RSO Certification for Radiation Processing Facility (RSO-RPF)

Introduction:

In recent times ionizing radiations have found wider applications in various industrial processes. Its unique but remarkable effectiveness in food processing for food security and safety, sterilization of medical products, mutation breeding, cross-linking of wires, vulcanization of rubber, wood-polymer and other industrial processes have now been well established. Thus the utility of radiation and radioisotopes has helped immensely in streamlining protocol for many industrial processes.

Industrial radiation processing facilities commonly known as irradiators contains high intensity $\gamma$-radiation sources or machine sources (electrons and photon accelerators) along with source storage (DM plant), conveyer systems, ventilation system and other supportive electrical/mechanical/electronic devices, hydraulic/pneumatic systems connected to each other by interlock systems for enhanced radiation safety.

Radiation doses required to achieve desirable effect range from tens of Gy to several kGy. Since these radiation doses are detrimental to human health, utmost care needs to be taken during operation of these facilities. Even during the transportation of radiation sources ($\gamma$-sources) from the place of its supplier to radiation processing facility, radiation hazards could occur if proper care is not taken with respect to procedure for safe transport of radioactive material. In such irradiation facilities both personnel and product safety are therefore of paramount importance. Supervising and operating personnel in such facilities must therefore possess in-depth knowledge of radiation safety, including design and operational aspects of the equipment/facility. This necessitates the need of establishing effective training programme for the personnel involved in operation and safety of radiation processing facility.

Training course covering radiation safety aspects and operational features of industrial radiation processing facility caters to the need of imparting training to personnel to function as Radiological Safety Officer (RSO).

Eligibility Criteria:

I. A basic degree in Science from a recognized university with physics as one of the subjects; or

II. Diploma in Engineering from a recognized University/Institution with minimum of five years experience in radiation surveillance supported by personnel monitoring badge (TLD) service in a radiation processing facility.

Duration: 12 weeks (300 h)
{6 weeks (150 h) Theory and Practical + 6 weeks (150 h) Field Training}

Examination: The examination shall consist of

I. Three written paper of 100 marks each (Three papers of total 300 marks), (80 marks descriptive including short answers + 20 marks objective)

II. Practical of 50 marks

III. Viva-voce of 50 marks
Criteria for qualifying the examination:

One must score minimum 50% of marks in each written, practical and viva-voce examinations. But total aggregate marks secured must be 60%. In case a candidate could not succeed in first attempt, he/she shall be given two more attempts for reappearance in the examination. But there must be a gap of minimum three months between the examinations.

Course Content:

Paper 1: Radiation Physics, Radiobiology and Radiation Measurement (38h)

A.1 Lectures

1.1 Basic Radiation Physics 4 h
1.2 Interaction of Radiation with Matter 4 h
1.3 Radiation Quantities and Units 2 h
1.4 Radiation Biology & Biological Effects 8 h
1.5 Operational Limits 2 h
1.6 Radiation Detection & Measurement 6 h
1.7 Radiation Hazard Evaluation & Control 6 h
1.8 Radiation Protection Standards 2 h
1.9 Radiation Sources/Generators and their Properties 4 h

Paper 2: Design Features, Radiation Safety and Regulatory Aspects of Radiation Processing Facility (32 h)

A.2 Lectures

2.1 Overview of Industrial Applications of Radiation 3 h
2.2 Design Details of Irradiator Sources 1 h
2.3 Overview of Radiation Processing Facilities 1 h
2.4 Design Safety Features of Gamma Irradiators 5 h
2.5 Design Safety Features of Electron Beam Facilities 3 h
2.6 Planning of Radiation Processing Facilities 3 h
2.7 Regulatory Aspects of Radiation Processing Facilities 3 h
2.8 Transport of Radioactive Material 2 h
2.9 Disposal of Radioactive Waste 2 h
2.10 Quality, Health, Safety and Environment (QHSE) 1 h
2.11 Management of Radiation Processing Facility 2 h
2.12 Radiation Accidents, Case Studies and Lessons Learned 3 h
2.13 Emergency Response Plans and Preparedness 2 h
2.14 Medical Management of Radiation Accidents 1 h
Paper 3: Radiation Dosimetry, Process Control and Radiation Processing (24h) Technology

