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REVIEW ARTICLE

Radioactive Waste Management in a Medical Cyclotron Facility - A Review

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ABSTRACT

The cyclotron is a device used to create radioactive atoms with a short half-life (radioactive isotopes) that can be utilised for research and medical imaging. When nuclear and radiation facilities are utilized, serviced, or decommissioned, radioactive waste is produced. The amount of radioactive waste produced is greatly decreased by good operating procedures. Iodine-123, Technetium-99m, Iodine-131, Gallium-67 Thallium-201 and fluorine-18 fluorodeoxyglucose are among the radionuclides utilised in medicine. The most widely used gaseous/aerosol radionuclides are (aerosolized) technetium-99m, xenon-133, and krypton-81m. The use of radionuclides (radioactive element) for industrial process control and instrumentation, medical diagnostic and therapeutic purposes, as well as numerous uses in research, education, agriculture, geological exploration, construction, and other human endeavors, results in radioactive waste. These applications generate a variety of radioactive waste, which can come from sealed sources and be in solid, liquid, or gaseous form. If the trash containing considerable amounts of radionuclides is not handled properly, there may be serious concerns to both the environment and human health. Due to the wide variety of waste kinds addressed, special consideration must be paid to safety concerns and regulatory management. This article will examine the fundamental procedures for managing radioactive waste in compliance with the regulatory agencies like AERB (Atomic Energy Regulatory Board) and IAEA (International Atomic Energy Agency).

Keywords: Radioactive waste, Cyclotron facility, Radioisotopes, PET tracer, Waste management

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INTRODUCTION

Nuclear medicine is a branch of medicine that employs radioactive atoms for treatment or diagnosis.[1] Positron emitters, which can be utilised for molecular imaging of the organs, are the major product of medical cyclotrons.[2] To create radioisotopes that emit positrons, the medical cyclotron accelerates particles like protons and deuterons and bombards them with a suitable target material.[3] To create radio pharmaceuticals from the positron emitting radioisotopes created in medical cyclotrons, a chemical synthesis module is required. The accelerated particles might activate any nearby materials that are present in the cyclotron room and leave behind radioactive residue.

When protons/Alpha particles are made to collide with high atomic number atoms in a cyclotron, radioisotopes are produced.[4] Radioisotopes attached to biological molecules to target particular organs, tissues, or cells in the human body are known as radio pharmaceuticals.[5] These radiopharmaceuticals can be used to diagnose ailments and, in a growing number of cases, to treat them. In both diagnostic and therapeutic radiopharmaceuticals, radionuclides are utilised. They can frequently be visualised using SPECT (single photon emission computed tomography) or PET (positron emission tomography) (PET).[6]

Gases, liquids, and solid materials can all be used as the targets for the synthesis of radiopharmaceuticals. The radiopharmaceuticals synthesis is preceded by the manufacture of the required radionuclides. A high intensity of the bombardment particle flow with sufficient energy is required for the production of the artificial radionuclides in the requisite quantity for the investigation of chemical and biological processes.[7] The majority of radioisotopes created by cyclotrons have short half-lives, which means they lose most of their radioactivity in a matter of hours. These comprise fluorine-18, carbon-11, oxygen-15, and nitrogen-13 for PET, a type of imaging. Around the world, cyclotrons produce 95% of the radiopharmaceuticals utilized in PET to display both regular and aberrant metabolic activity.[8] The production of radioactive by-products having significant levels of activity with in target components during proton irradiation in

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Figure 1: An image of Cyclotron for generating radioisotope[10]

medical cyclotron is highly reliant on the particular operating parameters of the cyclotron facility.[9]

Radioactive waste generation in Medical cyclotron:

Solid Waste

During cyclotron maintenance and after the creation of radiopharmaceuticals, solid radioactive waste is produced. During cyclotron maintenance, notable solid wastes with induced radioactivity include cyclotron targets, foils, components, etc. Elements in the cyclotron tank that shatter due to normal use-related wear and tear are another source of solid radioactive waste. Additionally, solid radioactive waste is produced while cleansing targets. Radiopharmaceutical synthesis and dispensing activities generate solid wastes such as reagent vials, syringes, cassettes, tubings, separation and purification cartridges, membrane filters, etc. in regular radiochemistry operations. Paper chromatography strips, syringes, rubber bungs, pipette tips, needles, tissue papers, aluminium caps, etc. are among the radioactive waste products produced during Quality Control operations.[11]

