radioactivity in the target organ is considered sufficient. Number of MIRD pamphlets giving basic methodology and tables of data required (S-factors in $SvBq^{-1}$) for dosimetry are available. Using as far as possible human bio kinetic data (for normals) best estimates of the dose for several radiopharmaceuticals used in diagnostic nuclear medicine have been published. At this point it must be emphasized that all the physical data tabulated so far are for specific mathematically defined models although human bio kinetic data are used. Therefore, the dose estimates in the above MIRD pamphlets should be used as guidelines for general population not for a specific individual or patient.

Level-2: Patient Specific Dosimetry and Personalized Radionuclide Cancer Therapy:

With the increasing use of multimodality imaging systems (like SPECT-CT, PET-CT, PET-MRI) to obtain time-activity and anatomic structural details at the level of a defined 3D volume element (voxel) or a group of voxels in a tumor/organ/tissue for a specific patient (that is patient specific bio kinetics of the radiopharmaceutical) in nuclear medicine, dose estimations to patients undergoing targeted radionuclide therapy are made. Accuracy of dose estimation for therapeutic use of radionuclide has to be more stringent as compared to that for diagnostic use to assess any normal tissue injury. Hence the radiation dosimetry in nuclear medicine is evolving from population- and organ-average to patient- and position-specific dose estimation. Estimation of spatial variation of dose within a target tissue, tumor or normal, of a patient will be useful to arrive at specification of therapeutic dose to be delivered to the target and computing the isodose contours as well as dose-volume histograms.

I-124 based PET imaging studies were made for assessment of time dependent voxel by voxel spatial distribution of activity in the source regions (Sgouros *et al.*, 2004). Time integrals of the activity in the voxels of the source regions were computed to get the 3-dimensional cumulated activities using the software package Multiple Image Analysis Utility (MIAU). This information was used as input to the 3-dimensional internal dosimetry package (3D-ID) to get the mean, minimum and maximum absorbed doses, isodose contours, dose-volume histograms for patient specific dosimetry in I-131 therapy of metastatic thyroid carcinoma in case of a total of 56 tumors. Mean absorbed dose values for individual tumors ranged from 1.2 to 540 Gy. The absorbed dose distribution within individual tumors was widely distributed ranging from a minimum of 0.3 to a maximum of 4,000 Gy. From this detailed dose values dose-volume histograms were generated.

In near future it would be possible to plan personalized treatment of targeted radionuclide therapy with anatomic and molecular characteristics determined by imaging modalities complemented by genetic evaluation of the patient and use of a matrix of targeted therapeutics offering multiple radionuclide labels for molecular carrier combinations.

Level-3: Local Dose vs. Biological Toxicity of Auger Electrons:
Heterogeneity of activity distribution in a biological system with radiations emitted from the radionuclide penetrating enough as compared to the linear dimensions of a defined target of interest the dose distribution could still be uniform and hence the average dose estimate will be sufficient. But if the radiations emitted are of low energy with smaller range as compared to the target, the average dose estimate at an organ or gross tissue level loses meaning and dosimetry is to be done at a local level with the knowledge of micro localization as well as micro distribution of the radionuclide, its decay characteristics and range-energy or energy loss relationships. This has become essential in case of radionuclides that decay by electron capture and isomeric transitions resulting in Auger electron emissions (whose ranges are nearer to the linear dimensions of the subcellular structures).

Relative radio toxicity of Auger electron emitters, such as I-125, Br-77, tagged to an appropriate chemical that concentrate in either nucleus, or cytoplasm, or cellular plasma membrane was extensively studied. These studies brought out the importance of local dose estimate to explain the observed radiobiological end point. Also the RBE for the same radionuclide and for the same end point is dependent on where the radionuclide concentrates.

Level-4: Microdosimetry and Track Structure Computations for Targeted and non-targeted
Radiation Damage:
Stochastic nature of radioactive decay and the consequent stochastic nature of energy deposition in targets of smaller and smaller dimensions are taken into consideration in microdosimetry. Essential motivation for the research in the field of microdosimetry has been the evolving notions about relevant biological targets, in particular, their sizes (fluctuating from nanometers to 1 micro-m to 10 micro-m and back again to few nanometers) and the biological structure (DNA strands - cytoplasm - plasma membrane - neighboring cells - cells distributed in tissues) in relation to the microscopic features of emitted radiation from certain internal emitters. The probability distributions of the specific energy imparted to such targets have been computed for some electron emitters and alpha emitters. The methodology also computes

the number of targets that would not receive any energy deposition at all, in addition to the probability distribution mentioned above. The mean, or expectation value, of a large number of determinations of a stochastic quantity (like specific energy imparted) is a deterministic quantity (like average absorbed dose).

Microdosimetry does not specify the structure or character of the deposited energy and its spatial distribution in the target. It is assumed that the energy deposited in a volume and the number of atomic as well as molecular changes produced in the same volume are directly related and that the spatial correlation among these molecular changes do not influence the final effects under consideration. These assumptions are shown to be not correct by taking as examples the irradiation situations at different structural levels, viz., atoms, macromolecules, cell nucleus.

Energy deposition in matter due to radiation interaction (whatever may be the primary ionizing radiation) is ultimately through electrons. Fine structure details one is seeking in track structure calculations are therefore due to electron transport in matter. Monte Carlo codes for electron transport in water have been developed by several investigators to obtain the above detail of energy deposition. Statistically valid tabulations of energy deposition in microscopic volumes in water (representing macromolecular targets in tissue) have been produced from these computations. Analyses of these results led to expectations that local clusters of ionizations within a track in or near DNA could explain what is called 'clustered damage' in DNA. Clustered damage is predominantly confined to around 10 base pairs or few nanometers along the DNA strands. Monte Carlo track structure computations showed that the clustered ionization will have a spectrum of cluster sizes in terms of number of ionizations and the distance within which these are created. That means the clustered damage in DNA also will have a spectrum. Simple volume model of clustered DNA damage (of few nanometer dimension) along the DNA strands was assumed to represent this analysis.

Perfecting these codes with accurate cross-section data, intercomparison of the results, classification of the obtained track structure data with reference to radiation biology, radiation chemistry, derivation of the more familiar zF, zD and yF and yD values for submicron target dimensions, search for relevant parameters to describe the track structure computations, have been the subjects of study over the last 2 decades.

Over the last decade and half interest in 'non-targeted' processes in biological system subjected to radiation exposure is evinced. Genomic instability,

bystander effects, adaptive responses, induced radio resistance and homeotic effects are the phenomena observed as non-targeted processes far away from radiation affected targets of dimensions 3-10 nm (clustered DNA damage). Target dimensions per say for the above non-targeted phenomena although are not identified sensitive volume of interest range from 0.1 - 0.5 um for chromosome exchanges; around 10 um for intracellular non-targeted effects; and up to mm or more for inter-cellular bystander effects and influences of the tissue microenvironment.

Summary

Dosimetry of internal emitters is discussed at four levels. Generic dose estimations mentioned as Level 1 is sufficient as guidance reference values for diagnostic nuclear medicine applications. Patient specific and personalized radionuclide therapy dosimetry presented as Level 2 demands patient specific details of the involved tumor and normal tissue size and shapes as well as radiopharmaceutical kinetics in them obtained with modern SPECT-CT, PET-CT, PET-MRI imaging systems along with Monte Carlo computational 3D software packages to arrive at appropriate dose and dose-volume histograms. Local dose estimations mentioned as Level 3 dosimetry is to assess the dose-response relationships observed with various Auger electron emitters in radiobiological studies. At Level 4 stochastic nature of radiation emission in radioactive decay, and energy depositions in different target sizes and their relevance in explanation of radiobiological effects observed, both targeted and non-targeted, have been the subject matter in Microdosimetry and Track structure computations. At the end I would confidently say that predictions of Dr. Ganguly in the First NSRP in 1970 are realized amply in medical as well as radiation protection issues of radionuclide applications in the form of more realistic bio kinetic and dosimetric models for dose estimations. Developments in microdosimetry and track structure computations enabled identification of sensitive biological structures, energy depositions as well as stochastic in which are important, in explaining many observed targeted and non-targeted radiobiological phenomena.

2.9 Industrial Hygiene program

K S Somayaji

One of the earliest activities in the Radiation Hazards Control Section which Dr. Ganguly headed was the induction of industrial hygiene under direct instructions from Dr. Bhabha. Dr. Bhabha, in somewhat a foreboding manner and rightly so, envisaged that that while the radiation hazards were unique to the atomic energy program, the need for invoking industrial safety from conventional accidents. The hazards from radiation is controlled to a

large extent due to the importance given to it but the injuries and casualties due to conventional accidents are more of a concern. The person who was identified to oversee these activities was K S Somayaji and A Ramamoorthy Sr. Somayaji was recruited in 1956, after a brilliant academic career at the Presidency College, Madras University, to the Air Monitoring Section headed by Dr. Vohra. Somayaji began his career with the study of health physics, which includes the effects of radiation on humans, monitoring the environmental parameters which cause radiation hazards to workers and evolving and implementing control measures. A S Rao to whom Somayaji was reporting gave certain assignments to Somayaji to collate and analyze the information on the extent and composition of radiation fallout from the large number of nuclear weapons that were being tested in the open by USA and USSR then.

Somayaji notes that at that point of time in administering the newly formed Centre AEET, Dr. Bhabha was ably assisted by five Senior Scientists: Dr. A. R. Gopal-Ayengar, Dr. Brahma Prakash, Homi N. Sethna, Dr. R. Ramanna and A. S. Rao. The administrative wing was being developed by one of Dr. Bhabha's trusted friends, a British by birth, Mr. E C Allardyce who was the Controller AEET. He was from the former ICS service and was a strict disciplinarian and meticulous on good housekeeping. Dr. Ganguly was placed in-charge of the Radiation Hazards Control Section, while Dr. K. G. Vohra was in-charge of the Air Monitoring Section; both under Mr. A. S. Rao, Head of the Health Physics and Electronics Divisions. Later, Dr. Ganguly rose in rank to Head the Health Physics Division which functioned under the Electronic Group headed by A S Rao.

Somayaji started his career with activities connected with radiation safety and initiated measurement of the concentration of radon/thoron daughter products at the then newly started Thorium Plant of Indian Rare Earths Ltd. (IRE) at Trombay, using conventional filter air samplers and beta counting set ups. He studied the effect of ventilation in the plant on the thoron concentration, perhaps the first study of its kind. A paper on this study was the first from India published in the *Health Physics* journal. Later, he took part in the environmental studies prior to large scale exploitation of uranium at Jaduguda and in similar work at the IRE units in Kerala.

Dr. Bhabha, the visionary, recognized the vital importance of developing all aspects of a large-scale atomic energy program for a vibrant, emerging free India. Paying particular emphasis to safety, he instructed Dr. Ganguly and Mr. A. S. Rao to initiate activities to study conventional health hazards that co-exist with the radiation hazards, along with the due importance given to assessing and placing control measures in the field of radiological health. Somayaji

was identified to head this program and, along with A. Ramamurthy Sr., was earmarked to undergo one year's training in industrial hygiene under the Point Four Program of the US International Cooperation Administration.

Somayaji underwent basic Industrial Hygiene training at the School of Public Health (SPH), University of Michigan at Ann Arbor during 1959-1960. Toward the end of the course, in the summer of 1960, Somayaji visited uranium processing plants, other related units and uranium mines in Utah. He successfully completed his Master's degree in Public Health (Industrial Health) from the University of Michigan. In the same time frame, Ramamurthy received similar training at the School of Public Health, Harvard University at Boston; and S. Somasundaram and S. Vasudeva Murthy in radiological health at SPH, Ann Arbor. These were the first foreign deputations after that of Dr. Ganguly himself to Chalk River and S D Soman to NRX reactor. Soman, it may be recalled was overseeing the day to day health physics surveillance of the TIFR laboratories having joined TIFR in 1950. In 1960, Somayaji and Ramamurthy were placed in charge of the Industrial Hygiene program and their unit was transferred to the RHC Section under Dr. Ganguly.

The program with the worker's health as its primary concern, encompassed a variety of checks and balances at the work place. The health hazards to workers are principally due to work related exposure to chemical and physical agents. These are to be recognized, their extent evaluated and in case of potential threat, control measures are to be recommended and implemented. Fortunately, wherever work with radioactive chemicals was being conducted, sufficient control measures were in place to safeguard the workers from their toxicity as well. The laboratory fume-hoods were to be checked for proper air flow. However other types of experiments done required proper planning and adoption of safety measures. In certain operations exposure to dust, fumes and chemicals was possible, which require evaluation. Similarly exposure of the workers to industrial noise, illumination levels at the job site, etc. are required to be checked and controlled. Whenever a new project is to be taken up, scrutiny from the industrial health point of view is required. So more persons were assigned to the team.

Over a period of time, it was observed that a large number of accidents were occurring at the work place, in the premises of the Establishment and also outside, as the staff members are brought to work and dropped back, by the transport provided for the purpose. The absolute necessity of practicing Industrial Safety was recognized. Safety is everybody's business but sometimes it appeared to be nobody's. Often what was required was just the application of common sense and observing simple discipline.

The Accident Prevention Program was officially initiated on August 1, 1962. It put into place the important check measures in the form of a mandatory requirement for the direct supervisor at a work related injury, to file a formal intimation report (Injury-on-Duty form) with the Industrial Hygiene & Safety (IHS) unit. The IHS unit in turn would conduct an unbiased inquiry in to the causes and suggest corrective actions to the Supervisors/Heads of Units. There was initial reluctance to observe the procedure. On occasions, Dr. Ganguly himself had to intervene to seek compliance. Slowly the culture of preventing accidents started taking root and the work place became safer.

Reports highlighting the critical analyses of accidents, observations made and subsequent remedial actions recommended were released periodically for general alertness and education. Some typical accidents were pictorially represented to provide greater impact. Dr. Bhabha himself read these reports with great interest and annotated them with his comments. The illustration of typical incidents was entitled "This need not have happened". Over time, this became a catch phrase among the staff during even routine meetings. Safety posters were prepared in the safety unit and also obtained from the National Safety Council for display in different areas as a part of the safety promotional activities. A few lectures on Industrial Hygiene & Safety were included in the training program of the Training School. Thus the IHS unit was slowly but steadily gaining importance; and recognition in its vital role.

Occurrence of minor injuries is generally considered common place. When the employee has to stay away from work as a result of the injury, it starts disturbing our minds. More serious are cases of partial or total permanent disabilities. The worst that one has to deal with are the fatalities. These have great social impact as well. There should not be any excuse or compromise on such incidents.

