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भारत की पहली खाद्य किरणन अनुसंधान एवं विकास सुविधा का प्रौद्योगिकीय-आधुनिकीकरण – भा.प.अ. केंद्र में खाद्य पैकेज किरणक

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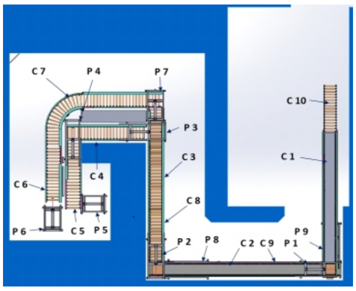

आधुनिक खाद्य पैकेज किरणक की उत्पाद प्रहस्तन प्रणाली में संवाहक और कर्षक का लेआउट।

सारांश

खाद्य पैकेज किरणक (एफपीई) भारत की पहली प्रायोगिक कोबाल्ट 60 आधारित गामा विकिरण प्रसंस्करण सुविधा है। इसे एटॉमिक एनर्जी ऑफ कनाडा लिमिटेड द्वारा अभिकल्पित किया गया और वर्ष 1967 में परमाणु ऊर्जा प्रतिष्ठान, ट्रॉम्बे द्वारा कमीशनन किया गया। इसकी स्थापना के बाद से ही इस बहुउद्देशीय सुविधा का उपयोग खाद्य उत्पादों की एक विस्तृत श्रृंखला के लिए गामा विकिरण का उपयोग करते हुए अनुसंधान एवं विकास गतिविधियों हेतु लगातार किया जा रहा है, ताकि अंकुरित मूलों (जैसे प्याज़) एवं कंदों (जैसे आलू), अनाज तथा दालों में कीटाणुशोधन, मछली तथा मांस से व्याधिजनक रोगाणुओं के उन्मूलन के साथ-साथ मसालों में सूक्ष्मजीव निर्जमीकरण सहित वांछित उद्देश्यों को प्राप्त किया जा सके। इसके अतिरिक्त, इस सुविधा का उपयोग विभागीय हित के विभिन्न पदार्थों एवं घटकों के विकिरण अनुक्रिया अध्ययन के लिए भी किया गया। इसके कमीशनन और कालप्रभावन के बाद से पांच दशकों से अधिक समय तक निरंतर उपयोग के कारण, उत्पाद/स्रोत प्रहस्तन प्रणाली में बार-बार गड़बड़ी/टूट-फूट होना चिंता का विषय बन गया है। कल-पुर्जों की उपलब्धता विशेषकर नियंत्रण प्रणाली हेतु एक अन्य चुनौती रही है जो रिले लॉजिक पर आधारित है। इन समस्याओं को दूर करने के लिए वर्ष 2020 में संयंत्र का पूर्ण उन्नयन किया गया । सिविल संरचना को छोड़कर, सभी उप-प्रणालियों, जैसे उत्पाद प्रहस्तन, स्रोत की आवाजाही और नियंत्रण को बदल दिया गया है, परिणामस्वरूप, खाद्य पैकेज किरणक का प्रौद्योगिकीय-आधुनिकीकरण हुआ है। उन्नत सुविधा ने वर्ष 2022 में पुनः प्रचालन आरंभ किया। इस लेख में, इस कार्य का संक्षिप्त विवरण एवं महत्वपूर्ण विशेषताओं को प्रस्तुत किया गया है।

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Techno-modernization of India's First Food Irradiation R&D Facility - Food Package Irradiator (FPI) at BARC

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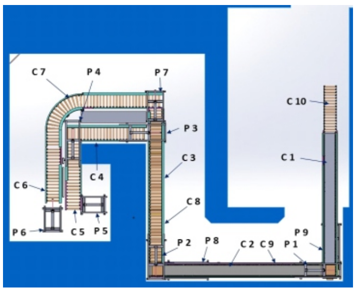

The layout of the conveyors and pushers in the product handling system of the modernized FPI.

ABSTRACT

The Food Package Irradiator (FPI) is India's first pilot Cobalt 60 based gamma radiation processing facility. It was designed by Atomic Energy of Canada Limited and commissioned in the year 1967 by Atomic Energy Establishment, Trombay. This multipurpose facility has been continuously utilized since its inception for R&D activities using gamma radiation for a wide range of food products to achieve the desired objectives ranging from sprout inhibition of bulbs (e.g. onion) and tubers (e.g. potato), insect disinfestation in cereals and pulses, elimination of pathogenic microbes from fish and meat as well as microbial decontamination in spices. In addition, this facility has also been used for radiation response studies of various materials and components of the departmental interest. Due to continuous usage for over five decades since its commissioning and ageing, frequent disruptions/breakdowns in the product/source handling system became matter of concern. Availability of spares, particularly for the control system which was based on relay logic, was another challenge. Complete upgradation of the plant was taken up in 2020 to overcome these issues. Except the civil structure, all the subsystems, viz. product handling, source movement and controls have been replaced, resulting in the techno-modernization of Food Package Irradiator. The upgraded facility resumed the operation in 2022. This article presents an overview of this work and important features in brief.