A.3 Lectures

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B. Discussions: 10 h

C. Practicals: 36 h (3h each)

1. Introduction to Radiation Monitoring instruments– Area & Personnel
2. Characteristics of GM counter
3. Inverse square law & attenuation of gamma rays
4. Absorption and back scattering of gamma rays-Determination of HVT & TVT
5. Statistics of counting and activity measurement
6. Gamma ray spectrometry with germanium detector using multi-channel analyzer
7. Output measurement in a gamma irradiation chamber using Fricke dosimeter
8. Calibration of survey instruments and pocket dosimeter
9. Calibration of gamma ray spectrometer and identification of unknown sources
10. Survey and evaluation of a radiation processing facility
11. Dose distribution measurement in the product box of a radiation processing facility
12. Biological dosimetry

D. Technical visit to associated facilities: 10 h

Technical visits to Gamma and Electron beam radiation processing facilities.
E. FIELD TRAINING: 6 weeks (150h)

Familiarization with radiation processing facility, design and operational aspects, control consol, source hoist mechanism, types of conveyor system and its design principle, familiarization of safety components and interlock systems, loading/unloading procedures of radiation sources, familiarization with handling tools for source transfer, radiation protection survey and evaluation of irradiator facility, DM Plant, contamination checking of water pool type and dry storage irradiators; pH, conductivity and temperature measurements, requirement of ventilation systems and ozone measurement, dosimetry of irradiated products, process control, understanding the emergency situation and its handling, Good Manufacturing Practices (GMP) and Good Irradiation Practices (GIP), Operation & Maintenance of radiation processing facility.
Syllabus

Paper 1: Radiation Physics, Radiobiology and Radiation Measurement

1.1 Basic Radiation Physics

Atomic Structure, atomic number, mass number, isotopes, radioisotopes, radioactivity, specific activity, electron capture, characteristics and properties of alpha, beta and gamma radiations, neutron sources, laws of radioactivity & successive transformations, natural and artificial radioactivity, radioactive equilibrium, radioactive decay, decay constant, decay chain of radioisotopes, half-life, mean life, nuclear cross section, X-rays (Characteristic and bremsstrahlung).

1.2 Interaction of Radiation with Matter


1.3 Radiation Quantities and Units

Particle flux and fluence, energy flux and fluence, cross section, linear and mass absorption coefficient, stopping power and LET, w-value, charge particle equilibrium, (CPE), electronic equilibrium, activity, energy, exposure, rate constant, air kerma, absorbed dose, relative biological effectiveness (RBE), radiation weighting factors \( (W_R) \), tissue weighting factors \( (W_T) \), equivalent dose, effective dose, ambient and directional dose equivalent and their relevance to dosimetry, personnel dose equivalent, tissue equivalence, commitment and collective dose.

1.4 Radiation Biology and Biological Effects

Organization of cell structure and functions, indirect interactions, tissues, organs, systems and organization of human body, hematopoietic, digestive, respiratory, skeletal, nervous, endocrine and urinary systems; sensory perception.

Mechanism of cellular level damages by radiation, cell killing and mutation induction, target theory and linear quadratic models of cell survival, modifying factors of radiation damage, classification of radiation damage, radiation carcinogenesis, genetic effects, dose and dose rate effect (DDREF), radiation damage and classification, cell division, basic genetics, direct and indirect interactions. Stochastic effects: radiation carcinogenesis- latent period, sensitivity variation among different organs and tissues, age and sex, genetic effects of radiation, doubling dose, risk factor. Deterministic effects, tissue reaction, acute radiation syndrome, damage to individual organs, LD 50/60, prenatal effects, management of tissue reaction, management of acute radiation injury, biological dosimetry.
1.5 **Operational Limits**

Introduction to natural background radiation, concept of occupational risk, philosophy of radiation protection, system of dose limitation, ALARA, dose limits to radiation workers and general public, AERB/ICRP recommendations.

1.6 **Radiation Detection and Measurement**

Principles of measurement of radiation and radioactivity, Gas filled detectors (ionization chambers, proportional counters, GM counters), solid state detector (scintillation detectors, TLD), chemical detectors, photochromic emulsion (films), characteristics of organic and inorganic gas counters, dead time, resolving time, semiconductor devices and BF$_3$ counters for neutron detection, spectrometers, pulse height analysis of spectra.