In the early days a few soul shaking fatalities took place. As Mr. Somayaji narrated, once a fire fighting staff was required to enter into a room in the Thorium Plant where trays of thorium nitrate were kept (for drying) when a fire broke out there. One of the firemen attending to it was exposed to copious concentrations of fumes mostly consisting of oxides of nitrogen. Despite all the medical treatment, the fireman succumbed to the doses of inhaled irritating gases. It was recognized in hindsight that the firefighting personnel were not equipped with air supplying type protective equipment. This lapse appeared to be due to failure to appreciate the need for providing such equipment or administrative delays. Subsequently the Fire Service Section was brought under

the administrative control of the Chemical Engineering Division. Thus the industrial hygiene program visualized by Dr. Bhabha grew under Dr. Ganguly.

In July 1964, there was an unusual type of accident in which an Engineer was heavily exposed to benzene. In one of the Engineering Halls, a distillation set up was erected to purify p-terphenyl with benzene as the solvent. As the Engineer stood up on a stool to check the setup, the bung on the vessel blew up exposing him to copious levels of benzene vapor. Some quantity of hot solvent was also aspirated. Despite prompt medical attention, his life could not be saved. The accident became headline news on the next day. It became more tragic when following the Engineer's death, his newly married wife committed suicide. An inquiry was ordered into the unfortunate accident. H. N. Sethna, Dr. Ganguly and Somayaji were among the members of the Inquiry Committee that was formed.

Going back in time: A worker, handling benzene at the set up referred in the previous paragraph, suffered an eye injury, caused by a drop of benzene entering the eye. This incident occurred on August 2, 1962, one day following the inception of the Accident Prevention Program. Generally such an accident was considered insignificant. We had close cooperation with the Medical unit at Trombay from the very beginning. Any injury at work, needing medical attention, gets recorded at the Dispensary and then the IHS unit gets the information. This led to a visit by the industrial hygiene team to the work place where the distillation plant was erected. After conducting air monitoring to assess the levels of benzene exposure around the production unit, control steps required to be taken were recommended. The toxicity levels of the chemical had been mentioned in the survey report. Although fatal poisoning with benzene would be a very remote possibility with the type of operations carried out in a large open hall, on Mr. Ramamurthy's suggestion, the exposure levels at which fatality can be expected was included in the survey report.

During the inquiry into fatal accident at the Engineering Hall, nearly two years later, this comprehensive report proved to be a saving feature for the IHS team. When Mr. Sethna asked whether the team had informed the supervisors on the exposure limits for fatality by benzene, Dr. Ganguly promptly pointed out the page number in which the same had been mentioned in the report that was presented before the Committee. But for the eye injury that took place nearly 2 years back which threw light on the type of work that was begun, the survey that was conducted and a survey report sent to the production team, IHSS unit would have had a difficult time explaining. As is true of many inquiry reports, the recommendations cover

generalities. However, one major point made in the report was that the industrial hygiene and safety unit should be strengthened. Dr. Ganguly was very supportive to his colleagues and offered proper guidance regularly.

There were a few other fatalities which occurred due to lack of minimal safety considerations. In one incident, coverings on some floor openings were removed for the purpose of lowering some equipment to a basement level in CIR, however the basic safety measures of providing barriers around the floor openings or at least display of warning signs were not done. As a result, one person, returning from a lunch break, fell down fatally a few floors below through the floor opening.

In another instance, a heavy vehicle operator reversed the vehicle without taking the simple precaution of taking somebody's help to reduce his blind spots. This seemingly simple error led to a worker, just behind the vehicle, suffering a fatal knock down. The safety team connected and contrasted this accident to an earlier case of minor injury in which a person had a narrow escape from a similar unsafe practice of reversing a heavy vehicle without taking a second man's help, following which recommendations to avoid such practices had been made. But they were ignored. These could be considered as cruel and avoidable accidents, pointing at personal causes (Supervisor failures). Corrective actions slowly being enforced had probably helped to develop a high level of safety consciousness in the organization.

Safety can be best built in to the facilities by interacting at the planning stage. With this in mind, the team provided architects with appropriate suggestions during the early stages of planning and building the new plants and the Modular Laboratories. The IHS team played a key role in the Modular Laboratories Safety Committee, initially chaired by Dr. Ramanna and later by Dr. Vohra

The unit was assigned to perform Industrial Hygiene surveillance and Safety training in other units of the Department of Atomic Energy, in their early stages. Uranium mining started in Jaduguda. After initial surveys, based on the need for monitoring dust, noise levels and for prevention of accidents, industrial hygiene and safety personnel were deployed. Similarly a health physics team was also stationed there. Periodic surveys were done at ECIL, NFC, Nuclear Power stations and later Heavy Water plants. In 1969 the IHS team became an independent Section under the Health Physics Division.

Beryllium is one of the highly toxic materials. The Beryllium Metal Plant set up at Vashi, where production, purification and machining of the metal were

done, was provided with regular industrial hygiene surveillance. Apart from monitoring of air and surfaces, biological monitoring was also done by a team stationed there.

Noise levels were regularly measured at compressor rooms, machine shops, air conditioning plants, etc. Use of personal protective equipment was suggested at the operations. An audiometric booth with low ambient noise level was specially built with a view to check workers, who would have been exposed to high levels of noise at work, for their hearing capacity and possible loss in their hearing acuity. This was the forerunner of the audiometric test room currently in operation in the BARC Hospital. Lack of proper illumination levels at work places is a cause for concern. Surveys were conducted by measuring the levels and appropriate suggestions given where they were short of the lighting standards.

Come to think of it, a good suggestion made to improve safety will be opposed by the stake holders; as a standard quick reaction, a sort of inertial mode fuelled by personal ego. Unless the mirror is shown to, the wart on the face is not recognized. A number of traffic accidents involving the drivers of powered two-wheelers, the pillion riders and the pedestrians were occurring. Accidents do not happen; they are caused. The Section compiled the statistics of this type of accidents that occurred over a period of 18 months and presented the extent of loss (in man-days) to the persons who were unfortunately involved in them. A strong recommendation was made to impose a rule, within the premises of the Centre, for the users of the two-wheelers to compulsorily wear a suitable safety helmet. Dr. Ganguly got this suggestion approved at the Trombay Scientific Committee (TSC). This safety measure which is now enforced throughout the Mumbai City was enforced, perhaps for the first time, inside the BARC campus and brought good results.

Similar to the above there was another area of correction required. There are a number of places, especially in the Modular Laboratories, where glass panes were used for enclosure, from the floor level to the ceiling. It used to be difficult to differentiate the door from the fixed glass panes of the partition wall. One such accident actually took place. Suggestions made to provide prominent mark/strips on the fixed glass panes were ignored. Somayaji notes that when positive efforts at improvement repeatedly do not yield the elementary responses, the entire exercise can be frustrating and result in psychological stress to the staff. The only consolation that remains for the safety team then is that a sincere effort has been made and that should have been an enough reason for getting a good night's sleep.

A need was felt to get increased cooperation of all staff in general to aim at higher levels of safety. Supervisors have a key role to play in achieving this. An effort was implemented to develop individuals as effective liaisons between their own teams and the IHS team. The Divisions/sections were asked to earmark one to two of their staff members to be designated as Safety Coordinators, who then underwent basic health and safety training. In 1978, a two-week course, entitled "Accident Prevention & Promotion of Occupational Health and Safety" was started. It consisted of a wide range of subjects on health and safety, including radiological health, fire safety and first aid measures. Similar courses of short duration were conducted at other units of the DAE as well. National Safety Day was observed with a daylong programmer of safety exhibition, guest lectures, screening of safety films, etc. as a part of the continuous training efforts.

The Traffic Safety Committee was formed to inquire into road accidents that were taking place involving BARC buses and other staff vehicles and fix responsibilities, with Mr. Somayaji as Chairman. Later Dr. Ganguly chose Mr. Somayaji for chairing the Cosmetic Maintenance Committee for BARC, whose assignment was closely related to safety in the Centre. This was Dr. Ganguly's way of encouraging his staff members.

Performance in any field needs evaluation periodically. The number of disabling injuries and the resultant severity (measured in terms of number of working days lost) were compiled, taking the number of persons employed in the unit as reference. The Injury Rates (Frequency Rate, Severity Rate and Injury Index) are intercomparable with one unit/Division with the other, with other units of the DAE and with different industrial activities in the country. Later years AERB on the basis of the vast experience gained by the industrial hygiene program of the BARC instituted award among DAE units on the basis of the parameters developed by IHSS program. The industrial hygiene program started in AEET in a modest scale thus grew into a program benefiting all the DAE units.

Annexure 1

ANIL KUMAR GANGULY - THE GENTLE GIANT.

D. V. Gopinath
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A Tribute

Dr. Anil Kumar Ganguly joined the Department of Atomic Energy in 1956 after a successful stint in theoretical Radiation Chemistry at the University of Notre Dame. That was the time when Apsara reactor was in the final stages of commissioning. For many of us then health physics and radiation hazard control meant only REP, RAD, REM and radiation monitors. It is to Dr. Ganguly's credit that he provided a strong scientific content to the health and safety program. Besides laying a firm foundation for an exemplary health and safety practice in all our nuclear installations, he recognized, nurtured and established a multi-faceted R and D program in health, safety and environmental disciplines.

An area which stands out as a monument to Dr. Ganguly's foresight and scientific pursuits is radiation physics. By mid 60s, chemical and biological aspects of interaction of ionizing radiation with matter had developed as independent and active disciplines as radiation chemistry and radiation biology. However study of the physical aspects in this area was still quite diffused. Different topics of radiation physics were being developed as supports to various other disciplines. Dr. Ganguly could clearly discern the need for and immense potential of developing radiation physics as a distinct discipline. Thanks to his foresight and initiative Radiation Physics stands out today as a vibrant and active discipline. It was due to his incessant encouragement and guidance that the Indian Society for Radiation Physics took its birth in 1976 at Mysore. The exercise was so successful that it led to the formation of International Radiation Physics Society in 1985 at Ferrara, Italy. This is one of the rare instances where a scientific discipline which took a formal shape in India has firmly established itself in the international arena.

Dr. Ganguly's another outstanding contribution has been in the environmental science. His interests in this area were deep, varied and diverse, encompassing the nature as a whole, be it atmosphere, hydrosphere lithosphere or biosphere. Long before environmental issues became the bandwagon, Dr. Ganguly showed immense concern for environmental sanctity. Realizing its importance way back in 50s he laid a strong foundation for environmental studies in the Department. The chain of Environmental Survey Laboratories at all the DAE

installations we see today is entirely due to his foresight and persistence. His studies covered soils, water -fresh as well as sea, marine sediments, organisms and a whole lot of them. He maintained that it is the chemical form rather than the total quantity of the elements that greatly influences the dynamics of the elements in the environment. Later on, this has come to be known as speciation and now forms an important aspect of the environmental chemistry. Dr. Ganguly's contribution to the environmental sciences did not confine to the realm of Department of Atomic Energy alone. It extended to the entire National sphere as well. He organized the first national seminar on pollution and human environment in 60s and provided an effective forum for environmental activities at the national level. As a member of the several apex committees he contributed significantly to the evolution of a national environment policy and the creation of the department of environment.

There are several other areas such as reactor safety evaluation, safety research, fission Physics, radiation ecology, etc., where Dr. Ganguly made lasting contributions. For Dr. Ganguly research was not just a profession but an intimate part of his life. For him the research problems did not have to be the imported ones nor did they have to be glamorous. Nature itself was his laboratory; every observation in the environment was a means for a closer understanding of the nature.

Dr. Ganguly was a teacher *par excellence*. It is not that he was solving all our problems; he was more interested in developing our own ability to solve our problems. What endeared him most to us, his students, is that we could always discuss and share with him our ideas, our excitement and our concern. He would listen to us with genuine interest, discern the little substance amidst a lot of chaff and nurture the substance.

There was never a dull moment with Dr. Ganguly around; whatever may be the activity with which he was associated, his involvement was complete and whatever be the topic for discussion, his participation was total. But the spirited discussions with Dr. Ganguly never left any rancor. Whenever I think or talk about Dr. Ganguly a certain amount of soul searching becomes inevitable and in the final analysis the question stands out; what made Dr. Ganguly what he was? To me it appears that he was living on two different planes; outwardly he was in complete resonance with his surroundings, sharing its excitement, its joy and its anxiety. Deep inside there was this person with total objectivity and scientific detachment.

Kalpakkam
December 1988

My Golden Days with the Master

(When Dr. Iyer asked me to write this part I was reluctant, very reluctant, because I thought it would be mostly 'I, me and myself' which should not have any place in a Compendium on Dr. Ganguly. But he was very much insistent and his argument was that a vital and beautiful part of Dr. Ganguly's life was the interactions he had with his students and the compendium cannot be complete without an intimate account of such interactions. I got sold on that point. Having agreed and started writing, I have enjoyed it thoroughly. Reminiscing and reliving those golden days of my professional life has been a delightful experience. Thank you Dr. Iyer, for taking up this sacred and endearing task and providing me an opportunity to be a party to that.

This note is being written by recapitulating events that have taken place starting from 55-60 years back. That too, at a time when there was intense activity in DAE- new developments, new programs, new structures, etc. So, the dates and sequencing of events in my narration may not be exact and I also may have jumped back and forth in time. At places I have briefly digressed from the main theme with the fond hope that it would provide the latter entrants a picture (albeit partial) of the exciting and enjoyable time we had during those beginning days.

Dr. Ganguly was respectfully and affectionately addressed by everyone as 'Doctor'. I am doing that often in this note also.)

I joined the Department of Atomic Energy (DAE) in 1955. Atomic Energy then was an exciting field and DAE was considered to be highly prestigious. So, it was a dream-come-true occasion for me. I was a mere B.Sc. and joined as Junior Scientific Assistant (JSA), what is now called as SA (A), the lowest in the science cadre. Still I was hoping that someday I am going to make big contribution to science. Low on stock and very high on aspirations! Immaturity of the youth! But it did not take much time for me to come down to ground state.

They were the beginning days for the Department and it did not have its own bearings. The administrative and a few small technical groups operated from the Old Yatch Club (OYC) which then belonged to Tata Institute of Fundamental Research (TIFR). The Trombay site had not been developed as yet. So, newly formed and forming Divisions of the Department were being sent to the 'Job Shacks'- abandoned military barracks at the land's end in Colaba behind the present grand edifice of TIFR.