KEYWORDS: *Food Package Irradiator (FPI) , Bulbs, Tubers*

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Introduction

Food irradiation in India has been undertaken for preservation of food for safety, security and international trade. Based on the product profile and suitability there are different types of irradiators, such as gamma, electron beam, and X-ray systems. Gamma irradiator provides deep penetration and uniform dose distribution but involves handling radioactive materials with stringent safety requirements. In contrast, electron beam irradiator offers high process rate and lower regulatory hurdles but may struggle with thicker products, whereas X-ray irradiator has issue of conversion efficiency.

Food Package Irradiator (FPI), a Co-60 based gamma irradiator, was setup in the year 1967 at Food Irradiation Project Laboratory (FIPLy), current Food Technology Division in Bhabha Atomic Research Centre, Trombay, Mumbai. The original plant was a gift from Atomic Energy of Canada Ltd., a token of friendship to Dr. Homi Jehangir Bhabha, the founder of India's atomic energy program, from his rowing teammate at Cambridge, Dr. W.B. Lewis, later the chairman of the Canadian Atomic Energy Program. The plant utilizes gamma radiation from Co-60 source with a maximum allowable activity of 100 kCi. It is a multipurpose facility where a wide range of food commodities can be processed for R&D purpose in the dose range of 30 Gy to 25 kGy. This facility houses split source frame for variable dose rates and therefore suitable to deliver desired dose in wider spectrum. FPI, BARC has been remained the work horse since its commissioning for food irradiation research, allied R&D activities and services in India. The facility is the first Category IV food irradiation plant in India. Category IV irradiator has wet storage system for the radiation source which is made movable for radiation processing. At present (till February 2026) there are 32 commercial food irradiation facilities are operational across the country. Success in R&D at FPI, BARC has resulted in development of the scaled-up version of these gamma irradiators for food processing.

Scope of Techno-modernization

Because of more than five decades of utilization, various components of the facility have been deteriorated leading to difficulties in smooth plant operation. Unavailability of spare parts was another problem in plant operation and maintenance. Additionally, limited technical details were available without much elaboration. Efforts were made to reconstruct the detailed design of the existing mechanical and civil structures in order to assess the possibility of technical upgradation of the systems. Based on the information and operational experience the upgradation of the facility was planned without altering existing civil structures. The major scope includes a) Replacement of the old product handling system with upgraded design, b) Replacement of the entire source drive systems including source lifting mechanism, and c) Up-gradation of control system by replacing relay-based logic with PLC-SCADA-HMI interface.

Overall Requirements of an Industrial Irradiator

An irradiation facility should have the following basic components, a) a radiation source (radionuclide or machine source), (b) biological shield, (c) a product handling system, (d) control system, and (e) dosimetry laboratory. The facility must be equipped with adequate source shielding to protect personnel and the environment from radiation exposure. This typically involves thick layers of lead or concrete. In case of Category IV irradiator, demineralized water of adequate column depth is used as a shielding for source during storage. The water also serves as a medium for heat dissipation.

Design Features of an Irradiator to Ensure Safety

System is required to be designed for safe and efficient handling of gamma radiation sources. This includes secure storage, easy replacement, and proper shielding. It is ensured that the design provides uniform irradiation of products. This often involves precise positioning systems and consistent source-to-product distances. Automation system is required for product handling, irradiation cycles and monitoring tool to enhance efficiency and reduce human error. System is designed for safe and efficient loading and unloading of products to be irradiated. This may involve conveyors, robotic arms, or other handling mechanisms. Easy access to all components is required for routine maintenance and repairs which includes source replacement and shielding inspections. Materials, components which can easily withstand radiation are used inside radiation cell.

The design features of irradiation facility are made to prevent unauthorized or accidental access to the irradiation cell. This includes locked doors, interlock systems, and controlled entry points. Emergency stop systems and alarms should be incorporated, along with SOPs (Standard Operating Procedures) for handling radiation emergencies. The facility must be equipped with radiation monitoring systems to detect and measure radiation levels, ensuring safe radiological environment. During operation of the facility, the trained and authorized operators should use personnel monitoring dosimeters and radiation survey meters. Facility is required to be designed and operated as per the national safety standards and regulations issued by the BARC Safety Council and Atomic Energy Regulatory Board (AERB) in India. In general, national safety standards are well aligned with International one particularly in terms of safe operation of radiation facilities. All necessary licenses and permits need to be obtained for the use and handling of radioactive materials. Comprehensive records of safety procedures, radiation surveys, maintenance, and training need to be documented.