Radiation monitoring instruments, personnel monitoring, digital pocket dosimeters using solid state devices, teletector, portable survey meter, gamma area zone monitors, contamination monitors for alpha-beta and gamma radiation, scintillation monitors for X-and gamma radiation, neutron monitors, tissue equivalent survey meters-flux meters and dose equivalent monitors, calibration and maintenance of radiation monitors.

Thermoluminescent dosimetry (TLD): Process and properties, glow curves and dose response, photon energy dependence, fading, material form, Residual-TL and annealing procedure for reuse, repeated readouts of TLDs, TL instrumentation, personnel monitoring.

1.7 **Radiation Hazard Evaluation & Control**

Radiation hazard perception, internal and external hazard and their perspective, evaluation and control of hazard due to external radiation-Individual and workplace monitoring; application of time, distance and shielding, specific gamma ray constant, shielding calculations for beta, gamma and neutron radiation, choice of materials, primary and secondary radiations, source geometry and shielding requirements for industrial and research installations including accelerator installations, operational safety and radiation protection survey.

1.8 **Radiation Protection Standards**


1.9 **Radiation Sources/Generators and their Properties**

Production of beta and gamma sources by neutron and charge particle bombardment, nuclear cross section, growth of activity, specific activity, neutron sources, fission products, basic features of nuclear reactors used in isotope production, X-ray machines and electron linear accelerators.
Paper 2: Design Features, Radiation Safety and Regulatory Aspects of Radiation Processing Facility

2.1 Overview of Industrial Applications of Radiation
Application of ionizing radiations in industry, principles of industrial radiography with X-and Gamma ray, radiography exposure devices, radiation hazard potential in industrial radiography, principles of nucleonic gauges, application of nucleonic gauges: level, density, thickness, composition gauges, well logging, XRF gauges; radiation hazard potential in nucleonic gauge applications, principles of operation of consumer products using radiation sources: smoke detectors, baggage inspection systems, static charge eliminators, luminous dial paints and gas mantles.

2.2 Design Details of Irradiator Sources
Details of source assembly, national/international sealed source design standards, types of encapsulation, method of preparation of sources, prototype type tests, acceptance criteria, leak test methods, sealed source classification.

2.3 Overview of Radiation Processing Facilities
Radionuclide sources and machine sources, applications of irradiation, gamma irradiators: Self –contained and panoramic irradiator; throughput, dose uniformity ratio (DUR), dose control parameters, mode of operation of irradiator: batch mode, continuous mode, pallet irradiator; optimization of throughput and DUR, source overlap and product overlap geometry, split source and mobile shield design, electron beam accelerators, types of accelerators: low, medium and high energy.

2.4 Design Safety Features of Gamma Irradiators
Type of irradiation facilities, Category of irradiators (Dry and wet storage irradiators), radiological safety objectives and safety philosophy in design i.e. concept of defence-in-depth applied to the design process; national/international design standards, design features and requirements; source storage (dry/wet) and source frame, radiation cell shielding, integrity of dry shielding, designing of water pool, access to radiation source and interlock, personnel access door, integrity test, source hoist mechanism, product handling system, transport, loading and unloading of sources; source guard, removable shielding plugs, individual and work place monitoring, DM plant, water level and contamination monitoring; pH and conductivity and temperature monitoring, ventilation system, noxious gas production, periodic servicing and maintenance of safety systems/components; maintenance of safety records.

2.5 Design Safety Features of Electron Beam Facilities
Classification of EB accelerators, categories of EB accelerators, depth dose, principle of electron beam and photon accelerator and types of accelerators, philosophy of radiation protection and safety, safety interlocks, operational procedures, safety consideration in the design of electron beam accelerators: national/international design standards, shielding, operating parameters,
accelerator hazards: electrical safety, magnetic safety, RF and microwave safety, SF6 gas safety: ventilation requirement, preventive maintenance, product conveyor system for EB accelerator, accelerators for application in industrial processing, merits and demerits of machine source applications.