I was taken in the Health Physics and Reactor control Group headed by Sri. A. S. Rao and that group was also located at the Job Shacks in Colaba. It was essentially Reactor control group, developing control instrumentation for the

Apsara reactor being built at Trombay. The Health Physics part had only one member, Sri. S. D. Soman and I was asked to report to him. To begin with I did not know what health physics is; later I learnt that it is the discipline to protect workers against the hazards due to exposure to ionizing radiation. Health Physics then had only two programs-Area Monitoring using portable radiation monitors and Personnel Monitoring using Film badges. Film badge is a wonderful gadget, the first one to be widely used as a personnel radiation monitor. It is a very simple device, inexpensive, easy to process and provides reliable record of the individuals' exposure to radiation. It is essentially a dental X-ray film pack worn by the individuals working with radiation. It is collected from the users periodically, processed in the dark room like any other X-ray film and its opacity (called optical density) is measured by a densitometer. Using a calibration curve of 'Opacity Vs. Exposure' generated by a set of films exposed to known radiation doses and processed along with the test films, exposure of the test films (and thereby the exposure of persons wearing them) is determined. It is as simple as that. In one of the job shacks, which was mostly occupied by the Reactor control people, health physics unit had been given two rooms, one for processing films (dark room) and an adjacent one for all other activities. I was assigned to Film Badge Service and dark room was my work place.

My assignment was to periodically send the required number of films to various user units, process them on their return after a specified interval and report the exposures. Initially it was alright but after a while I was losing all interest. Week after week same collection and processing of film badges, same densitometer reading and same reporting; the excitement was gone. That was not the type of work I dreamt of, in that Super Department. Since that did not take much of my time, I tried working on some R & D problems on my own. While there was not much of guidance for such efforts, there wasn't any hindrance either; Sri. Soman had given me complete freedom. The support we had in terms of technical/scientific literature was nothing much to speak about. We had access to TIFR library but its *repertoire* of literature, books or journals, related to our discipline was quite limited; the only journal I remember to have had been browsing frequently was Nucleonics (I think it is extinct now). Journals like Nuclear Science and Engineering, Health Physics, etc., weren't even born yet. So the major scientific input for us was the technical reports we used to get from atomic energy laboratories abroad such as AERE (Harwell, UK), ANL, BNL, LASL, ORNL, etc., (all from US) and University Centers like UCLA. Based on some of those reports and influenced by persons around me who were mostly electronics engineers, I picked up two problems involving

instrumentation. One is the development of a wide-range densitometer for film badge work, based on an AERE report given by Sri. Soman and the second was extrapolation chamber for measuring the tissue dose. I worked hard on them but did not succeed because they called for expertise in precision engineering which I did not possess nor could I muster it from others. Frustration was setting in. And then, Dr. Anil Kumar Ganguly joined the Department and that changed everything for me.

Even a month or so before Dr. Ganguly joined, it was in the air that a senior scientist who has done very good work in USA on radiation chemistry would be joining the health physics division as Head of Radiation Hazards Control (RHC) and Radioactive Waste Disposal. Then, on one fine day in early 1956, when I came out of the dark room to the adjacent room, I saw a new table and a chair laid out and a robust person occupying the chair. Intuitively I felt it must be Dr. Ganguly and instinctively I got attracted to him. I introduced myself and told him about my work with film badges. He showed genuine interest in what I was saying (that has been his hallmark all through!), came into the dark room with me, got to know all the details and went back. Nothing more happened on that day but somehow I felt highly elated. Then and there I decided that I am going to work with Dr. Ganguly.

Next few weeks, or perhaps a few months, I continued to haggle with my film badge processing, reading and reporting. During that period Doctor was busy planning RHC section and a Chemistry laboratory for radioactive waste disposal studies. I was in close contact with him all along, just barge into his room at any time and he was ever patient with me (that has been the case throughout my interactions with him; immense patience at my oddities). I wanted to work with him on his research problems. At first his advice was that one can find interesting research problems in any scientific field including the area where I had been working, I should continue to work there and surely I would find interesting problems. This continued for quite some time. But I was persistent in working with him and finally he agreed.

As mentioned earlier, one of the major responsibilities of Doctor was radioactive waste disposal. At that time the only two sources for radioactive waste were Apsara reactor which had been commissioned just around that time (in August 1956, but we continued to be stationed at Colaba) and the Thorium plant located at what is now called South Site in Trombay. In Apsara, the reactor core is located inside a pool of water. During the reactor operation, the pool water along with its impurities is continuously exposed to neutrons resulting in the buildup of induced radioactivity. Computing the buildup of such activity

is necessary for estimating the radiation fields in the pool surroundings as well as to have control over the radioactivity that gets released to the environment when the pool water is drained out. Doctor asked me to try and calculate the activity buildup in the pool water taking into account the various impurities likely to be. That was the first problem I got. At that time (I am talking of mid-50s) there wasn't any exact formula for induced activity buildup- at least not any that I knew. So I had to start from scratch, from fundamentals. For a few days I tried several numerical approaches but none of them were satisfactory. By then I was fairly familiar with the natural radioactive series, their build up equations, etc. Suddenly it occurred to me that the neutron-induced activity build up equation is identical to that for a radioactive daughter product build up in a natural radioactive chain with the decay constant λ of the parent isotope replaced by $\sigma\varphi$ where σ is the absorption cross section of the isotope being irradiated and φ is the neutron flux. The solution was extremely simple, exact and elegant. I immediately rushed to Doctor and explained my observation. He felt immensely happy and said 'Good, very good! Now complete the calculations'. That part was easy, sort of filler work. I completed it without any problem and it turned out to be a very good document. I will come to that a bit later.

That was the stage when the DAE was growing very rapidly with several developments taking place simultaneously. The Health Physics part of the Group had been made into a separate Division with Sri. Rao continuing as Head of the Division. The Division had two Sections; Radiation Hazards Control Section (RHCS) with Doctor as the head and Personnel Monitoring Section (PMS) under Sri. P. N. Krishnamoorthy. By then few more persons had joined the Division. First, I think, it was Vasudeva Murthy and Nagaraja Rao (he left the Department shortly afterward) and then the Trinity from Madras University-Madhvanath, Somasundaram and Somayaji. Of them, Madhvanath was posted to PMS and the rest joined Doctor. There was a little excitement about Somayaji when he joined. We were told that he was an all-time record holder for high marks in Madras University next only to Prof. S. Chandrasekhar, the great Astrophysicist and later Nobel laureate. I found Somayaji to be one of the most unassuming and modest persons. A little later P. R. Kamath and K. C. Pillai, the pioneers of environmental chemistry work in the Department, joined Doctor. Around the same time Gnanapurni, M. S. S. Murthy, K. R. Das, Parthasarathy and others joined PMS. I continued to be in PMS with Madhvanath and Gnanapurni as my immediate bosses. But they were very friendly and never treated me as their subordinate. All those who joined PMS then were young, enthusiastic, helping and fun-loving type

and we had a very pleasant work-atmosphere. But I had a problem. PMS was not reporting to Doctor and I couldn't be working for him. Again I started nagging him for change of the section which only Sri. Rao could do. It did not happen any soon. Doctor must have very much pleaded my case with Sri. Rao. Finally the change did materialize and formally also I was working under Doctor. After the change, my work place got shifted to the basement of the TIFR building under construction.

A little diversion here. I said earlier that I was just a B.Sc. when I joined the Department. I was from the University of Mysore and at that time B.Sc. graduates were not admitted to M.Sc. in that University, may be in some other universities too. Entry to M.Sc. was only through B.Sc. (Hons.), a three year course. So, for persons of my type it was practically a dead end for academic pursuits. Of course, there was a small possibility; one could join the II- year Honors course, complete it and then go to M.Sc. But the intake for that route was very limited. Besides it involved further three years of regular schooling (or is it colleging?) which, with my economic background, appeared impossible to me. Even then my craving for further studies remained unabated. That was my situation when I came to Bombay. After going there a good information I got was that Bombay University admits B.Sc. graduates for its 2-year M.Sc. course. Another and much more important information I got after joining DAE was that in Bombay University one can obtain M.Sc. by research (to the extent I know, this is the only university in the country which has that provision) and DAE has applied to the University for recognition as a research establishment. That meant one could obtain higher degrees by research while working in DAE under a guide recognized by the University. Great! What more could I ask for? At the time I got this information recognition had not arrived as yet. From then on I was a regular visitor to the university office to track the progress. Finally, after several months, the recognition letter did arrive. Immediately I rushed to Doctor to inform him about the development. Needless to say he was quite happy and agreed for my registration for the M.Sc. degree. But there was a small problem; since he had joined the Department very recently his name was not in the list of recognized guides. Further, his basic discipline was chemistry which meant he would be recognized as a guide for degrees only in chemistry whereas my work was supposed to be in physics. Fortunately Sri. Rao had been recognized as a guide in physics discipline and I could register under him. Again, it was Doctor who took the initiative and persuaded Sri. Rao to sign my application. No further hassles; my registration was done. Incidentally, I am the first one to have done this and it became a trend setter. Subsequently almost everyone who joined the Department with only B.Sc.

degree went through the same route, obtained his/her M.Sc. and Ph.D degrees and many of them went up pretty high academically as well as professionally. I must say here that this had been possible only because of the affection and concern of Doctor for his people and the enlightened, progressive and liberal outlook of the Department as well as Bombay University. Now almost all research institutions and universities follow this system.

Coming back to the activity build up calculations, after obtaining the exact expression further work was very easy; its simplifications under various practical situations and their identification with prevalent approximate expressions, saturation activity and saturation time as a function of decay constant, neutron flux and relevant cross-sections, etc. and finally detailed computation of activity buildup for the expected impurities in the pool water. When the work got completed and the final report ready, the document appeared quite impressive. Suddenly one day Somasundaram asked me whether I would consider publishing it as a technical report and that he would do the entire spade work. As I mentioned earlier, our major source of scientific input at that time was the technical reports from laboratories abroad and Somasundaram felt that this work definitely qualifies for that type of report. He had always been very enthusiastic, systematic and would go out of the way to help others (incidentally, he was well known for his manuscripts; neat, meticulous and print-like hand writing. Another person for that type of writing reports was T. Subbaratnam who joined us later). I gladly agreed with him (why not?) and we approached Doctor. His response was as expected, 'Go ahead, do it'. Then on, Somasundaram did all the boring (to me) job of editing, structuring and formatting the report, designing the cover page and bringing out the final report. That was the beginning of series of technical reports in DAE and we titled it as 'AEET-HP-Th-1: Radioactivity Build up in Reactor Coolant Water.' Now a word about the series title. At that time, due to the far-foresight and dynamism of Dr. Bhabha (with singular support from the Prime Minister!) there was tremendous activity in the Department; new ideas, new programs, new divisions and units, very large intake of personnel and so on. It was blossoming into an unprecedented science and technology program in the Country. Again due to the foresight of Dr. Bhabha, amongst all the developmental activities, primacy of research and development was well recognized and a separate Unit for this activity was created within the Department. This Unit, to be located at the upcoming site in Trombay, was named as Atomic Energy Establishment Trombay -AEET (Probably in line with the Atomic Energy Research Establishment (AERE), Harwell, England). That's why our report series was named as AEET-HP-Th- where HP-Th

stands for Health Physics-Theoretical studies. That was another trend setter which, to a great extent, was due to Somasundaram and he became the chief editor for all our reports (subsequently, after the sad demise of Dr. Bhabha in 1966, AEET was renamed as Bhabha Atomic Research Centre-BARC and the report series titles were also changed accordingly).

While at this point, I would like to mention one other yeomen service of Somasundaram to the radiation protection community. In mid 60s (I am jumping in time here) there was a move to start Indian Association for Radiation Protection (IARP) as an affiliate to the International Radiation Protection Association (IRPA). Actually the idea came from the top; S/ Sri. A. S. Rao and P. N. Krishnamoorthy. We all joined the movement enthusiastically. Unfortunately some difference of opinion cropped up while evolving its constitution and the senior persons withdrew. That was a setback for the organization. At that stage Somasundaram came into picture, worked silently and steadfastly for a few years and put IARP on a sound footing organizationally as well as financially.

After the report on activity build up in reactor coolant got published, I continued to work on similar lines on the activity build up in time-dependent nuclear operations. There were two time-dependent situations which were then considered as relevant; one was the cyclic operation of reactors and the other was the automatic startup of a reactor whence reactor power (and hence the neutron flux) would continuously vary till the set-power is reached. Today, with all the powerful computers available, these are trivial problems. But in those days, analytical solutions for such problems had meaning and importance. The work got completed within short time but it did not find as much application as we thought. Its only outcome was a paper jointly authored by me and Doctor and a good addition to my thesis work. Around that time, one day Doctor called me and said 'Gopinath, you are always making a lot of noise. Instead, why don't you do some useful work also?' Harsh words but a smiling face! In any case I was not to be perturbed by such words because by then I was quite used to getting chided by him. He continued 'Look, there is a great interest in the study of natural radioactivity in the environment. The activity is essentially due to Uranium and Thorium elements and their long chain of daughter products. Chemistry boys are already studying it but they need good data on the radioactivity buildup of all the members in these chains. Why don't you work on that and generate the required data?'. Of course, I could and I did take up that task immediately. But before I talk about it, a few words about the breadth and depth of Doctor's thinking in this context.

As the names indicate, our Section and Division were responsible for analyses and control of hazards from the radioactivity generated in the nuclear operations. That activity was still to come up on a big scale. But then, radioactivity and ionizing radiations are neither new nor specific to nuclear operations; they have been existing in the nature all along and mankind has evolved in this ocean of radioactivity. So, in Doctor's reckoning, an appropriate and immediate task would be to thoroughly study the behavior of this natural radioactivity in the environment; its transport and deposition, its bio-accumulation, its radiation fields and exposure to mankind and so on. Fall out of such a program would be

i) Establishing methodology and standards for radioactivity measurements and analyses in the environment, understanding its dynamics in the environment, be it atmosphere, hydrosphere, lithosphere or biosphere.
ii) Generating base line data for radioactivity in the environment –living as well as nonliving-which should serve as a reference to discern the impact, if any, of the radioactivity from nuclear operations.

Implementation of this line of thinking of Doctor, with his inspirational involvement, has been an eminent success and it has led to one of the most comprehensive and successful environmental study programs, nationally and internationally. It has also resulted in building up of a highly competent school of environmental chemistry with members like P. R. Kamath, K. C. Pillai, I S Bhat T. N. V. Pillai, M. V. M. Desai and others. It has brought meteorology (Shirvaikar & Sitaraman), ecology (Patel & Balani), marine biology (K. V. K. Nair) and oceanography (J. R. Naidu) into the realm of environmental studies. It has become the fore-runner and a model for the environmental radioactivity studies in the entire country. The Environmental Survey Laboratories set up at all major nuclear installations in the country as a part of this scheme have established and demonstrated to the Society the excellent safety record of our nuclear power program.

