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Development of an irradiation system for a small size continuous run multipurpose gamma irradiator*

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Abstract. The Radiation Technology Center from IPEN-CNEN/SP, Brazil, developed a revolutionary design and national technology, a small-sized continuous run and multipurpose industrial gamma irradiator, to be used as a demonstration facility for manufacturers and contract service companies, which need economical and logistical in-house irradiation system alternatives. Also, to be useful for supporting the local scientific community on development of products and process using gamma radiation, assisting the traditional and potential users on process validation, training and qualification of operators and radioprotection officers. The developed technology for this facility consists of a continuous tote box transport system, comprising a single concrete vault, where the automated transport system of products inside and outside of the irradiator utilizes a rotating door, integrated with the shielding, avoiding the traditional maze configuration. Covering 76 m^2 of floor area, the irradiator design is a product overlap sources and the maximum capacity of cobalt-60 wet sources is 37 PBq. The performed qualification program of this multipurpose irradiator was based on AAMI/ISO 11137 standard, which recommends the inclusion of the following elements: installation and process qualification. The initial load of the multipurpose irradiator was 3.4 PBq with 13 cobalt-60 sources model C-188, supplied by MDS Nordion – Canada. For irradiator dose optimization, the source distribution was done using the software Cadgamma developed by IPEN-CNEN/SP. The polymethylmetacrylate (PMMA) dosimeter system, certified by the International Dose Assurance Service (IDAS) of the International Atomic Energy Agency (IAEA) was used for irradiator dose mapping. The economic analysis, performance concerning with dose uniformity and cobalt-60 utilization efficiency were calculated and compared with other commercial gamma irradiators available on the market.

Key words: multipurpose irradiator • gamma irradiator • compact irradiator • cobalt-60 irradiator • gamma facility

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Introduction

In the optimization of the design, operation and maintenance of a gamma irradiation plant, concerning the cost and safety analysis of the installation, the following decisions must be under taken before the construction of the irradiator:

- define the capacity of the plant;
- calculate the performance of the radioactive installation (cost of the product processed per kilogram);
- define the storage type of the radioactive sources (dry or underwater);
- define the geometry of the source rack in relation to the products to be processed (product overlap source or source overlap product);
- define the products pathway by the radioactive sources (number of rows) and
- define the transport system of products (carrier, pallet or tote box).

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The analysis of criteria of these parameters are fundamental to the irradiation system development [6, 8]. Currently, the world-wide trend in the construction of cobalt-60 industrial irradiators follows two lines: large size irradiators, with maximum capacity from 111 PBq (3 MCi) up to 444 PBq (12 MCi) and compact or dedicated irradiators, with up to 37 PBq (1 MCi) of capacity [9]. The compact irradiators have been developed with the principal idea to be installed integrated to the productive units, having as main characteristic the batch processing [3]. The most recent cobalt-60 compact type irradiator models are the BREVION™, developed by the Canadian company MDS Nordion Sterilization Technologies, the MICROCELL™ and the MINICELL™, both developed by the American Company SteriGenics International Incorporation and the BP1 PALLET IRRADIATOR™, developed for the French company Picowave Technology [4].

The cobalt-60 multipurpose compact type irradiator follows the same trend of these irradiator models, referring to the size of the irradiation chamber and the activity of sources. But it presents unedited systems like the rotating door and irradiation of products.

Some R&D projects at the Institute for Nuclear and Energy Research (IPEN-CNEN/SP) and in the national and international academic communities can benefit from the use of the multipurpose irradiator. It allows developing continuous processing technology to validate dosimetric systems and computational codes of dose mapping, making the radiation applications in industrial processes available, contributing to the productive processes optimization, increasing the competitiveness of the national products in the country.

Objective

The main objective of the research is to start the qualification program of the cobalt-60 compact type multipurpose irradiator, developed with a revolutionary irradiation system for a small size continuous run gamma irradiator and national technology, in the IPEN-CNEN/SP's Radiation Technology Centre, based on the standards CE-EN-522, ISO-11137 and the Safety Series 539 – International Atomic Energy Agency (IAEA) besides optimizing the dose uniformity and the efficiency factors of the radioactive installation for products with different densities.