2.6 Planning of Radiation Processing Facilities

Planning of gamma irradiator and electron beam irradiation facilities, site selection, area requirement, shielding calculation parameters- workload (W), primary and secondary protective barriers, use factor (U), occupancy factor (T); effects of scattering, albedo, skyshine, noxious gas production, ventilation requirements, shielding requirements for transport and storage containers for high activity sources, Safety consideration in the planning of electron/X-ray accelerator facilities, shielding, production of bremsstrahlung radiation and neutron production, non radiation hazards and control, safety and security measures.

2.7 Regulatory Aspects of Radiation Processing Facilities

National regulations, regulatory framework, regulatory aspects of new and operating irradiation processing plants: Atomic Energy Act, Rules, Codes, standards, Guides, Food Irradiation Rules, licensing requirements, approval of Radiation Generating devices, consenting process: siting, design, construction, commissioning and operation, decommissioning of radiation processing facilities and disposal of radiation sources, responsibilities of operating organization and certified personnel, transport regulations, waste disposal rules.

2.8 Transport of Radioactive Material

Regulatory aspects of transport radioactive material, introduction, terms used (e.g. Competent Authority, A1&A2 values, unilateral & multilateral approval, special form radioactive material, special arrangement, transport index etc.), transport scenarios (routine, normal & accident), variety of packages covered under the transport regulations, general requirement of all packaging, requirements for transport by air mode, test requirements, preparation, marking, labelling of packages, preparation of transport documents (Consignors Declaration, TREM Card, Instructions to the Carrier & Emergency in Writing), general instructions and response to off-normal situations during transport.

2.9 Disposal of Radioactive Waste

Regulatory aspects of Radioactive waste disposal, sources of radioactive waste, classification of waste, treatment techniques for solid, liquid and gaseous effluents, permissible limits for disposal of waste, sampling techniques for air, water and solid media, geological, hydrological, meteorological and ecological considerations for waste disposal. Disposal of radioactive wastes, general methods of disposal, management of radioactive waste in medical, industrial, agricultural and research establishments.
2.10 **Quality, Health, Safety and Environment (QHSE)**

Familiarization with Quality, Health, Safety and Environment (QHSE) policies including organizational responsibility, safety culture, setting safe working environment, quality management system (QMS), awareness, training, implementation, compliance, inspections & audits, corrective actions.

2.11 **Management of Radiation Processing Facility**

Introduction, good manufacturing practices (GMP), {Primary production and/or harvesting}, good irradiation practices (GIP) packaging, handling, storage and transport, operational management (Manpower management and training, standard operating procedures, preventive maintenance and scheduling, plant and personnel safety, liaison with licensing authorities, customer relation and feedback, health of workers, recordkeeping and emergency preparedness.

2.12 **Radiation Accidents, Case Studies and Lessons Learned**

Accidents with fatal consequences and severe radiation injuries, major causes of accidents, fire, explosion, prevention and remedial measures, abnormal events, overexposure cases, case studies and lessons learned from abnormal events & accidents in industrial irradiators.

1.13 **Emergency Response Plans and Preparedness**

Basis for emergency response planning, normal and potential exposure, orphan and vulnerable sources, emergency handling, graded approach, radiation hazard assessment due to different emergencies, written emergency procedures, responsibility of operating organization and certified personnel, identification and list of emergency authorities to be contacted, emergency scenarios and potential exposures, remedial actions, communication links and incident reporting system, responsibilities of employer, licensee, RSO, operators and manufacturer and designer of facility, source supplier in case of emergency.

2.14 **Medical Management of Radiation Accidents**

Radiation injuries in high intensity irradiators (Dose vs. Symptoms), healing of wounds and post care of radiation injuries, grafting etc., case studies and lessons learned. Radiation injuries and their medical management.

**Paper 3: Radiation Dosimetry, Process Control and Radiation Processing Technology**

3.1 **Radiation Dosimetry**

3.1.1 **Radiation Dosimetry - An overview**

Importance of dosimetry in radiation processing, types of dosimeters: physical and chemical dosimeters, measurement of exposure and absorbed dose, Bragg-Gray principle and ionization, X- and gamma ray dosimetry, electron beam dosimetry, dose distribution in process load- its measurement and significance.