Getting back to the work on the buildup of natural radioactivity, it did not involve any new derivations and did not pose any new problems. I had all the necessary trappings; by then I was quite familiar with the details of the three radioactive chains, uranium, thorium and actinium, I was well acquainted with the Bateman equations for radioactive chains and their analytical solutions for buildup calculations and then I had my Friden calculator. Yes, of course, the Friden calculator, my most trusted workmate. They were the pre-computer days and this task involved massive computations. So, whole day I used to sit before the machine, making Trrrr, Trrrr, sound all along (additional fun for me, a little sadistic of course, I could continuously annoy people around but

they could do nothing except cursing me). Anyway, the work got completed fairly fast, generating a huge amount of data and analyses. Doctor was quite happy with the work. Again Somasundaram was there to help me bringing out the final report and we titled it as AEET-HP-Th 3- 'Radioactivity Buildup in Naturally Occurring Radioactive Minerals' (Later, when Hari Singh joined us we revised it adding some new data). For quite some time, that report was widely used as a reference document in studying natural radioactivity in the environment. Very recently M. R. Iyer told me that after about 55-60 years, he retrieved this report from BARC achieves to get data on the buildup of stable isotopes in the radioactive chains in connection with his conjectures on the origin of monazite on the West Coast of India.

For some more time, I continued with the activity build up calculations. Notable work during that period was calculations on i) U-232 buildup in thorium reactors and ii) Strength enhancement of Ra-Be neutron sources. From the very beginning, the Indian Nuclear Power Program has envisaged a 3- phased strategy, the third and the final phase being Th-232-U-233 power reactors. Apart from many technological problems associated with this system, there is one major safety problem. When Th-232 is irradiated to obtain the fissile isotope U-233, it also leads to the production of U-232 due to the n-2n reaction of different isotopes in the Th-232-U-233 production chain. This U-232 has a half-life of about 69 years and a long chain of short lived daughters many of which are hard gamma emitters. They build up rapidly and pose severe radiation exposure problems in handling U-233. Doctor wanted us to study this system and see the influence of reactor operating cycle parameters on U-232 production. We, myself and Hari Singh, made a detailed study and made a report. But it was not pursued further essentially because the program of utilization of thorium itself had been bogged down with formidable problems (I understand that much later Dr. A. M. Bhagwat and others did make some measurement of radiation exposures in handling U-233 contaminated with U-232 and its daughters. I am not aware of further developments).

The second study, strength enhancement of Ra-Be Neutron source, was quite an interesting one and to appreciate this, a little background information would be helpful. From reactor kinetics theory it is known that the peak power in a criticality accident is greatly influenced by the shut-down power of the reactor; smaller the shut-down power, higher will be the peak power and severity of the accident (sounds odd but true due to reactivity feedback mechanisms). To minimize this peak power and the total energy released in such accidents, an external neutron source is introduced in to the reactor which increases its shut down power. This is especially important for small reactors. Accordingly,

Apsara also had a Ra-Be neutron source installed during its commissioning. After about 3 years of reactor operation, Radiation Standards Section got interested in measuring the strength of this neutron source as Ra-226 in the source could have depleted due to irradiation by reactor neutrons. I also got interested in calculating the effect of such irradiation. There was a surprise waiting for both us. No doubt Ra-226 gets depleted by neutron capture which should lead to the reduction of the neutron strength. But then, on neutron capture Ra-226 goes to Ac-227 (through Ra-227). Ac-227 has a half-life of about 22 years and a long chain of short-lived α emitting daughters, similar to Ra-226 chain. Decay constant of Ac-227 is about 800 times that of Ra-226 (half-life~1600 y) and hence for the same quantity of Ra-226 getting converted to Ac-227, the total activity goes up enormously. That would result in the increase in the neutron yield of Ra-Be neutron source. Of course, the measurements also had shown significant strength enhancement. I made detailed calculations and they were quite revealing. I envisaged two applications of the study; one is to increase the neutron yield of existing Ra-Be sources and the second one is to use the installed source as a clock to estimate the total kW-days of reactor operation. When I showed this work to Doctor, his first (and smiling) comment was 'You are a crazy fellow!' and then asked me to write a paper on this for the forthcoming conference at Calcutta. That brings me to the Calcutta Conference and my unforgettable meetings with three eminent personalities.

In 1960, Indian Chemical Society was organizing the National Conference on Nuclear and Radiochemistry at Saha Institute of Nuclear Physics-SINP, Calcutta (now Kolkata). DAE, being the premiere national organization working in that area, was expected to be there in big way. Dr. Jagdish Shankar, heading the Chemistry Group in DAE (he was then called the Chief Chemist) along with some of his senior colleagues and Doctor were scheduled to go there. It is to that Conference that Doctor had asked me to submit the paper. He suggested presentation of another paper also: 'Radioactivity buildup in time-dependent nuclear operations' jointly authored by me and him. So I was going to a National Conference as a DAE delegate! (These days when we attend a conference we are just 'Participants'. It was different then; we were called 'Delegates', a dignified designation!). On that night, at Bombay VT when I boarded the first class compartment (mind you, 'First Class' compartment for a person used to travel by third class-unreserved!) of the Calcutta train as a DAE delegate in the company of leading scientists of the country, I was feeling super (I didn't make my chest measurements then but I think it would have swelled up by a few inches). We reached Calcutta the day before the

Conference inauguration. After reaching there, some of us, the honorable delegates from the prestigious Department of Atomic Energy, were lodged in a hall on the first floor of SINP (mercifully, the organizers had provided some hired beddings - but no cots. I don't think any of us minded it). As we were settling down, in walks a huge gentleman. The moment he appeared at the door, almost all in the hall jumped up, ran here and there, got hold of an elegant chair and placed it in the center. This gentleman walked slowly and occupied the chair majestically. Then again, almost everyone reverentially prostrated – performing Sashtang Namaskar - before him and he was acknowledging it with grace and affection. I was wondering what was happening and who this gentleman was. Dr. Srivastava from the Chemistry Group of DAE, who had finished his Sashtang Namaskar by then and standing by my side, whispered to me that he is Prof. N. L. Dhar - Nil Ratan Dhar - the Doyen of Physical Chemistry in Bengal and teacher of almost everyone there. He stayed there for some time, made enquiries about the comfort of all of us, me too, and left the hall. The whole event was a pleasant experience to me. I was used to see the teachers being seen just as teachers, may be some are more respected and loved than others but still teachers. Here it was quite different; Prof. Dhar was much more than that, a GURU commanding life-long awe and reverence.

On the same day I met another interesting person in quite a contrasting style. That evening there was the pre-conference Tea and when I went there I saw this person of small built, with little care about his dress and even less care about his big mop of hair, constantly chewing pan, constantly laughing and talking (mostly in Bengali). He seemed to be a very popular person there, talking to everyone with roaring laughter and back-slapping. Of course, Doctor too was there in the group and when he saw me he called me and said 'Gopinath, meet Prof. Purakayastha, the spirit behind this conference'. So, that was Prof. B. C. Purakayastha, organizer of the conference, known to be the first Nuclear Chemist in the country and founder of the nuclear chemistry program in SINP. Looking at him, it was very difficult to believe he was all that; so simple, unassuming, jovial and friendly.

The most important and enchanting person I met there was Prof. Sushil Kumar Mukherjee and it happened on the third day of conference. After lunch everybody was taking it easy and chatting in the dining hall. Suddenly Doctor called me and said 'Gopinath, meet my teacher Prof. S. K. Mukherjee'. Looking at him, I was stunned. Doctor had indeed told me earlier about his teacher being Prof. Mukherjee and the image I had of him was entirely different; a serious, grave looking senior gentleman (someone Like Prof. Dhar). But here I see a handsome young person, looking a lot younger than Doctor (though he was

about 4 years elder), with an endearing, affectionate smile. He was very cordial to me; we talked for a while and when he came to know that it was for the first time I was in Calcutta, he said 'Then you must see something of Calcutta. I am free this afternoon and I will take you round the city. Come on, Let us go!'. I was taken aback. Here is the master of my master, an internationally reputed soil scientist, a leading light of the Bengal science circle (later he became Vice-Chancellor of Kalyani University, Calcutta University and so on), offering to be a guide and show me around the city. Can you imagine that!. We did go out and he spent the whole afternoon and evening taking me to several places, like, Kali Temple on the Banks of Ganga where Ramakrishna Paramahamsa lived, Writer's Building- the HQ of WB Government- and a beautiful Jain temple with all marble and glass (whose name I don't remember). We were conversing freely throughout but not even once did he talk about his position or accomplishments. He left me in the late evening and at the time of parting I presented him Hermann Wyle's famous book 'Space, Time and Matter' which I was carrying with me; he quipped 'Great! I gave you some of my time and in return you have given me your Space and Time.' That half-a-day I spent with him has been a spiritual experience for me. With a teacher like that, no wonder Doctor was what he was! I understand that they had great respect and affection for each other.

Another interesting person I met was Dr. A. M. Ghose (Ananda Moy Ghose) of Bose Institute. During the Conference someone mentioned to me that in the Bose Institute, which was next door to the Conference venue, one Dr. Ghose is working on radiation scattering. I got very much interested and on the day of my departure I went to Bose Institute and met Dr. Ghose. His laboratory was a fair-sized old room (Bose Institute itself was a pretty old building). At the center there were two work tables on which he had spread out gamma ray counters, shielded sources, shield materials, etc. On knowing that I had come for the conference, he was quite happy that a conference delegate from DAE is interested in his work and very enthusiastically explained his on-going studies on gamma ray Scattering. I don't think I understood much of what he said but I liked his enthusiasm and happy to know such studies are going on outside our Department also. At that time I didn't have the faintest idea that over the years we will come very close and he would play an active and important role in our campaign to establish radiation physics as a distinct discipline

Coming back to my work, by then my interests were shifting from radioactivity build up analyses to analyses of radiation fields, again essentially governed by the Division's interests. But before getting into that, I would like to mention one very interesting development in my radioactivity studies though it occurred later

(1964-65). At that time there was a considerable interest in portable neutron sources for research purposes. But their availability in terms of number or type was quite limited (as I understand, even now the same situation prevails regarding the availability but the need has reduced considerably). One type which was historically and most widely used was Ra-Be source. There were also Pu-Be, Am-Be and Po-Be sources which had appeared around that time. In all these cases, the α radiation from the radioactive elements would interact with beryllium to produce neutrons by (α, n) reaction. Making these sources involved handling of open α activity, calling for elaborate radio chemistry set up with high integrity glove boxes, etc. We were not making any of these sources and they were being procured from Amersham, UK. As I had been closely associated for years with natural as well as reactor-produced radioactivity, it occurred to me that we should be able to produce easily another type of neutron source with significant advantages over all the existing ones. The idea was as follows: Po-210 in the Po-Be source, with a half-life of about 150 days, is produced by the β-decay of Bi-210 (half-life of 5.2 days) in the Ra-226 chain. But that need not be the only way to obtain Bi-210. It can also be produced by neutron irradiation of Bi-209 which is the naturally occurring, stable isotope of bismuth. If we prepare an intimate mixture of Beryllium and Bismuth (both non-radioactive materials and hence easy to handle), compact it and irradiate in the reactor, it leads to *in-situ* production of Bi-210 which decays to Po-210. In effect, we will have a Po-Be neutron source. Of course, compare to regular Po-Be sources, the yield of neutrons from such a source could be less because of dilution of the source material with inactive bismuth. On the other hand I could see significant advantages of this source but I will come to that little later.

I had only this idea and nothing else; no materials, no equipment and no laboratory. But then, I was working in AEET with its unique features and that made all the difference. Firstly, it was an ocean of resources, men and materials (even at that time!). If your program needs something, expertise or equipment, but you do not have it, scout around and you are most likely to find it with someone in the Centre. Second, more important, was the prevalent informal atmosphere and the sense of sharing. Having identified the person who has what you want, you didn't have to go through your Section Head, Division Head, Director and similarly down the hierarchy on the other side; you approached the person direct. If that person has what you want, material, equipment or expertise, he would most likely provide it to you. Quite often it was more than that; he would go out of the way to further help you in your pursuit. That's how I landed on S. N. Sinha of Atomic Fuels Division (AFD)

for making this new neutron source. AFD had the necessary materials and equipment - beryllium, bismuth, ball mill, pelletizer, etc., and Sinha had the necessary expertise, particularly in powder metallurgy. He readily agreed to provide all the help for this venture. In fact he was so enthusiastic we became partners for the entire study. But with all our enthusiasm, success did not come easily. For about 6 months we struggled with different ratios of Be and Bi, different milling times and different irradiation times in the reactor without any success. Finally, with Be to Bi atom ratio of more 20, continuous grinding of the mix in the ball mill for more than 7 days, pelletizing and irradiating the pellet for about a month the neutrons did appear. And they appeared in plenty. By then, Uppal, from our instrumentation group, had set up the fast neutron counting system with Zn S-plastic Scintillator and even as the irradiated pellet was being brought near the counter, it exploded into profuse counts. It was a thrilling moment for me and I ran into Doctor's room (by then we had moved to what was called Health Physics shed in the South Site) and babbled that BeBi source has been a great success. I do not remember what he was doing but he immediately got up and came with me. On seeing what was happening, he was equally, if not more, thrilled. Several persons told me that for quite some time after that Doctor was excitedly telling everybody that Gopinath has created something new; the Be-Bi neutron source. (A slightly related occurrence: Around that time I was interviewed for my promotion. During that period, I was also involved in the study of criticality of condensed fissile systems which was considered to be very important. I expected that I would be examined essentially on that. But no! The entire interview was on Be-Bi neutron source and that means Doctor must have spoken very highly about it.)

Going back in time, by 1960 I had obtained my M.Sc degree and that was just a cakewalk. The thesis was on Radioactivity build up in natural and man-made systems based on the work I was doing since I joined Doctor. The most enjoyable part of my M.Sc. work was the discussions I used to have at Doctor's residence. By then he was residing in the government quarters at Ghatkopar. While writing the thesis I was discussing with him all the details and that used to be mostly after 6.30 pm in the office. One evening he said 'Gopinath, come home this Sunday morning with all your papers. We will discuss it there.' That was the beginning of a glorious tradition. A typical discussion session would go on like this: I go to his house around 10-10.30 am. Most of the time he would open the door, say 'come in' and take me to the front room, a fairly big room but sparsely furnished, just a table and a few chairs. He would then shout 'Shiboni, do chai dhabo'. Within a few minutes, his daughter Shiboni would bring two cups of tea. He would take his cup, sit on one of the chairs, take

a deep sip, put the cup on the table, his palms on his laps and say with great satisfaction 'Good, very good, now let us start'. Discussions would go on for 3 to 3 ½ hours. This went on week after week, even after my thesis work got completed. In fact most of my work, including the one on radiation transport, was the outcome of such intense and long discussions with him. So, to be fair, many of my publications should have been co-authored by him. It did not happen because he was following the practice of his teacher Prof. S. N. Mukherjee. It seems Prof. Mukherjee also used to intensely participate in his students' research work but refused be a co-author for their publications as he wanted the students to get the full credit. Worthy disciple of a worthy teacher!