Bibliographical revision

Under the safety aspect, the International Atomic Energy Agency (IAEA) classifies the gamma irradiators in the categories I, II, III and IV, in accordance with the installation design, the accessibility and the shield of the radioactive sources [8]. The cobalt-60 compact type multipurpose irradiator adopts all the electrical systems and mechanical of interlocking, alarms and emergency devices and is classified by the Brazilian National Nuclear Energy Commission (CNEN) as being of GROUP I and by the IAEA as a CATEGORY IV irradiator [5].

Calculation of the dose uniformity factor in the product, for the cobalt-60 multipurpose irradiator has been done using Eq. (1):

$$f = D_{max} / D_{min} \tag{1}$$

where: f – factor of dose uniformity; D_{max} – maximum dose in the product, after irradiation (kGy); D_{min} – minimum dose in the product, after irradiation (kGy).

The efficiency factor has been calculated by using Eq. (2):

$$F = 18.7 \frac{X \cdot D}{A\,^{60}\mathrm{Co}} \tag{2}$$

where: F – efficiency factor of the irradiator; X – throughput (kg/h); D – absorbed dose (kGy); $A\ ^{60}Co$ – activity in ^{60}Co (Ci, 1 Ci = 3.7×10^{10} Bq).

Experimental development

Acquisition, transport and inspection of the radioactive sources

Thirteen model C-188 sealed ^{60}Co radioactive sources have been acquired, with a total activity of 3,407.7 TBq (92,099 Ci) from the MDS Nordion Sterilization Technologies, a Canadian company. The thirteen ^{60}Co sources have been carried from the MDS Nordion Sterilization Technologies (Ottawa/Canada) to IPEN-CNEN/SP (São Paulo/Brazil), in one transport container type B, F-168 model, made of lead, steel carbon and stainless steel AISI 304, with 5,445 kg of total mass, certified by the Atomic Energy Board Control in Canada, under number CDN/2063/B(U)-85 and settled in a marine container of 6.1 m (20 feet) of length and volume of 30 m^3.

The transport container type B, F-168 model, was submitted to the rubbing test, to determine the existence, or not, of superficial radioactive contamination. One also verified the integrity and leakage presence on the thirteen ^{60}Co sealed sources by flushing tests. The paper filters and plastics, hoses, connections and the flushing water of the ^{60}Co sources had been monitored, using a Eurisys Mesures pancake type Geiger-Müller radiation detector model MIP-10, calibrated in the IPEN-CNEN/SP.

Planning and distribution of the radioactive sources

Planning and distribution of the 13 radioactive ^{60}Co sources in the 2 racks of the multipurpose irradiator, was done by means of the absorbed doses simulation in irradiation systems with gamma rays – software Cadgamma, developed as contribution of a Master of Science Dissertation, in the Radiation Technology Center (CTR) of the IPEN-CNEN/SP.

The flushing and rubbing tests were applied to assure the integrity of the ^{60}Co encapsulation and the lack of superficial contamination of the new sources, according to the radioprotection proceedings. Then, the 13 sources were installed in 6 magazines (sub-racks) which were assembled on 2 independent source racks.