Comprehensive training for all the involved personnel on the operation of the irradiator, safety protocols, and emergency procedures are required to be provided to ensure operational safety. Standard Operating Procedures (SOPs) for all aspects of irradiator operation, maintenance, and emergency response should be available and required to be implemented. The design and construction of an irradiation facility influence the dose delivery to the products. The optimized design is therefore of paramount importance to ensure adequate dose delivery. The major objectives to be considered during design of an irradiation facility are the dose uniformity in the irradiated product, efficient energy utilization and cost effectiveness.

System Description

Prior to delving into the specifications of the techno-modernization of FPI design, it is essential to outline the

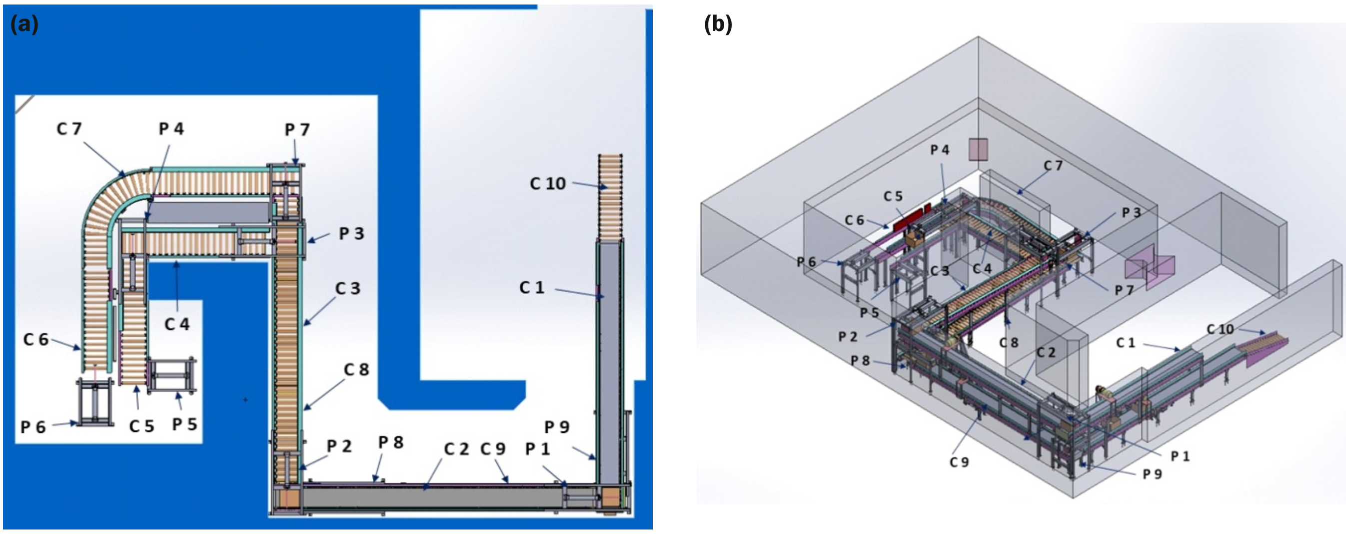

Fig.1: a) Plan view and b) Isometric view (3D model) of the conveyors (C) and pushers (P) of the Product Handling System of the modernized Food Package Irradiator (FPI), FTD.

overarching design requirements that ensure efficient and safe operation of the facility. The modernization of the irradiation facility must incorporate robust safety features, including adequate shielding to protect operators and the environment from radiation exposure. The mechanical design needs to facilitate seamless product handling while adhering to strict dose uniformity standards. Key requirements include a layout that minimizes radiation exposure to sensitive components and personnel, as well as the use of materials capable of withstanding high radiation levels. Moreover, the system must allow for easy maintenance and access to critical components without compromising safety. Ergonomic considerations are also vital, ensuring that product loading and unloading can be performed comfortably and efficiently. In addition, the design must comply with national and international safety regulations, ensuring that all operational aspects prioritize operator safety while maintaining adequate dose delivery and reliability in irradiation processes. These foundational requirements guide the development of the two major sub-systems: the mechanical system, which includes the product handling and source drive systems, and the electrical and control system, which governs the operational integrity and safety of the entire setup.