Week-end discussions at Doctor's residence continued. Others like M. R. Iyer, T. N. V. Pillai, and K. C. Pillai kept up the tradition. This happened essentially because of Doctor's liking for his people and his joy in interacting with them. This bonding had another delightful spinoff; Division's picnics, envy of others in the Centre. For Doctor the Division was his extended family and he liked holidaying with this family. At his instance (or insistence!), every year we used to have one or two days' excursions to various picnic spots around Bombay, starting from Elephanta Islands close by to Matheran, Lonavala and Mahabaleshwar in the south and National Park, Lake districts, Basin fort and Tarapur in the north. Doctor's participation (often along with Mrs. Ganguly) in these picnics was total and his zest and joy were infectious. With him around we could not be anything but cheerful and everything used to be glorious

By 1960 there were also several changes in our set up; we had moved to Trombay and the Division had grown considerably in terms of staff as well as activities. Two major groups had been formed**;** operational health physics group to provide health physics services to various units and chemistry group for environmental radioactivity studies, bioassay and other services. Other smaller groups such as instrumentation and industrial hygiene were evolving. I was no more a loner; a few persons had joined me. First it was Ramakrishna Iyer (now Dr. M. R. Iyer). Almost immediately after joining, he started working on fission products' inventory and their characteristics and then shifted to the study of fission kinetics; he and doctor did some pioneering work there. Next, it was Kalyanasundaram. Little later Santhanam, Krishnan and Krishnamoorthy joined us. Others like John, Basu, Kotewala, and Mrs. Damle also joined us but they didn't stay for long. We were calling ourselves as R & D group (nobody had designated us that way. Others were making fun of us saying that we have no responsibility and so call ourselves as R & D group). Around this time, Doctor was heading the Safety Evaluation Group of the upcoming reactor CIRUS (then called C I R- Canada India Reactor) and asked us to check the

shielding adequacy of the flask intended to transfer the irradiated fuel elements. That triggered the major and long-standing activity of our group-Radiation transport and shielding. Exact computation of radiation flux/dose from shielded volume sources involves the solution of transport equation which is very tedious calling for major computational facilities. General practice then (and to an extent even now) was to calculate the uncollided flux from the volume source and multiply it by a correction factor called 'Build up factor' to account for the contribution of scattered radiation. At that time 'Reactor Shielding Design Manual' by Theodor Rockwell used to be the 'Bible' for all shielding calculations. Rockwell also had employed the standard practice of computation of the uncollided flux to be corrected by 'build up factor' and had given some recipes for calculating the uncollided flux. While working on the problem referred by Doctor we could improve up on the recipes of Rockwell and that ended up as a technical report AEET-HP-Th 9 'Radiation dose from volume sources' by Krishnamoorthy, Kalyanasundaram and myself. More importantly, it laid the foundation for all our future work on Radiation transport.

After completing M.Sc, obviously I wanted to do my Ph. D. Since I could not be a formal student of Doctor for my M.Sc, I was particular of registering under him for the Ph.D. Degree, be it in chemistry. Finding a problem for my Ph. D work was no problem at all; I was already planning to work on Ganguly-Magee model in the radiation chemistry of water. This model was an improvement over an earlier one called Samuel-Magee model. They were all called Spur- diffusion models which assume occurrence of spurs of radicals along the track of an ionizing particle. The radicals in the spur, while diffusing out, react amongst themselves and solute molecules and their distribution is governed by a non-linear diffusion equation. While the earlier models assumed constant distance between the spurs, Ganguly-Magee model removed this limitation and accounted for random location of spurs along the track (Doctor once told me that he was inspired for this work by Prof. S. Chandrasekhar's work in Astrophysics on the distribution of stars). At that point of time, this was considered to be the most advanced model in the radiation chemistry of water. But it had its limitations. First, while the model accounted for random spacing between the spurs, the spur size itself was kept constant which was not realistic. Second, the initial distribution of radicals within the spur was considered to be Gaussian (Called 'Prescribed diffusion') which again was not correct for a non-linear diffusion process. The model had other limitations but I wanted to work on these two shortcomings either by mathematical simulation, that is Monte Carlo techniques, or by machine simulation, that is

Analogue computers where non-linearity can easily be handled by electronic multipliers. I had discussed these ideas with Doctor; as ever, he had said 'Go ahead, do it' and I registered for Ph.D. in chemistry under him. At that point a break occurred; I had to go on deputation.

During that period, staff members from BARC used to be sent on deputation for training/research, mostly to US under USAID (United State Agency for International Development) scheme. I was hoping that someday I may also be sent and I wanted to go to Radiation Research group headed by the well-known physicist Dr. Ugo Fano, at National Bureau of Standards (NBS). During 1954-56, Fano, Lewis and Spencer had published seminal papers on the application of Moments method for electron transport which had impressed me very much. Later, Goldstein (of 'Classical Mechanics' fame) and Wilkins used the same method for gamma ray transport and generated the celebrated 'Build up factors' which I have mentioned earlier. Moments method is a mathematical beauty but it has serious limitations for application to gamma ray shielding calculations. It assumes the medium to be homogenous and infinite which the practical shields are not. My intention was to work on this problem and for that I wanted to join Dr. Fano's group. I had even talked to him about this during his visit to India in connection with PL 480 program and he had agreed for the proposal. But when the deputation materialized, it was not to that group but to somewhere else. One day Doctor called me and said that he has proposed my name for training in fast reactor safety at Argonne National Laboratory (ANL). I protested and told him of my interest in working with Dr. Fano at NBS. He said 'No, no, fast reactors are the reactors of the future and there are challenging problems in their safety. You better go there!'. It looks like I was thinking years ahead and Doctor was thinking decades ahead. So in 1962, I went to ANL and it was a good thing I did that.

During the deputation to ANL, general practice for us was to attend the formal lectures at the International Institute for Nuclear Science and Engineering (IINSE) for about 6 months and associate ourselves with an appropriate research group for the remaining period. Accordingly, first I joined IINSE. Director of the Institute was Mr. Marshall Grotenhuis, an elderly gentleman, very pleasant, kind and benevolent type. He was quite friendly and helpful to all of us but with me there was a little extra familiarity and friendship. I was wondering why, since we had not met before. Once I was going through the report ANL 6000 on reactor shielding authored by him and there I found the expressions I had obtained for induced activity buildup and reference to AEET-HP-Th-1, the report on my first assignment from Doctor. That explained the extra closeness of Mr. Grotenhuis; I was familiar to him by the

work I had done with Doctor. We remained in contact long after he retired. Much later, around 1976, when I was to give a talk at NBS on our work in radiation transport, he came there specifically to attend the talk (by then he had moved to somewhere in Maryland). That was a sweet reunion.

For the second part of the deputation I joined Dr. Charles Dickerman in the Reactor Engineering Division. For me he was another Dr. Ganguly at Argonne; extremely nice, understanding, and encouraging type. His group was working on "Melt Down" studies and with great patience he explained to me the entire background for such studies. Fast reactors have a unique safety problem; in case of a reactor accident if the fuel pins melt, it can lead to a configuration with increased reactivity resulting in a recriticality accident which could be far more severe. The severity of such an accident depends not only on the total reactivity addition but also on the rate at which it is added, that is, on the coherence in melting of fuel pins. Dr. Dickerman's group was studying this phenomenon with the computer code ARGUS- a heat transfer code- and I was taken in the group. After working with ARGUS for a few weeks, it occurred to me that the analogue simulator I was planning earlier at Bombay for the study of diffusion of radicals in the Ganguly-Magee model could very well be adopted for fast reactor transient studies. Advantages of such a simulator would be that it will be a dedicated tool, quite pliable, improvement/modifications can easily be incorporated and provides a second method to check our calculations. I mentioned all of this to Dr. Dickerman. I am not sure whether he was convinced of the need or feasibility of my ideas but being such an open-minded person as he was, he agreed that we can pursue those ideas. It is not just that; next day he called one Mr. Larry Bryant from the Analogue Computer Division for discussing the ideas. After discussion, Bryant agreed that it is feasible and we started the work. Within about 3 months the simulator was ready. We studied the same accidents on the simulator as well as with the code ARGUS. A surprise was waiting for us there; temperature transients generated by the two methods were identical almost throughout the range but near the melting point they differed significantly. I could see the reason; at the melting point, the heat that is generated in the transient is consumed as latent heat of melting. So, the rise in temperature halts till the melting is complete. This aspect was taken into account in the simulator but not in the ARGUS code and hence the difference. Dr. Dickerman was shocked to see this lapse in ARGUS and felt very happy that studies with the simulator have brought out this vital point. As suggested by him, I stayed there for two more months for completion of two reports on this work; one on Fast Reactor Excursion Simulator (ANL 6844) by me and Bryant and the

other on Calculations of Coherence of Pin Failure in Fast Reactor accidents (ANL 6798) by me and Dickerman. After completing the reports, I returned to India in November 1963.

Back home, I found a very interesting assignment waiting. On the very first day of my return, Krishnan and Santhanam told me that a strong interest has developed in the criticality studies of condensed fissile systems and Doctor has asked us to look into it. They also told me that another group of senior persons was working on the same. At that time, studying such problems was usually done with 'Discrete ordinate methods', also called Sn methods. While the members of the other group were all stalwarts and well experienced with those methods, we had no experience whatsoever (only Santhanam had a little exposure to those methods in an entirely different context). Strangely, our being novice turned out to be to our great advantage; we were not pre-conditioned and didn't have to unlearn anything. We started from fundamentals and for me the driving force in this task was the immense confidence Doctor had in us. That lead us to an entirely new approach, what we called 'Source-Collision Iteration Technique (SCIT)'. Myself and Kalyan concentrated in establishing the new approach. Since it was new, we had to validate its results. For that purpose Krishnan and Santhanam worked on the adoption of an Sn code obtained from abroad. We completed the job and it turned out that the SCIT code was far more efficient, accurate and simple (Kalyan, in his note to this compendium has given a more detailed description of this exiting assignment). Successful completion of that work led to two things; first, we were seriously questioned for doing such a work. Once, a very senior officer confronted me and asked why am I indulging in such studies. Of course, for me answering that question was very easy. I said we are doing it because Doctor has asked us to do it. Doctor himself had to face similar questions.

The second and more important off-shoot of that work was our development of ASFIT methodology. The SCIT code, as I mentioned earlier, very efficiently served the purpose for which it was developed. But as a general transport-theoretic code it had its limitations. One serious limitation was that its formulation assumes isotropic scattering, that is, when a particle (neutron or photon) collides with the nucleus, the emergent particle comes out with equal probability in all directions. This assumption is not valid in general and particularly so for gamma ray scattering or fast neutron scattering with light materials. Direction of the scattered particle is indeed correlated to the direction of the incident particle resulting in its anisotropic distribution. We, myself and Santhanam, struggled for about 6 months and succeeded in introducing this anisotropy in SCIT formalism and called it as 'Anisotropic Source-Flux

Iteration Technique'. Meanwhile we had also introduced several improvements in the method such as analytical removal of singularities in the distribution of scattered radiation sources and fluxes, exact handling of interface conditions, etc. With all this done, the code ASFIT based on this method turned out to be extremely fast and accurate. It found instant recognition as the most accurate code for radiation transport in one dimensional finite systems. Radiation Shielding Information Center (RSIC) of ORNL, USA, heralded the development of this method by a special note in their Newsletter and took up world-wide distribution of the ASFIT code. There were large scale computations with the code which provided explanations for several anomalous features observed in the environmental radiation. Since the code could handle finite, multiregion systems exactly, it mitigated the serious limitations of moments method (applicable only to homogenous infinite systems) in the computation of buildup factors and generated the exact buildup factors to be used with practical shields. In fact, it went far beyond that in providing an understanding of gamma ray transport. American Nuclear Society, in its Standards ANS 6.4.3 on Gamma ray Build up Factors included a large amount of data, particularly on Finite region build up factors and Tissue dose build up factors, obtained by the ASFIT code. It also led to our intense interaction with other international teams working on radiation transport problems; in particular, Dave Turbey of RSIC, ORNL, and John Hubell of NBS. Dave became a close collaborator in our further studies and we have several joint publications on ASFIT calculations.