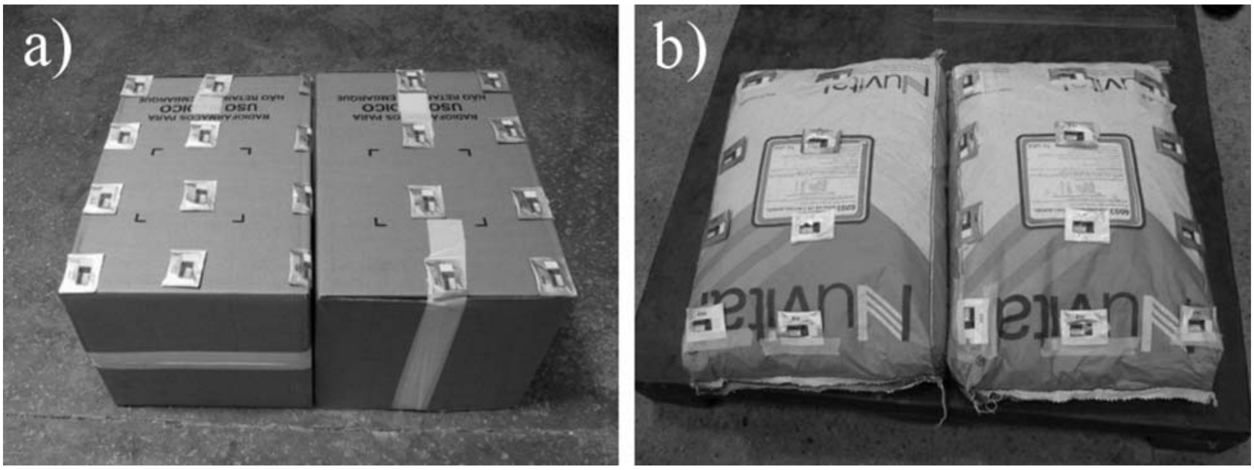

Fig. 1. Positioning of the 20 type Red Perspex 4034 (batch GD) routine dosimeters by plan, used in the dose mapping of the products: a) the covers and polymeric hoses of the ^{99m}Tc generators and b) animal food.

The magazines were fulfilled with empty AISI 316L pencils (dummies) and the ^{60}Co sources, to fix them in their planned position. With the aid of special tools, each piece was manually assembled on the bottom of the storage water pool. Once fulfilled, each magazine was positioned on the sources rack.

Qualification program of the multipurpose irradiator

The ^{60}Co compact type multipurpose irradiator qualification program, of which the control of the documentation, the equipment tests and calibration and the irradiator and products dose mapping are part, was fulfilled according to the norms CE-EN-522, ISO-11137 and Safety Series 539 – IAEA (AAMI/ISO 11137/R2-94) [2] and IAEA Technical Report Series 539 [7].

Dose mapping in the multipurpose irradiator to evaluate the dose uniformity of the products with different densities (ASTM E 1276-93) [1] was done using the Red PMMA 4034 dosimeters supplied by the Harwell Dosimeters Ltd.

Products from the IPEN-CNEN/SP's Radiopharmacy Centre (covers and polymeric hoses of the ^{99m}Tc generators) and Biotechnology Centre (animal food) were used for the cobalt-60 compact type multipurpose irradiator qualification. The absorbed doses requested by these R&D Centres for the products were 20 kGy and 10 kGy, respectively.

Dose mapping of products

The cardboard boxes containing the covers and polymeric hoses of the ^{99m}Tc generators (apparent density of 0.09 g/cm^3) were placed in the tote type aluminum boxes of the multipurpose irradiator transport system. Dose mapping in the products inside one of the aluminum boxes was done by placing 80 routine dosimeters type Red Perspex 4034 (batch GD), 20 dosimeters in each of the 4 horizontal planes. The same distribution of dosimeters was adopted for the animal food bags (apparent density of 0.49 g/cm^3), as shown in Fig. 1. Figure 2 represents the schematic distribution of the 80 routine dosimeters in the 4 planes (0, 1, 2 and 3). The dosimeters of the inner sections 1 and 2 were located at 1/3 and 2/3, respectively, of the cardboard boxes total piling-up the height (1.03 m) of the aluminum box. The Red PMMA 4034 (batch GD) reference dosimeter was also fixed in the central region of the external face of the box with the 80 dosimeters and in the two adjacent aluminum boxes.

The time setting of the multipurpose irradiator (time in which each aluminum box stands still in the position on the transport system, near to the 2 source racks), for the ^{99m}Tc generators was 85'66", while for the animal food, the time setting was 60'66". Measurements of the 83 PMMA 4034 dosimeters were carried out in the CTR's Laboratory of Industrial Dosimetry.