Liquid waste

The manufacturing of radiopharmaceuticals and target maintenance both produce liquid radioactive wastes. Radioactive organic liquid wastes include liquid scintillation, solvents, oils, and a variety of biological fluids produced by nuclear research facilities and hospitals.[12]

Gaseous waste

By activating the air in the cyclotron vault and chronically releasing radioactivity, particularly F-18, during synthesis processes in the radiochemistry hot-cell, gaseous radioactivity can be produced while the cyclotron is operating.[13]

Regulations:

The AERB has set safety standards for radioactive waste produced in medical facilities that use radioactive sources for diagnostic and/or therapeutic purposes. The amount of radioactive waste produced is greatly decreased by good operating procedures. If the trash containing considerable amounts of radionuclides is not handled properly, there may be serious concerns to both the environment and human health. The handling of radioactive waste section of the Atomic Energy Regulatory Board's (AERB) safety code (AERB/NRF/SC/RW, 2007) offers instructions on how to safely dispose of radioactive waste that results from the use of radionuclides in industry, agriculture, research, and medicine.[14] The advice is meant for businesses, individuals who use radioisotopes and produce radioactive waste, as well as those who handle that trash. The AERB safety guide titled "Classification of Radioactive Waste," AERB/NRF/SG/RW-1, should be followed while classifying waste.[15] The Safety Code for the Transit of Radioactive Materials, AERB/SC/TR-1, 1986, should be followed for correctly packing the radioactive waste to be transported in order to assure safe transport.

Management and Safe Disposal:

Basic Steps in Radioactive Waste Management

The waste must be characterized to ascertain its physical, chemical, and radiological characteristics as well as to make keeping records and accepting radioactive waste through one step to the next easier. Characterization can be used to separate radioactive waste for avoidance, recycling, or disposal techniques, as well as to ensure that waste packages comply with the rules for safe preservation and disposal. Transport may be required between the radioactive waste handling procedures, it should be highlighted. The needs of secure transportation should be taken into account in proper management of radioactive waste. Storage of radioactive waste entails keeping the waste in a condition that: (i) provides isolation, environmental protection, and monitoring; and (ii) facilitates procedures such as treatment, conditioning, and disposal. Storage may occasionally be used for purely technical reasons, such as the decay and eventual release of radioactive waste that largely contains short-lived radionuclides or the storage of high-level radioactive waste due to thermal issues before geological burial. Other times, storage may be used for economic or political reasons.

After garbage generation, the first step in waste management is pre-treatment of the waste. It includes things like collection, segregation, chemical adjusting, and decontamination, and it might also involve a temporary storage phase.[14] This first phase is crucial because it frequently provides the finest opportunity to separate waste streams for purposes like recycling throughout the process or disposal as regular non-radioactive trash when the amounts of radioactive substances they contain are exempt from regulatory constraints. Additionally, it gives the chance to separate radioactive waste for near-surface or geological burial.

Sinks for specialised waste disposal are normally not needed in FDG production facilities.[16] Sinks and pipes should be made of a suitable material if necessary; for the majority of uses, stainless steel is chosen. The ionising radiation symbol should be used to identify drainage pipelines for radioactive effluents.

Solid-waste Management

When handling, removing, collecting, transferring, and storing created radioactive waste, necessary radiation safety protocols must be implemented. The facility's radiation safety officer

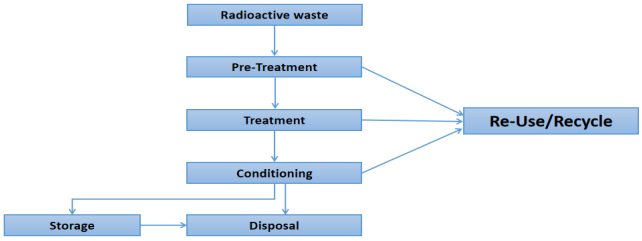

Figure 2: Basic steps in Radioactive Waste Management[14]