Around 1965-66, Doctor and myself were very much interested in the low energy gamma radiation in the environment. Starting from a few MeV down to about 100 keV, the gamma ray interaction cross sections vary smoothly with energy. Consequently, the secondary radiation spectra will also have an essentially smooth behavior. But below 100 keV, photoelectric cross sections are dominated by shell-edge discontinuities. Because of this and the resulting shell X-rays, which are element-specific, we were wondering whether the secondary radiation spectrum in this region will have any peaks and valleys characteristic of the environmental constituents (sort of naturally occurring X-ray fluorescence). A wild conjecture but we wanted to investigate it. We had our counting room in the basement of Mod Lab with several detector systems and shield materials. Doctor, myself and Peshori, who was in-charge of our Instrumentation group, used to go there almost every afternoon to study the low energy spectrum of radiation passing through different materials (Poor fellow Peshori had a tough time arranging and rearranging massive shield configurations every day for months together). One of those days I

said 'Doctor, we have Radiation Chemistry and Radiation Biology as well established and active disciplines. But it is the physics which is the starting point and most basic aspect of interaction of radiation with matter. Why is it we do not have Radiation Physics?' Doctor, in his very characteristic way, fired 'Yes, but why are you complaining? If you feel strongly about it, you start it'. Now I feel those were prophetic words. See the boldness of that diktat! Doctor said that neither to close the chapter nor to shirk the responsibility but because he had firm belief that no task is too big to be afraid of and he had full confidence in his people. As for me, from then on it became my obsession. Of course, circumstances also were very favorable for the task. Firstly, there was Doctor to provide inspiration, guidance and rock-solid support. In addition, I had talented, enthusiastic and exemplarily cooperative colleagues like. Krishnan, Santhanam, Nambi, Somasundaram, etc. There was complete resonance in our thinking. Second, the field was nascent with intense activity in different areas of what we considered as radiation physics. Globally, there were new and exciting developments taking place in basic data, detectors, instrumentation, mathematical methods, etc. Within the country, at BARC Health Physics Dn., DRP, Theoretical Physics Dn., Reactor Physics Section, Technical Physics Dn., Electronics Dn., etc., were actively pursuing different parts of the subject. Outside BARC, several universities having nuclear physics departments had strong programs in the study of basic interactions of radiation with matter. Besides universities, institutes like IIT Powai in Bombay (Kane and Basavaraju), INMAS in Delhi (Nagarathnam and Reddy) and Bose Institute in Calcutta (Ghose and. Roy) also had active programs in the area. Fortunately I was in contact with most of them, both in and outside BARC. Everybody agreed that identification of Radiation Physics as a distinct discipline would be very good for development of the subject as well as for workers in the field; it provides an effective forum for interaction of persons of similar academic interest and dispels the sense of isolation prevailing amongst them. Our plan for starting the movement was to have periodic conferences, topical meetings on different aspects of radiation physics, forming a National society for radiation physics, bringing out a newsletter, publication of booklets on different sub-topics, and so on. Immediately in 1966, at the instance of Doctor, we had the conference on the metrology of radionuclides which was essentially Instrumentation part of Radiation physics. That was followed by the first National Symposium on Radiation Physics at BARC in 1970, inaugurated by Dr. Ramanna. The conference was successful beyond our expectations; it brought together almost all the groups in the country working in different areas of radiation physics and helped establishing its identity as an independent discipline. After that, in

1974 the first International Conference on Radiation Physics was organized by Prof. A. M. Ghose at Bose Institute, Calcutta. By then, Ghose had become our close associate and another ardent follower of Doctor (Doctor was Anil da to him and he was Anando da to me; Da, short form of Dada, is elder brother in Bengali). The Conference was truly an international one with the participation of leading workers from US, UK, France, Germany, Russia, Hungary, Japan and several other countries. Doctor was immensely happy at the deliberations and in his summing up speech echoed Dr. Ramanna's feelings that the Conference has provided directions as to where we should go from there in Radiation Physics. It indeed did so; it increased our tempo of working leading to formation of Indian Society for Radiation Physics (ISRP) in1976 at the next National Symposium on Radiation Physics (NSRP) held at Mysore. Formation of ISRP has been a major land mark and it has acted/acting as a carrier for all our intended programs. It has institutionalized biannual NSRP, organized topical meetings, formed a number of chapters all over the country, started a very useful and popular series of ISRP booklets on various topics of radiation physics, facilitated taking radiation physics to academics and so on. It also led to the formation of International Radiation Physics Society (IRPS) in 1985 at Ferrara, Italy with Dr. P. K. Iyengar as its Founder President.

Doctor retired in 1978. By then he could see the full blossoming of his prophetic advice. Even after his retirement he was closely following the ISRP activities and the grand finale of his association was his total and inspiring participation in NSRP-VI held at Kalpakkam during 1986. Since the Symposium was being held at SRL-HASL which were also his creations, we were very particular of his participation and much to our delight, he could be there. Kalpakkam has a beautiful Guest house but with many of his disciples being there, we couldn't imagine his being alone in the Guest house; he stayed with me and those 5 days of his stay were festival days for us. The festivities started from the very day he arrived at Kalpakkam; that night we, some 20 of his 'Chelas' from Bombay, Kalpakkam and Calcutta, had a delightful meeting with him that went on up to 11- 11.30 PM. (Incidentally, during those 4-5 days me and Doctor had enough time to indulge in our pseudo-scientific discussions and I had my full quota of 'silly fellow', 'crazy fellow', 'mad fellow', etc. His latest discovery was that the pristine environment of Kalpakkam has made me a mad fellow) He was in his elements throughout, fully participated in the Symposium and made every session very lively with his presence. In Doctor's presence, we announced the formation of Kalpakkam chapter of ISRP. Overall, he was extremely happy and made all of us happy too. I was

told by V. K. Gupta and others that after returning to Bombay Doctor was telling his family that visit to Kalpakkam has been a rejuvenating experience for him. By next NSRP, Doctor was no more!

1969-70; formative years of the Reactor Research Centre (RRC, the present IGCAR). Dr. Sarabhai, Chairman, AEC, had called a two-day meeting of the Project Progress Review Committee at Kalpakkam. Dr. Sarabhai, Dr. Ramanna, Mr. N. Srinivasan, Dr. M. R. Srinivasan and other senior members were participating in it. All the Groups who had proposed programs for RRC were to make their presentations in the meeting. Health Physics Dn. had proposed research program related to fast reactor safety. Doctor and myself were supposed to participate in the meeting but since Doctor's return from abroad got delayed, only I went there (I think L. V. Krishnan was already there). On the first day of the meeting there were about 7 to 8 presentations. At the end I presented our proposal for Safety Research Laboratory and the presentation went on well. Toward the end, I saw Paranjape, Head, Design Group, whispering something to Dr. Sarabhai and Dr. Sarabhai asked 'Gopinath, Paranjape says that his Design Group has plans to carryout whatever research program you have proposed. What is your reaction?' I said 'In my understanding, the task of Design Group is to evolve the best possible design at the earliest with all the available data. In this task if it finds that some data is wanting, it should discuss with the concerned Group/laboratory in the Centre which should work on that, generate the data expeditiously and provide it to the Design Group. If the Design Group itself tries to generate all the data required then it will not be a part of RRC; RRC has to be a part of that Group'. Everybody laughed and Dr. Sarabhai was smiling. Then Dr. M. R. Srinivasan said 'Gopinath, you are proposing studies on sodium fires and aerosols, sodium safety, etc. But there is nothing nuclear about them. Don't you think that we should entrust these studies to outside institutions like IIT, Madras, with proper funding and get the results?' My impulsive response was 'Dr. Srinivasan's suggestion is very appropriate for projects like MAPP (he was the Project Director of MAPP at that time) which have specific, time-bound targets. In working toward that target if they face any technical problem, they should second it to outside institutions, get the results and move expeditiously. But I think the RRC case is different. The interest here is not in solving just a particular problem but in developing our expertise, our ability to solve all the related problems and in developing a technology, fast reactor technology. If we second this to some other agency, the very objective of RRC gets compromised. ….' I went on like that for a while. All along I was looking at Dr. Sarabhai and Dr. Srinivasan. Dr. Sarabhai was smiling and looked amused but Dr. Srinivasan was not. After

that there were some more questions from others but nothing formidable. By then it was getting late and Dr. Sarabhai suggested that we can have a brief meeting next morning and discuss the budgetary aspects of safety research proposal. With that the meeting got closed. I was feeling a little apprehensive as to whether by my impetuous answers I have offended Dr. Sarabhai and other seniors. Coming out of the meeting, I met Mr. N Srinivasan in the corridor and asked him whether I showed any irreverence to Dr. Sarabhai in my answers. Just then Dr. Sarabhai himself passed that way. He might have heard his name being mentioned and wanted to know what we were discussing. Mr. Srinivasan repeated my question about being irreverent. Dr. Sarabhai smilingly said 'No, No, Gopinath, it is a scientific meeting and in scientific discussions there is nothing like reverence or irreverence'. So saying, he went away.

Next morning there was a brief meeting for discussing our budget. But there was not much to discuss; ours was the smallest requirement, about 30 lakhs, compared to several crores each for most of the other proposals. There were some questions just for the sake of questioning and it was approved. But I was feeling unhappy. While proposals involving crores and crores were approved with very little discussion, safety research with its insignificant budgetary requirement compared to them had to be discussed for two days for acceptance. I expressed this in the meeting. Just before the meeting was to close Dr. Sarabhai came in and he was briefed about the deliberations. At that time, someone (I think it was M. Srinivasan, a close friend of mine) mentioned to him what I expressed in the meeting. Dr. Sarabhai laughed and said ' No, no, all the other proposals also will be subjected to the same rigor before approval'. Then he looked at me and said 'Gopinath, I want to talk to you. I will come and see you when I am in Bombay next'. I was surprised but then I thought he is being nice and left it that. On my return to Bombay I reported all the deliberations to Doctor.

In spite of his hundred and odd pressing tasks, true to his word Dr. Sarabhai did come and saw us at Bombay. About 15-20 days later, one day around noon I got a message from Doctor's office that Dr. Sarabhai would be coming to us shortly. Within a few minutes, he walked in, sat in one of the chairs and listened to what all we are doing including work related fast reactor safety. At that time our *magnum opus* was the development of ASFIT methodology which was world-acclaimed and eminently successful for the study of neutron and gamma ray transport in one-Dimensional Finite Systems. I mentioned all of that and also told him how it can easily encompass the space radiation studies. He listened intensely for a while and then said 'No, Gopinath, this won't do. I would like to speak to you much more. But I have got to be going now because

of the other appointments. Definitely I will come again prepared for a much longer meeting'. With that he left us. After some time Doctor walked in and said "Gopinath, Dr. Sarabhai says 'Ganguly, you have a fanatic follower in Gopinath'. He seemed to be very happy." I did not say anything. Both of us knew that Dr. Sarabhai was right and we just smiled. Unfortunately the meeting that Dr. Sarabhai mentioned never materialized. Within about a month we got the shocking news that he expired on his way to Bombay from Trivandrum. So, we will never know what he had in mind for that 'long' meeting.

In 1972, Doctor having become Director, Chemical Group, moved to Central Complex. But that did not diminish our interactions; almost every day, after 5.30 PM he used to come down to Mod Lab to be with his 'boys'. By then, in addition to our studies on radiation transport, we had started working on fast reactor safety problems as a prelude to our future work at the Safety Research Laboratory (SRL), Kalpakkam.

Around 1973-74 there was a meeting between Doctor and Sri. N Srinivasan, the then Director, RRC. I was also present there. In the meeting Doctor suggested formation of a safety evaluation group for RRC before other activities start so that good safety practices are embedded right from the beginning. Sri Srinivasan, who had high regard for Doctor, acted then and there by forming Safety Evaluation Working Group- SEWG- consisting of very bright and dedicated young persons from the Centre. SEWG played a vital role and made a thorough design safety evaluation of FBTR in particular and all the other facilities of RRC in general. So much so, there wasn't any problem in obtaining safety clearances from regulatory authorities for any of these facilities. Other vital contribution of Doctor to RRC was the creation of SRL and HASL. As mentioned earlier, our proposal for SRL had been approved right in the beginning. Its construction and commissioning went on as per schedule and by 1975-76 it was in satisfactory operation. In addition to SRL, to provide the health physics services for all the units in the Centre and have necessary R & D backup for such services, we had proposed a well-planned Health and Safety Laboratory (HASL). Surprisingly strong opposition arose for that proposal from unexpected quarters. It is only because of Doctor's firm stand that the project got approved and today it stands as a witness to Doctor's foresight and commitment to health and safety.

I moved to Kalpakkam in 1975 (Krishnan had moved a little earlier, in 1974) and my luck continued to hold there. The time I spent there (15 years) was very pleasant, eventful and extremely productive. But that doesn't exactly belong to the subject matter of this compendium. So I will give only a brief account of that period.

As at BARC, I had a set of talented, enthusiastic and committed colleagues. It was a good combination of some senior persons from Trombay like Krishnan, Sundararajan, Natarajan, Raghunath, Mitraghotri and many directly recruited enthusiastic youngsters like Singh, Somayaji, Meenakshisundaram, Harvey, Subbaiah, Venkatesham, etc. I was supposed to be the Head of the laboratory but it was essentially an egalitarian setup and that suited me very well. The senior colleagues were willing and capable of functioning independently. For instance, Krishnan was practically running the SRL, meeting all its administrative and coordination requirements. Setting up of HASL was done entirely by Sundararajan. Right from the stage of layout planning, through interaction with civil, electrical and AC engineers during construction, equipping the laboratory and commissioning was done by him. Raghunath organized health physics surveillance and services at various units like FBTR, RDL CWMF, etc. They did all this independently while pursuing their own individual research interests. Krishnan was involved in 'Burst studies', a collaborative program with ERDL, Poona, for simulating reactor accidents by chemical explosives to study the stresses on the structures. Sundararajan was actively pursuing the study of sodium fires and aerosols. Raghunath, along with other youngsters, was conducting several radiation physics experiments. Dr. Seshadri single handedly built 14 MeV neutron generator and initiated fast neutron transmission studies. The new recruits, all youngsters, were very enthusiastic and highly motivated. Dr. Singh, a newly recruited electrical engineer, within a short time built the condenser discharge setup for our fuel-coolant interaction studies.

A little digression here to highlight the SRL atmosphere then: Right in the beginning, we wanted to study the streaming of radiation through ducts, an important topic in radiation shielding. Normal course for us should have been to request the Civil Engineering group for construction of a shield structure with specified ducts. They would have done it for us but it would have taken at least 2-3 weeks. We were impatient and had other ideas. There were a number of fair sized concrete blocks with us (discards from the Concrete Lab after their testing). Meenakshisundaram, Bhatnagar and Natarajan (who, just a few days before, had returned from US after his Ph.D. from a top-notch university, Carnegie Institute), went with crowbars and spades and dug a pit of the desired dimensions behind SRL. They fitted the pit with concrete blocks with a central opening to form the vertical leg of a duct. A linking horizontal duct-like arrangement of blocks on the ground surface and another vertical pile of concrete blocks at its end formed an eminently functional, double-bend duct. With the gamma radiation source at the bottom of the pit, the setup was ready for streaming studies and the whole exercise took about two days. We

could easily alter any of the duct dimensions such as the size of the central gap, length of different legs of the duct, etc., for parametric studies. With this simple setup, a whole lot of data was generated on the spectra and dose of streaming radiation. One of its important and interesting finding was the effect of duct lining on streaming radiation. It is obvious that in bent ducts, radiation can stream only due to scattering, particularly near the bends. Further, our transport calculations with ASFIT had shown that high Ze elements like lead are very poor back scatterers. So, we expected that lining the inner surface of the duct in the vicinity of bends with materials like lead should reduce the streaming radiation. Indeed, the measurements showed significant reduction in the streaming radiation. I am mentioning it here just to show the zeal and innovative spirit prevalent with the youngsters at SRL.

I had enough time to pursue newer and non-routine matters and group's research interests. That was the period when I could develop the 'Finite Transform' method, a totally new way of looking at radiation transport. In a way, it is the application of 'path integral' formalism for radiation transport problems; integrating the contribution of all the paths that a particle can take from source to target with a collision in between. In one-dimensional systems it reduces the spatial variable to a simple parameter and many of the earlier results like Chandrasekhar's H-function, X and Y functions, Milne's solution for semi-infinite systems come out as simple corollaries of this approach. It evoked good amount of interest in the field. When I gave a talk on this approach at NBS, Dr. Lewis, Head of Radiation Research section, a position held by Dr. Fano earlier, mentioned that he had similar ideas but somehow he could not pursue them. Prof. Paul Nelson of Mathematics department at Texas A and M university evinced keen interest on this development and even proposed a collaborative project to study the mathematical aspects this finite transform. It did not come through for some non-technical reasons but our close interactions with mutual visits continued. All along Doctor was kept informed of this work and he was extremely happy about it; in some context he wrote 'This can rightly be called as G-Transform'.