3.1.2 **Film Dosimeters**

Types of film dosimeters, principles, dose range, readout systems, mechanism,
3.1.3 **Chemical Dosimeters**

Types of chemical dosimeters, principles, dose range, readout systems, mechanism, ASTM practice number (if any)

3.1.4 **Dose Inter-comparison and Validation**

Intercomparison procedures with standards laboratory with respect to irradiation conditions, process geometry, number of passes to achieve desirable absorbed dose, \( D_{\text{max}} \), \( D_{\text{min}} \) and DUR.

For electron beam irradiation- verification of operating parameters e.g. electron energy, beam current, conveyor speed, scan width, etc.

3.2 **Radiation Processing Technology**

3.2.1 **Radiation Processing of Food – An Overview**

Current status, marketing, economics, regulations and consumer issues

3.2.2 **QA in Food Processing for Extension of Shelf-Life: Food Quality Parameters**

(i) **Microbiological Quality**

Source of contamination, factors affecting quality of food, effect of ionizing radiation on microorganism, radiation sensitivity of microorganisms (intrinsic and extrinsic factor), radurization, radicidation, radappertization (sterilization by radiation), good manufacturing practice (GMP), good irradiation practice (GIP).

(ii) **Nutritional Aspects of Radiation Processed Food**

Effect on macronutrients like carbohydrates, proteins and lipids, effects on micronutrients like vitamins.

(iii) **Safety, Security and Wholesomeness of Radiation Processed Food**

Microbiological safety, safety of chemical changes, nutritional adequacy, animal feeding studies, human trials, technological benefits and advantages of radiation processing, absence of residual activity.

(iv) **Labelling, Packaging and Transport of Irradiated Food**

Types of packages, labelling of radiation processed products (radura), environmental conditions of transport and storage

3.3 **Radiation Processing of Food Products**

3.3.1 **Bulbs & tubers, Fruits and Vegetables**
Purpose of irradiation, general properties of fruits and vegetables, chemical composition, shelf-life parameters and deterioration, ripening of climacteric and non-climacteric fruits, delayed ripening, sprout inhibition, disinfestations for quarantine purpose, radiation processing of minimally processed fruits and vegetables, effect of radiation on sensory and nutritional quality of fruits.

3.3.2 Cereals and Legumes
Factors affecting quality of cereals and legumes, different methods of control of insects, effect of radiation on insect, extension of shelf life of cereals and legumes.

3.3.3 Radiation Processing of Fleshy Foods (Fish, Meat and Chicken)
Factors affecting the quality of fleshy food (fish, meat and chicken), current conventional practices for processing and preservation of fleshy food (e.g. low temperature, drying), purpose of radiation processing of fleshy food for preservation, extension of shelf life, elimination of pathogens and parasites, radiation processing methods for extension of shelf life/preservation of fish and fishery products like radurization, radicidation, radiation disinfestations, radiation processing of meat for preparation of shelf stable products, hygienisation of fresh meat and meat products and intermediate moisture meat products.

3.4 Detection of Radiation Processed Food
Requirement of the method for the detection of irradiated and processed food, criteria to evolve a standard technique, present status, physical methods (ESR, Luminescence (TL/OSL/PSL), chemical methods (induced hydrocarbons, detection of 2-Alkyl cyclobutanones), biological method based on microbial load, mechanism of detection methods, applicability of detection methods to different food products.

3.5 QA Programme in Commercial Irradiation Facility (Personnel and Product safety)
Assessment of the probabilistic hazards in the normal operation of irradiation facility, Quality assurance (QA) programme, personnel safety, parameters under consideration, codes and protocols on: irradiation cell integrity, QA programme for safety interlocks, storage of pool water, radiation monitoring instruments and mechanical, electrical, pneumatic and hydraulic system.
QA programme for product safety: Plant commissioning dosimetry, calibration and traceability studies, dose mapping and absorbed dose in the product.

3.6 Other Applications of Radiation Processing Technology
Principle and applications of radiation processing, radiation processing for sterilization of medical products, non-food items (herbal and other medicinal products), rubber vulcanization, wood polymerization, cross linking, treatment of sewage sludge (waste water), dose limits for these applications, dosimeters used and quality assurance of end products.

3.7 Food Irradiation Regulations (Codes, Standards, Guides)
Current regulatory practices in food irradiators, food irradiation rules, licensing and national/ international food irradiation standards, codex standard, dosimetry studies, acceptance criteria, competent authority for food irradiation, certificate of approval, licence for radiation processing of food.