Modernization in Product Handling System

A new product handling system was introduced replacing the old conveyors. There were ten conveyors and nine pushers. Electrical actuators were used to run the conveyors. Pneumatic pushers were used to transfer product boxes from one conveyor to next conveyor after satisfying interlocks. It was a roller and belt/chain arrangement which was moved by geared motors. Conveyors 1, 2, 9, 10 were close to control room and these were belt conveyors. Belt conveyors gave smooth and noise less operation. Overall noise level in control room was reduced significantly in comparison with the earlier setup. However, other conveyors, near the source were exposed to higher radiation level. As belts cannot withstand high radiation, metallic roller conveyors were used near source. Before selecting the belt material, radiation test was carried out on different belt samples. There were total eight number of motors and nine pneumatic cylinders. Product boxes, made of aluminium of size 13”X13”X9” have tare weight of 3.0 kg. These boxes were used to carry products/samples intended for radiation processing. The layout (plan view) of the conveyors and pushers in the product handling system is presented in Fig.1a. Fig.1b illustrates an isometric view of the 3D model, showcasing all the conveyors and pushers integrated into the system. As a part of the operational procedure, the product boxes are loaded manually on belt conveyor-1 at the loading station. Boxes move from one conveyor to another conveyor and finally reach inside irradiation cell. After getting required radiation exposure, these boxes come out from irradiation cell through various conveyors. Boxes are unloaded from conveyor-10 manually at the unloading station.

Modernization in Source Drive System

The modernized FPI has now been equipped with a sophisticated source & source drive system designed for optimal performance. The designed capacity of the facility is to house maximum source activity of 100 kCi and the loading after refurbishment of the facility was of 89 kCi as on November 29, 2022. There are two source racks that can accommodate up to 34 source pencils (W-91 type). The source is stored in a water pool of 5 m deep, lined with ceramic glazed tiles. The source handling system facilitates the movement of source pencils stored in two racks submerged in water. Sources are raised to operating level and lowered back to its safe underwater storage position with the help of the source frame driving unit. Water levels are monitored at various stages to ensure operational safety and efficiency.

The modernized source driving unit comprised of pneumatic cylinders, wire ropes, multiple pulleys and source frames. Multiple pulley arrangements had replaced long pneumatic cylinders of stroke length of 5.5 meter, reducing to 1.4 meter. Stainless steel wire rope of diameter 4 mm was used in the source handling system replacing the older rope of

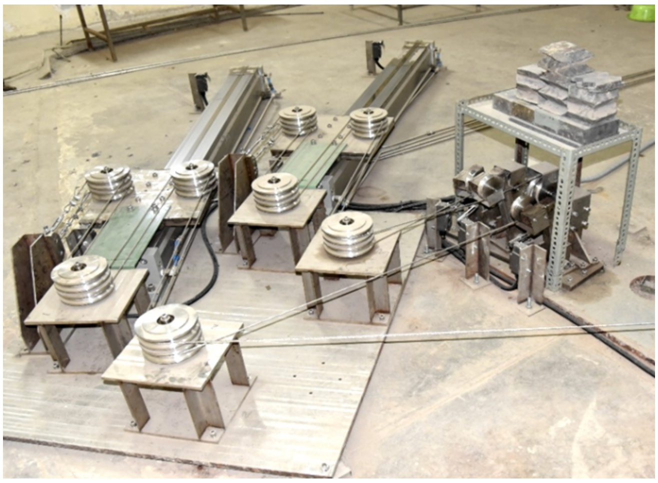

Fig.2: Layout of cylinders, pulleys of source drive system installed at the cell roof of the modernized FPI.

Fig.3: Control room with control panel and SCADA panel of modernized FPI.

diameter 2.5 meter. Source frames were connected to wire rope using qualified swaged socket. Driving unit was installed at the rooftop of irradiation cell. In order to take the lifting ropes to the cell, four existing openings at the roof were utilized. Two guide ropes were kept unaltered to guide each source frame during vertical movement. Pneumatic cylinders were employed in this facility due to the lighter weight of the source frame. Loose wire protection systems were employed to detect and signal any rope failure or loosening. The layout of cylinders, pulleys of source drive system is shown in Fig.2.