Around 1982, Sri C. V. Sundaram moved in as Director of the Centre and almost immediately a very strong rapport developed between us and him The safety group, (that is, SRL-HASL) was officially still a part of BARC at that time. But he treated us very much part of the Centre, encouraging and supporting all our programs. When we formed the Kalpakkam Chapter of ISRP, he (a rank Metallurgist) became the Founder President of the Chapter. In turn, safety group also identified itself with the Centre and fully participated in all the Centre's activities. It played a significant role in FBTR criticality and

again in its rehabilitation after the severe incidence of bent guide tube. It evolved an elaborate Radiation Emergency Plan for the Kalpakkam site, of course, with strong support from Sri Sundaram and exemplary cooperation from the District authorities. That was highly appreciated even by the Prime Minister and got accepted as a model for all our nuclear installations. Similarly, the Cyclone Emergency Preparedness Plan for Kalpakkam site developed by us became model for all the coast-based DAE installations. It also led to a Guideline Document issued by National Safety Council for cyclone emergency preparedness for all the coast-based industrial installations in the country. As mentioned earlier, Doctor visited Kalpakkam in 1986 in connection with NSRP-VI and by then SRL-HASL was fully operational. He was delighted to see the setup; the well planned laboratories, range and scope of their activities and the enthusiasm of the staff. He talked to almost every one of the staff and got to know their work. He went back very happy and that was of immense satisfaction for us.

Sometime in the beginning of 1988, we got the news that Mrs. Ganguly passed away. Within about 15 days I was at Doctor's house and I was shocked to see his condition. Looking at me he completely broke down; with his hands on my shoulders and tears in his eyes he narrated a pathetic event on that fateful day. It seems that after all the rites at home were over and her body was taken away, out of shear mental tiredness he dozed off. During that semi-sleep state he dreamt that whatever he saw right from the morning was a only a dream, a very bad dream, Mrs. Ganguly is alive and everything is alright. But alas! he had to wake up and face the realties. I met him a few more times later and I could see that he never recovered. Finally in November '88 the sky fell off. We got the news that Dr. Anil Kumar Ganguly is no more. (It is at time that, on suggestion from Dr. J. Shankar, I wrote the 'Tribute' given at the beginning of this note.)

I returned to Bombay in 1990. Obviously, it was a happy home coming for me, back to the lab and colleagues with whom I had spent those exciting younger days. But I grossly missed Doctor and his fond rebukes. It had become a habit for me to run to him for every small reason and at times for no reason at all. I couldn't do that anymore. (In a lighter vein, there was one other thing I missed; the pranks I used to play, sometimes with and sometimes at my colleagues. It is the price one pays for becoming a senior). Even though Doctor was not physically present, his memories always guided me; if I had to do anything important I always used to consider how he would have acted under similar circumstances. Without going into details, I tried to scrupulously follow his principles and practices in all my interactions. I think that specifically three

actions I took (of course, all with the strong support from Dr. Chidambaram, the then Director, BARC) are close to Doctor's heart. They *are* i)creation of a separate Division (RSSD) for R & D activities in radiation safety, ii) creation of Environmental Assessment Division (EAD) exclusively for environmental studies and iii) imitating Bi-annual National Symposia on Environment, a national forum for deliberations in environmental sciences. Knowing him well, I am sure he would have been very happy to see these developments. Again, living up to his tradition, I continued my own research pursuits in the Finite Transform development (along with A. R. Naik) leading to some significant results in the solution of Singular Value Integral Equations.

I retired from BARC in August 1993 after a gratifying service of about 4 decades.

Problem Child

1958-59; Doctor called me one morning and said 'Gopinath, come home this evening and have food with us'. I was a bachelor then and not used to say 'no' for such invitations from anybody and definitely not when Doctor himself is inviting. My response was an emphatic 'Yes, Doctor'. That evening I went to his house around 8 PM; I thought there was some function and expected to see some more people there. But no! None other than Doctor's family. Shortly afterward we had our dinner. Food was good, some Bengali sweets, Kichadi, etc. After dinner, when we were having a general talk, Doctor said 'Today is my father's anniversary and I wanted to have you with us for food'! What sort of a relationship is this?

1963-64; just then I had returned from my deputation abroad and was trying to set up the family. I did not have any accommodation of my own. My colleague Venkataraman was living as a sub-tenant in a house allotted to his relative in Ghatkopar government quarters and he offered that we could stay with him. So, I started my family life as a sub-sub- tenant in Ghatkopar. Doctor's house was close by. On some evenings he would walk down to our house, sit on the bare cot there and say 'Naga, a cup of hot coffee' (my wife's name is Nagamani and we all call her Naga). She would happily get him strong, hot coffee; he would enjoy his cup, talk for a while and go back. Thus they were familiar with each other right from the beginning. That was also the time when I was involved in the study of criticality of condensed fissile systems and I was going to TIFR for our computer work. In our fervor to get things done fast, quite often we used to stay there pretty late. Once, I left TIFR around 8.30 PM. TIFR to Ghatkopar is a long way and with changing buses and all, it used take more than 2 to 2 1/2 hrs to cover the distance. So, by the time I reached home it

was past 10.30. By then, because of her anxiety, Naga had gone to Doctor's house to find out whether he knows why I am late. Doctor was surprised to see her at that hour, told her that he had returned at the usual time and I did not join him coming home (which I used to do often). To calm her down he said that I have been used to stay in the office late in the night, everything would be alright and if there is any further delay he will make arrangement to find out. She returned and almost immediately I reached home. She was, understandably, very much upset and I did a lot of explaining and apologizing to sooth her down. But the real typhoon I had to face was still to come. Next morning, as I reached the office somebody told me that Doctor was looking for me. I went and saw him; he looked very angry and wanted to know what time I returned home last night and what was I doing outside so late. When I said that I stayed late in TIFR to get maximum work done, he became furious and fired 'You people have no sense of responsibility at all. You get married, bring an innocent, upcountry girl to this huge place totally unknown to her and leave her alone till late in the night saying that you had some urgent work. What sort of persons are you?' I tried to explain why we wanted to stay late but he wouldn't allow me and fired again; 'Stop it. You are talking about your project, your work and your urgency. But did you ever think of her state of mind and her anxiety? She is your wife and don't you think you owe her also some responsibility?' He went on like this for another 5-10 minutes and then said 'OK, you can go now. But whatever may be your work, make sure that you are back home by 7-7.30'. I sheepishly said 'Yes Doctor' and came out. (Now a strange observation: I was doing the work assigned by him, without caring for my comfort or working hours or anything. So I should have got some appreciation from him. Instead, I get severely rebuked and I should have felt pretty bad about it. But, no! I did not feel bad at all. Instead, I was feeling happy; happy to know how much he cares for me and my family, happy to see that his human nature, his love and affection overrides all other aspects. That was Doctor!).

1972-73. In connection with some collaborative program, myself and Santhanam, were to meet Director, ERDL, Poona, on a particular day. Just the previous day we received the intimation that Santhanam's interview for promotion has been fixed for the same day. (By the way, Doctor was the Chairman of that senior interview committee). On that evening I was standing in the Mod Lab corridor in front of my room talking to Dr. PRK Rao (of MDRS fame), Around 6 PM Doctor, as his usual practice, came from Central Complex and walked down toward us. I told him about next day's problem and wanted him to get Santhanam's interview postponed. Immediately he said 'No

no, it cannot be done. The schedule is drawn up after a lot of planning and it can't be changed now'. I told him how essential it is for us to go to Poona. But Doctor was very vehement and gave all the reasons why the change of date is not possible. Just then, Shri Mhatre, AO-III in-charge of organizing interviews, came there. Doctor said 'Mhatre, Santhanam's interview is fixed for tomorrow. We have to change it for some other day'. Mhatre was taken aback and said 'Doctor, it cannot be done. We have already informed the external expert and drawn up a tight schedule for the entire the week and all of it gets upset'. Doctor said 'I understand all of it Mr. Mhatre. But tomorrow they have an important meeting with defense people at Poona and you know that it has to be given priority'. Whole of earlier argument got repeated but with roles changed; Mhatre pleading why it cannot be changed and Doctor insisting why it has to be changed. Obviously, Doctor prevailed and Mhatre left with a worried face. After a while Doctor also left us. Dr. Rao, who was silently watching all this was shocked and said 'What is this Gopinath, he was all along vehemently arguing with you why the interview date cannot be changed and suddenly turns 180^0 and argues even more vehemently why it has to be changed. What is going on here?' I smiled and said 'That's me and Doctor'.

1976-77; by hen I had moved to Kalpakkam but used to visit Bombay frequently. During that period, Prof. Lakshminarayana from Andhra University, a close friend of mine, wanted to have the next NSRP at Waltair and asked whether I could help him in getting it BRNS funding. NSRP was gaining importance as a national event and I did not expect any problem in BRNS funding the symposium. Besides, I also knew that Doctor was a member of BRNS. So I told Prof. Lakshminarayana that I will try to get the funds. When I came to Bombay next, I told Doctor about the funds request. Doctor immediately said that BRNS meeting was over, all the available funds have been allotted to various projects and nothing is left now. I pleaded that something has to be done since NSRP is very important for us and I have almost promised help from BRNS. Doctor was furious and said I had no business to promise without knowing all the details and nothing can be done now. I sat there quietly for a while. After some time he asked his APO Rajagopal to get Chairman of BRNS, Prof. Udgaonkar, on phone. As he came on line Doctor mentioned about my request. There was some discussion between them with Doctor telling him how sometimes one may have to transgress the normal practices. Anyway, after some talk Doctor thanked Prof. Udgaonkar, looked at me and said 'OK, tell your Professor to make a formal application to BRNS. He will get his funds. But you don't get into such problems again'. I said 'OK, Doctor' and scrammed from there.

There have been several such instances and the pattern is the same: I have a knack of getting into severe problems and go to Doctor for solution. First, he will fire me and tell me how it is not possible to do what I am asking. I stay quiet. After a while he looks at me and says 'Silly fellow, you always get into problems. OK, where do you want me to sign now?' That means my job is done! If you look at all of this, ours was an extraordinary relationship and it is difficult to say why it was so. The only explanation I can think of has come from Pradeep Ganguly, Doctor's son and my colleague for some time at Kalpakkam. He told me that on some occasion Doctor was telling Mrs. Ganguly 'Gopinath is my problem child'. I think that's about explains all our interactions.

End note.

Looking back, for me it has been an unbelievably delightful, intellectually satisfying and professionally fruitful life. I had an enlightened, understanding and affectionate boss, capable and exemplarily cooperative colleagues, unlimited opportunities to do whatever I wanted to and the satisfaction of having contributed something to the field. All of this was entirely due to that great soul Dr. Anil Kumar Ganguly. So, with due apologies for being a little overly sentimental, I would like to add this: While I do not believe in rebirth and all that kind of stuff, if indeed there is such a thing as rebirth, I would like to be born again as a disciple of Dr. Anil Kumar Ganguly. (If he were to see this, I know what would have been his reaction; he would have roared into laughter and say 'you silly fellow!'. And if Mr. Vaze, the then Director, Electronics Group, a close friend and frequent companion of Doctor, who was well-known for his razor-sharp wit, were to be there, he would have added 'So, you fellow want to pester Doctor in his next life also! and both of them would have roared into laughter even louder'.

Annexure 2

REMINISCENCES OF DR. A K GANGULY

S D Soman
Former Director, Health and Safety Group, BARC
Former Chairman AERB

My ex-colleague and Dr. Ganguly's student M R Iyer is doing this commendable job of bringing out this publication on his centenary year. My best wishes to him.

First time I saw Dr. Ganguly, then a thin lean man, was in 1956 outside Mr A S Rao's Office at OYC. I had just returned after 3 months of work in Kerala carrying out radiation mapping of the high background areas around Quilon in Kerala along with G H Vaze and D S Bharatwal. UNSCEAR had called for a report from AEET on radiation in the High Background Radiation Areas of Kerala and Mr A S Rao and Dr. Gopal Ayengar had commissioned this team to carry out the first ever such survey in the west coast of India

Dr. Ganguly was recruited to develop Waste Management Program for the then newly constituted Atomic Energy Establishment Trombay, AEET. Later myself and Dr. Ganguly were part of a team of about 25-30 sent to Canada for familiarizing all activities connected with the setting up of the Canada India Reactor, CIR . Since he was originally selected by Dr. Bhabha for organizing the waste management activities, Dr. Ganguly was getting briefed on these aspects by Dr. C A Mawson who was in charge of the Waste disposal department at the Chalk River nuclear plant of Atomic Energy of Canada Ltd. while I was at the NRX reactor looking into radiation surveillance aspects. The engineering, design and operation aspects were looked after by a team consisting of V Surya Rao, S L Kati, M S R Sarma, M Dayal and others. P K Iyengar was working with Dr. Brockhouse who later became a Nobel Laurate in Physics, on the application of the proposed CIR reactor in neutron physics research. Thus the team put together by Dr. Bhabha for the setting up of the research reactor in AEET was a comprehensive one touching on all the aspects. The CIR research reactor in AEET was being erected by the Canadians as a copy of the NRX reactor in Canada. After 3 months Dr. Ganguly was asked to proceed to USA for familiarizing himself with the waste management activities at US National Laboratories.

On return to India Dr. Ganguly was asked to Head the Radiation Hazards Control Section in the Health Physics Division under Mr A S Rao and he started right earnestly working on setting up the waste management activities. He initiated the setting up of a radioactive laundry and decontamination Centre with T Subbaratnam, Victor Amalraj and Chinoy who were the initial crop of chemical engineers recruited by him for the purpose. He also started carrying out extensive investigations on the effect of possible release of radioactive wastes into the marine environment from the various plants being set up in AEET Trombay. As a result of this, the limits of possible radioactivity release from the waste management activities in AEET were prescribed by Dr Ganguly. He had in 1960 carried out computational research on the temperature distribution in radioactive spheres, a topic that was of far-reaching implication for incorporating radioactive wastes in glass matrix. The work on vitrificaton of radioactive wastes was initiated decades later. Thus Dr. Ganguly laid the foundation of the waste management activities in AEET even before the reactor and plants started operating there. He also started organizing the radiation monitoring activities along with me. However in 1962 while Dr. Ganguly was away in Egypt on an IAEA Mission, waste management activities were suddenly transferred to Chemical Engineering Division under H N Sethna and K T Thomas from IRE Alwaye who was a chemical engineer and a close colleague of Mr Sethna involved in the setting up the Thorium Plant was assigned the task.