(RSO) should provide direction and oversight for all aspects of handling, storing, removing, and disposing of radioactive waste. Solid waste produced during preventative maintenance should be collected and transported in an impermeable polythene bag to the designated lead lined storing pit inside the cyclotron vault. In the lead-lined pit, solid radioactive waste produced during routine use as well as radioactive Havar Foils should be kept for prolonged storage in a specially made lead pot. The lead pit should be used to contain and oversee the solid waste produced by the target cleaning procedure. To avoid accidental mishandling by other staff members, the contents of the lead pit should be securely stored and appropriately labelled as "Access Restricted". A Multi-Channel Analyzer Gamma Ray Spectrometry System may be used to analyse waste associated with cyclotron components that have produced radioactivity in order to recognize and comprehend the typical profile of the induced radionuclides per Ah operating of the Medical Cyclotron. This will help with the management of waste produced by later activities. The waste produced during the synthesis and dispensing of radiopharmaceuticals should be dealt with the following day, collected, and kept inside the radiochemistry lab in a lead-lined storage bin until decay. Within the QC laboratory, waste produced by quality control procedures should be kept in a foot-operated garbage container lined with lead.

Liquid-waste Management

When maintaining a target, liquid waste should be trapped in leak-proof containers and kept in a lead storage pit until the decay rate reaches acceptable levels. Liquid waste that is gathered during synthesis should be monitored, kept for a temporary decay period, then disposed of in lab sinks. Liquid waste should be disposed of in a way that keeps activity and concentration firmly within the regulatory body's set limits for disposal through sanitary sewage. Ion exchange/sorption, chemical precipitation, evaporation, or ultrafiltration/reverse osmosis are the principal treatment options for aqueous radioactive waste. However, before or after primary treatment, a liquid that contains suspended debris must be treated to eliminate the particles. To remove random debris or insoluble particles from the effluent wastes or to clarify the effluent wastes, sedimentation, decantation, filtration, or centrifugation are popular procedures. Radioactive organic liquid can be treated using procedures like distillation, wet oxidation, acid digestion, and electrochemical oxidation.

Gaseous-waste Management

During radiochemistry synthesis, radioactive gases are produced. The radioactive waste air should be compressed and stored in leak-proof cylinders for an adequate amount of time to allow for radioactive decay using a waste gas compressor system. The waste gas compressor unit should have a mechanism that only allows contents to be released through the stack when radioactivity levels are below the established threshold values. The cyclotron vault's air-changes are intended to be such that gaseous radioactive waste can be properly vented through a stack. To measure the activity generated through the stack, a calibrated stack monitor should be installed, and a record of such releases should be kept and reported. During radiopharmaceutical synthesis and radioisotope production processes, the facility should have safeguards in place to identify any emissions of airborne radioactive contamination as soon as possible. Systems for continuous online monitoring should be installed for this in the stacks and chimneys at the vault outflow. Radioactive compounds that could contaminate the air should only be prepared or dispensed in settings that prevent the substances from dispersing. Particularly, volatile radioactive substances must always be handled in suitable containment, like a fume cupboard, hot cell, or isolator; they should never be utilised in an open laboratory. Filters made of shielded activated charcoal can be used as radioactive gas traps on the gas outlet of hot cells. The exhaust stack should be 1.5m high from the nearest tallest building.

Disused, Spent Sources and long-lived radioactive waste

If available, sealed spent or unused calibration sources should be collected, kept, and then disposed of after obtaining the relevant regulatory body authorization.

CONCLUSION

Regardless of the facility's scope and size, establishing medical cyclotron facility is a significant task. The necessity for rigorous attention to the effective management of various categories of radioactive waste is of superior importance in the overall planning and successful implementation of the facility. The planning has to incorporate radiation safety from the radioactive waste not only throughout the life of the facility but also for the estimated time frame after decommissioning. Decontamination and disassembly, following waste management, a final radiation study, removal of radioactive materials and sources, and release of the facility for unrestricted usage and documentation are all steps in the decommissioning process. For the benefit of the planners and other stakeholders of a new facility, all of these challenges have been addressed and conceptually discussed in this article.

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