Source Replenishment

The Standard Operating Procedure for the replenishment of Co60 source pencils in the FPI involves collaboration among several agencies. Food Technology Division (FTD) is the user of the facility and responsible to execute the source replenishment exercise with necessary approvals. After the refurbishment of the facility the structural integrity of the source storage pool was assessed by the Structural Integrity Committee (SIC), BARC for the first time since commissioning ensuring safe storage of source. Board of Radiation and Isotope Technology (BRIT) was engaged in source handling operations, and Health Physics Division (HPD), BARC provided the safety coverage during the source replenishment activity. Initially, the water level in the source storage pool was lowered by 200 mm to facilitate accommodation of the source storage and shipping cask (BLC- 100) followed by the removal of the fencing around the pool. The source unloading process included careful lowering of the source cage to the bottom of the pool, removal of the necessary drain plugs and bolts from the shipping container, and transfer of the source pencils into isolated source cages meticulously following their serial numbers. The shipping container was sealed and secured. It was hoisted above the pool for drainage followed by a thorough radiation leakage assessment. The loading operation mirrored this process, starting with the introduction of a source cask into the irradiator room and ensuring proper placement of the new pencils according to the activity distribution design finalized using Monte Carlo based radiation transport code to achieve desired dose uniformity into the irradiated products. Final steps involved securing the pencils, performing radiation measurements, and transferring the shipping container to BRIT custody.

Modernization in Electrical and Control System

The modernized FPI is now featured with the electrical and control system encompasses motors, sensors and a PLC-based control system with HMI and SCADA operator terminal. Conventional 3-phase, 415 Volts, 50 Hz induction motors power all the drives. Pneumatic cylinders were used for pushing operation. Electromechanical limit switches were installed to sense position and sequence operations. Off-the-shelf PLC and HMI components were deployed for control and safety interlocks implementation. End-limit positions sensed by limit switches/sensors were installed to display and utilize for process interlocks. Two-position, five-port solenoid valves were used to control the operation of each cylinder. Radiation-resistant cables capable of withstanding 200 Mrad were utilized for signal and power transmission within the irradiation cell. Control room with control panel and SCADA panel is shown in Fig.3.

Plant Operation

The Standard Operating Procedure was prepared to start the modernized facility in Auto Mode with source providing a systematic approach to ensure safe and efficient operation. The procedure includes a) powering on the MCB and the main panel, b) initiating the compressor and checking pneumatic systems, c) activating all the radiation area monitors in Control room, d) starting the ozone exhaust blowers, and e) verification to ensure proper functionality of all the interlocks. The SCADA PC is then powered on, and the SIMATIC WinCC software starts automatically. Provision for manual launching was also provided depending on the situational need. After logging in, the operators can set the operation switch to manual mode, reset the SCADA panel to clear previous data, and switches to Auto mode. In addition, essential features were incorporated such as a) selection of source combinations, b) performance of search operation, and c) confirmation of the completion of the auto cycle. Upon finishing all the cycles, the provision was made to lower the source to its shielded position. Finally, the session can be concluded by exiting from the SCADA interface ensuring that all the protocols were followed for operational integrity and safety.

In the event of a power failure, the feature of auto-lowering of the source frame to water pool with conveyor system stop was incorporated. The design also ensured that the remaining cycle can proceed as long as the UPS is operational and supply power to the PLC and SCADA CPU.

Commissioning Dosimetry and Radiation Surveillance

The efficient upgradation of the facility was assessed by carrying out detailed dosimetry exercises to ensure desired dose delivery to the food commodity. The alignment of the exposed position of the source frame with the product box was assessed by the vertical placement of the dosimeters (Fricke and Ceric Cerous) inside the product box filled with rice as a medium. The variation in the absorbed dose between top and the bottom dosimeters was within ±5% ensuring acceptable source and product alignment. In order to obtain the entire dose profile inside the product box with food commodity, dose mapping with all possible source and product box configurations was carried out. The dose rates for small, large and total source configuration were measured as 5.84 Gy/min, 3.12 kGy/h, and 3.47 kGy/h with improved dose uniformity ration (DUR) of 1.36, 1.27, and 1.30, respectively. The transit doses at Dmin and Dmax positions were also measured. A variation in the transit dose was observed in the range of 9.6 to 28.6 Gy/transit depending on the source and product box geometries.

In order to evaluate the radiological safety of the modernized FPI, a thorough radiation surveillance was carried out in all the areas of the facility such as control room, maze portals, cell roof with source exposed or shielded conditions as per the standard procedures. The radiation levels at all the occupied areas were well within the permissible limit of 1 μSv/h.

Conclusion

It has been a challenging task to operate an old facility such as Food Package Irradiator, FTD, BARC complying with the safety requirements evolved with time. The facility has now been modernized by replacing all the mechanical, electrical, electronics and logic controls meeting all the present safety guidelines. The operation of the modernized facility has now become easy and ageing related breakdowns have been eliminated. Systematic preventive maintenances are in place to ensure smooth and safe operation of the facility. The facility has now been deployed for R&D exposures of various food and other commodities of departmental interest for regular utilization since 2022.

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