In the meantime India was to prepare 3 chapters (administrative control, accident analysis, and waste disposal) in the 10 part-safety report for CIR. The task was allotted to a combined team of engineers under V Surya Rao and radiation safety people under Dr. Ganguly. When completed the report was reviewed by N G Stewart from Dounreay Nuclear Power Development Establishment in UK. He was specially commissioned for this task by Dr. Bhabha. On instructions from Dr. Bhabha the report was then presented by Dr. Ganguly to AECL at Chalk River.

A reactor Safety committee for the three research reactors operating in AEET (Apsara, CIR and Zerlina) was constituted under the chairmanship of A S Rao with Dr. Ganguly and V Surya Rao as members.

Around this time site was to be selected for the first nuclear power plant. Dr Ganguly prepared guidelines for this and the Tarapur site was selected. Rajasthan and Kalpakkam sites were also similarly selected. In case of Narora Dr. Ganguly signed the report with a note of dissent.

With 3 power stations operating a DAE Safety Review committee (DAE-SRC) was formed under the Chairmanship of Dr. Ganguly by an office order of Chairman AEC. This was the first steps on regulation of atomic energy activities in India. This later on evolved into the Atomic Energy Regulatory Board.

Dr. Ganguly developed severe eye problem during this period following cataract surgery. DAE arranged for his treatment in a London hospital. N G Stewart a noted Health Physics pioneer of the Health Physics Division of AERE Harwell, UK received him at the London airport and looked after him during his stay in UK. H N Sethna who was AEC chairman personally oversaw these arrangements. Dr. Ganguly was hospitalized in BARC Hospital for a month before these arrangements were made, since the required laser treatment facilities were not yet available in India.

On his retirement he was a national fellow in environmental sciences of the DST for a period of 3 years.

Dr. Ganguly served in several ongoing national and international committees and was on a few IAEA assignments abroad. He was the recipient of Padma Shri Award in 1975.

Annexure 3

REMINISCENCES OF DR A K GANGULY

Abel Julio GONZÁLEZ
Argentine Nuclear Regulatory Authority (ARN)
Ex-Vice-Chairman of ICRP
Member UNSCEAR

Dr. A.K. Ganguly, the former Director of the Chemical Group at Bhabha Atomic Research Center, was a good friend of my motherland, Argentina, and we will never forget his amity ever since he spent 6 Months as an IAEA Expert in the sixties. We learned from him, not only about radiation protection but also its profound philosophy. We used to name him 'our Guru'.

He was a constituent of that special elite of scientists who around half a century ago created the globally used radiation protection paradigm, a scientific and ethical development very much entangled with the history of the International Commission on Radiological Protection, ICRP. Dr. Ganguly was heavily involved in this history, sharing experiences with other eminent scientist of his time such as B. Lindel, H. J. Dunster, D. J. Beninson, C. A. Mawson, G. Michon, C. P. Straub, E. G. Struxness and others.

Our admiration of his knowledge is only matched by the admiration that he himself had of another giant of India: Dr. Homi Bhabha. Dr. Ganguly worked under Dr. Bhabha's inspiration and recognized that he was unable to enumerate the many splendours, genius and accomplishments of that great son of India. Well, Dr. Ganguly's inabilities to describe Dr. Bhabha's achievements are only matched by our own inabilities to describe Dr. Ganguly's achievements for India and the world.

This incomplete prose is therefore delivered not as a summary of Dr. Ganguly's rich life but as a humble tribute to his memory. I therefore hope that the IARP-IC2018 Conference be a sequel to one of the noble exhortations that both of those pillars of India's science had made to those of us engaged in the work related to radiation protection and safety sciences, namely that "radioactive materials and sources of radiation should be handled in a manner which not only ensures that no harm can come to workers, members of the public and patients, 'but also in an exemplary manner so as to set a standard which others may be asked to emulate'".

Time after time, Dr Ganguly had reminded us that while radiation protection is concerned with the protection of individuals, their progeny and mankind as a whole, it should not prevent allowing necessary endeavours from which radiation exposure might result. The last part of this saviour reflection, which was a cornerstone of ICRP recommendations, has been many times ignored by our professional colleagues, particularly in Europe, resulting in a de facto phase out of one of the more important human benefits associated with radiation exposure: nuclear power.

For the memory of our Guru, I invite you to revitalize Dr. Ganguly's reflections on radiation protection.

Annexure 4

My uncle, Dr A. K. Ganguly

…….the man who showed me how to create and choose options in life

Prof. Prabuddha Ganguli,

CEO, VISION-IPR

Visiting Professor, IIT Kharagpur,

Fondly turning the pages of time, I recall that wonderful day possibly, in 1956, as an eight-year-old boy, when I went with my father to get my uncle on his arrival in Mumbai to our home in Dadar. My uncle's first warm and broad smiling hug transmitted a feeling of loving togetherness, the ripples of which run through me even as I pen these musings today.

I was told that my uncle is a scientist. For an innocent eight-year old boy those days, the concept of a scientist was a long haired and bearded man, quite different from others. My uncle failed these physical benchmarks of my conceptualised scientist, as I found him to be a total symbol of simplicity, a person who so straightforwardly accepted you as your own playmate, ready to share your toys, allow you to express your desires fearlessly and cry in his consoling sympathetic lap. These are a few first recollections of my dear uncle.

As fortune would have it, my uncle lived in Dadar with us for several months giving us and me in particular, the benefit of his quality time every evening after he returned home from work in AEET that is now BARC. I would store all my questions of the day for him, which he would respond querying me in a manner which would naturally appeal and draw answers from me. Little did I know then that he was implanting into me the basic tenets of logic and rudiments of a scientific process. This was the innate guru in him who knew how to induce the process of sustainable learning in anyone who came in his close proximity.

As I grew with time and transited through various phases of my career in Institute of Science, Mumbai, IIT Kanpur, TIFR, as an Alexander von Humboldt Fellow in Germany, then returning to India as a Visiting Scientist in BARC in 1980, and then moving to industry in 1981 for the next two decades to function in diverse roles, my uncle played a major mentoring role, guiding me to sift the difficult choices before me, but leaving me to decide my life's trajectory, without denying myself of emerging opportunities. This quality of non-dominating path-exploring guidance was my uncle's remarkable hallmark that prepared us as apprentices for our parenthood and a life well lived.

In one of my conversations with him on research, he mentioned *"if non-availability of scientific instruments are the only constraints to research, then all scientific instrument manufacturing companies would have discovered and invented all that was to be done. Do not enslave your mind to these instruments. These instruments only facilitate you to achieve your thoughts. So, do not subjugate your mind!"*

The silent genius in my uncle found expression in all what he did, whether at his workplace, community service or home. The ease with which my uncle related to everyone, irrespective of age, culture and nationality is a tribute to his humaneness, a trait which we all aspire to imbibe and treasure. Over the span of years that we knew him, he instilled in us a sense of purpose, a feeling of confidence and self-awareness, elements of joyous working, establishing bonds within and beyond the family and an urge to freely communicate and share thereby motivating us to transform our immediate and extended neighbourhood to a blissful home.

My uncle departed for his heavenly abode several years ago, but has left behind his immortal soul in us to enrich our lives for ever.

Annexure 5

Collected Works of A K Ganguly

Titles taken from "Collected works of A K Ganguly, 1978"

Full version of the papers are available in 6 volumes.
Contents of the volumes are arranged topic-wise
Many of the publications formed part of the theses submitted by the students of Dr Ganguly for their M Sc and PhD degrees.

CONTENTS VOL.I (37 PAPERS)

Topics covered: Fission Physics, Neutron spectrometry, Temperature distribution in radioactive solids, Thermo luminescence, AAS, and Tritium

1. Systematics of Asymmetry in Fission Based on Order-Disorder Model
   P.P. Chakraborty, M.R. Iyer, D.N.Sharma and A.K. Ganguly
2. Charge Distribution, Neutron Evaporation, and Energy Distribution in Higher Energy Binary Fission
   D.N.Sharma, M.R. Iyer and A. K. Ganguly
3. Fission Product Nuclear Data (FPND) and Environmental Aspects of Nuclear Fuel Cycle
   M.R. Iyer, D.N.Sharma and A.K. Ganguly
4. Nuclear Data in Fissile Material Estimation by Activation Techniques
   M.R. Iyer, P. P. Chakraborty and A.K. Ganguly
5. Neutron Evaporation and Energy Distribution in Individual Fission Fragments
   M. R. Iyer and A.K. Ganguly
6. Rapid Estimation of U-235 by Fission Product Gamma Counting
   P.P. Chakraborty and A.K. Ganguly
7. Nuclear Charge Distribution in Fission Fragments
   M. R. Iyer and A.K. Ganguly
8. Beta Decay of Pu-239 Fission Products at Short Times after Fission
   M. R. Iyer and A.K. Ganguly
9. Gamma Energy Release Rates from Fission Products at Short Times after Fission
   M. Ramakrishna Iyer and A.K. Ganguly
10. Compilation and Computation of Data on the Nuclear Properties of U-235 Fission Products.
    M.Ramakrishna Iyer and A.K.Ganguly

11. Studies on Fission Neutron Spectrum
    M.R. Iyer and A.K.Ganguly
12. A proton Recoil Scintillation Technique for Estimating Neutron Energy Spectra
    P.K. Sarkar, K. N. Kirthi and A.K.Ganguly
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Topic Covered: Trace elements in environment, Organo metallic interactions, Radioactive discharges into marine environment. Radioecology, Oceanography

2. Organo metallic interactions of Manganese and other heavy metals in the Marine Environment
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3. Evidence of covalently bound Radio cobalt in the Marine environment
   M.V.M Desai and A.K. Ganguly
4. Interaction of Some metal ions with fulvic Acid Isolated from Marine Environment
   M.V.M Desai, Elizabeth Mathew and A.K. Ganguly
5. Organic materials in the Marine Environment and the associated metallic Elements.
   T.N.V. Pillai, M.V.M.Desai, Elizabeth Mathew, S. Ganapathy and A.K. Ganguly
6. Nucleic acid in the Dissolved Constituents of sea water
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7. Differential Interaction of Marine Humic and Fulvic Acids with Alkaline Earth and Rare Earth Elements
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8. Studies on Organo-Metallic Interactions in the Marine environment
   A.K.Ganguly, Elizabeth Koshy and M.V.M.Desai
12. Solubility of Barium in Sea-Water in Presence of Dissolved Organic Matter
    M.V.M.Desai, Elizabeth Koshy and A.K.Ganguly
13. Studies on Organo-Metallic Interactions in the Marine Environment – Part 2
    Elizabeth Koshy, M.V.M.Desai and A.K.Ganguly
14. Methodology for Assessment of Radioactive and Non-Radioactive Discharges into Aquatic Environment - Indian Experience
    K.C. Pillai and A.K. Ganguly
15. Disequilibrium Studies in U-234/U-238 Activity Ratios in Coastal Sediments along the West Coast of India
    L.U. Joshi and A.K.Ganguly
16. Occurrence of Se-75 and Sn-113 in Oysters
    B. Patel and A.K.Ganguly
17. Water Transport in the Bombay Harbour Bay through Thana Creek
    I.S. Bhat, P R Kamath, J R Naidu, K C Pillai and A K Ganguly
18. Transport and Diffusion of Radioactivity from Bombay Harbour Bay
    K C Pillai and A KGanguly

19. Feed Back from Environmental Monitoring to the Chemical Control in Nuclear Plants Operations
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20. Environmental Behaviour of Discharged Radioactive Effluents at Tarapur Atomic Power Station.
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21. Radioecology of Bombay Harbour - A Tidal Estuary
    B Patel, C D Mulay and A K Ganguly
22. New Fields in Chemical Oceanography
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23. Concept of Acute and Chronic Tissue Concentration of Elements in Radioecology
    B Patel and A K Ganguly
24. The Distribution of Phosphorus in Northern Indian Ocean 1962-63
    R Viswanathan and A K Ganguly
25. Current Measurements off Mormugoa
    K.V.K.Nair, V.P.Neralla and A.K.Ganguly

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Topics Covered: Environmental impact of radioactive releases, Risk and impact assessment, Regulatory aspects, NPP Site selection criterion, Safety standards

1. Application of ICRP Recommendations in Practice
   P. Abraham, V.K.Gupta and A.K.Ganguly
2. Environmental Impact of Nuclear Industry and Lessons Therefrom for Conventional Industry
   V.K.Gupta and A. K. Ganguly
3. Risks and Hazards from Conventional and Radiation Sources
   A K Ganguly
4. Basis for Protection against Radiation and Conventional Hazards
   A.K.Ganguly
5. S. Regulatory Requirements for Radioactivity Management in India
   V K Gupta, S D Soman and A K Ganguly
6. Environmental Quality Control in Industry - lessons from Nuclear Industry
   A K Ganguly
7. Site Selection end Optimisation of its Use in India

CONTENTS VOL.IV (5 PAPERS)

Topics covered: TL, trace radioactivity in Marine environment Fission Physics, Environmental radioactivity, Neutron spectrometry

CONTENTS VOL.V (5 BARC REPORTS)

Topics covered: Radioecology, Trace element interaction in marine environment

CONTENTS VOL. VI (14 PAPERS)

Topics covered: Radioecology, Pre operational base line radioactivity at NPP sites, Environmental radioactivity, Radioactivity build up, Safety standards, Fission Physics

6. Temperature Distribution in Radioactive Solids Part II Gamma-Active Spheres
   V. K. Sundaram, D.V.Gopinath and A.K. Ganguly
7. Build-up of Nuclides in Cyclic Nuclear Operations - Mathematical Formulation
   P.P.Damle, D.V.Gopinath and A.K.Ganguly
8. Gamma Energy Release Rates from Fission Products at Short Times after Fission
   M.Ramakrishna Iyer and A.K.Ganguly
9. Data on the Nuclear Properties of U-235 Fission Products
   Ramakrishna Iyer and A.K.Ganguly
10. Maximum Permissible Levels of Surface Contamination
    S. Somasundarem, P.V. Hariharan and A.K. Ganguly
11. Transport and Diffusion of Radioactivity from Bombay Harbour Bay
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12. Evaluation of Maximum Permissible Concentration of Radioisotopes in Sea Waters of Bombay
    K.C. Pillai and A.K.Ganguly
13. Temperature Distribution in Radioactive Solid Wastes - Part I - Beta-Active Solids
    D.A. Kotewale and A.K.Ganguly
14. Tidal Movement and Water Renewal Rate in the Bombay Harbour Bay
    K. C. Pillai, T. Subbaratnam and A.K. Ganguly