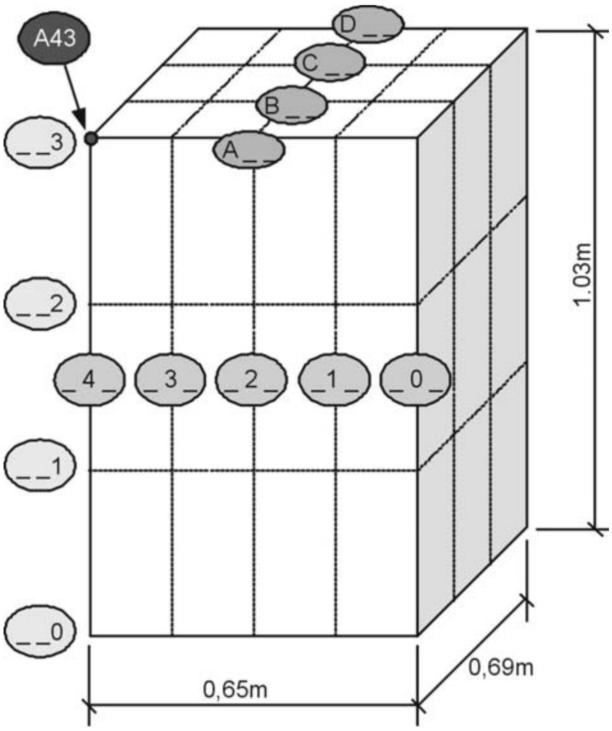

Fig. 2. Schematic drawing of distribution of the 80 type Red Perspex 4034 (batch GD) routine dosimeters, located in 4 distinct plants (0, 1, 2 and 3), in the products dose mapping. The dosimeter located in the left superior vertex is the A43.

Fig. 3. Compact type cobalt-60 multipurpose irradiator, projected, constructed and implanted in the IPEN-CNEN/SP, by a national technology and FAPESP financial support.

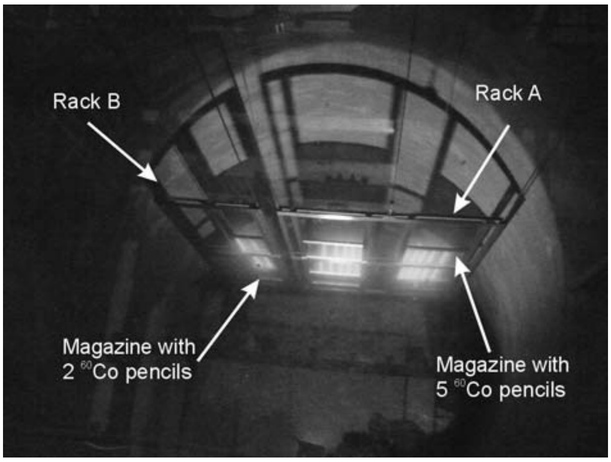

Fig. 4. Sealed sources of ^{60}Co reloaded in the 6 magazines of the 2 racks of the multipurpose irradiator, in the total of 9.12 PBq (256,550 Ci) in September 2008.

Thickness measurements of the dosimeters were performed using the model 293-801 Mitutoyo digital micrometer. Optical absorbances were performed at λ = 640 nm using the model 4001/4 Genesys-20 spectrophotometer. Equations (1) and (2) were used to determine the values of the dose uniformity factors and efficiency of the cobalt-60 compact type multipurpose irradiator in the processed ^{99m}Tc generators and animal food.

Results and discussion

Final specifications techniques of the cobalt-60 compact type multipurpose irradiator

The final characteristics of the cobalt-60 compact type multipurpose irradiator, shown in Fig. 3 and designed by the CTR professionals of the Project, Construction and Implantation of Large Size Irradiators and Industrial Electron Beam Accelerators Group are:

- total capacity granted by the CNEN: 37 PBq (1 MCi), Category IV;
- initial operation source activity: 3,407.7 TBq (92,099 Ci);
- sources storage pool: cylindrical, 7.0 m depth and 2.7 m diameter;
- concrete doors: one sliding for assembly and maintenance of the installation, with 4.0 m (length) × 4.0 m (height) × 2.45 m (width) and one rotating, for input and output of products in the irradiation chamber, with 2.65 m (diameter) × 4.0 m (height);
- concrete wall: 1.8 m thick (density = 2.35 g/cm^3);
- source geometry: 2 racks of rectangular sources, with capacity for 8 magazines each, in a total of 504 pencils of ^{60}Co;
- source dimensions: 1 rack with 1.4 m (width) × 2.1 m (height) and 1 rack with 0.7 m (width) × 2.1 m (height);
- cobalt-60 pencil magazine capacity: 40 (1.4 m rack magazine) and 23 (0.7 m rack magazine);
- irradiation system: product overlapping source;
- transport system type: tote box, continuous, box double piling-up, being that each level of box with the products is put into horizontal motion, but in contrary directions;
- irradiation chamber capacity: 14 boxes, approximately 6.47 m^3;
- products to be processed: foods; medical, surgical and biological materials; raw materials for the foods industries, druggist and cosmetic products, among others;
- dimensions of the aluminum boxes – 0.69 m (length) × 0.65 m (width) × 1.03 m (height);
- volume for box: 462 liters (0.46 m^3); and
- box maximum load capacity box – 400 kg.

Rubbing and flushing test results

The rubbing test in the transport container type B, F-168 model and the flushing test were negative. The monitoring of the paper filters and plastics, hoses, connections and flushing water of the sources of ^{60}Co, with a pancake Geiger-Müller radiation detector presented values < 185 Bq (5 nCi).

Distribution of the ^{60}Co sealed sources in the racks

Figure 4 shows how the ^{60}Co sealed sources are placed on the source racks A and B of the multipurpose irradiator, resting on the bottom of the source storage pool. Three of the ^{60}Co sources, 21.7% of the total activity have been installed in two magazines in the 0.7 m wide rack B. In the 1.4 m wide rack A, the other ten ^{60}Co sources, 78.3% of the total activity, were placed in four magazines to get the planned activity distribution.

Dose uniformity factor and efficiency analysis

For apparent densities of 0.09 g/cm^3 and 0.49 g/cm^3, the dose uniformity factor (*f*) and efficiency (η) of the cobalt-60 compact type multipurpose irradiator, compared to those from the MDS Nordion Sterilization Technologies Commercial Irradiators (the tote box, continuous transport system type, models PALLET

Table 1. Dose uniformity factor (*f*) and efficiency (η) of the multipurpose irradiator and the MDS Nordion Sterilization Technologies Commercial Irradiators for apparent densities of 0.09 g/cm³ and 0.49 g/cm³ [10]

Irradiators / factors	Multipurpose irradiator	(1)Pallet irradiator (design 8)	(2)JS-9500	(2)JS-9600	(3)JS-10000 (design 1)	(3)JS-10000 (design 2)
Apparent density: 0.09 g/cm³						
Dose uniformity (*f*)	1.33	1.45	1.40	1.50	1.25	1.30
Efficiency (η) (%)	11.6	15.0	14.6	16.8	18.7	25.1
Apparent density: 0.49 g/cm³						
Dose uniformity (*f*)	2.08	3.15	(5)1.85	(4)1.65	(5)1.85	1.90
Efficiency (η) (%)	36.6	23.4	(5)35.5	(4)33.7	41.1	(5)44.9

(1) Pallets in eight positions, two levels and two passes around of the ^{60}Co sources.
(2) Tote boxes in two levels and two passes around of the ^{60}Co sources.
(3) Tote boxes in two levels, four or eight passes around of the ^{60}Co sources.
(4) Apparent density = 0.30 g/cm³.
(5) Apparent density = 0.40 g/cm³.

IRRADIATOR™, JS-9500™, JS-9600™ and two design versions of JS-10000™) [10] are presented in Table 1.

Conclusions

In the cobalt-60 compact type multipurpose irradiator project and construction, the software Cadgamma was essential in the planning of the irradiation system (product overlap source), transport system of products (tote box, continuous and double piling-up of boxes), products pathway (two passes) and in the radioactive source distribution, keeping the doses in the specified limits for the material, with the lower waste of ionizing radiation, better efficiency and dose uniformity factor by rack, for different product densities.

In the product dose mapping, with densities of 0.09 g/cm³ and 0.49 g/cm³, the values found for the dose uniformity factors and efficiency demonstrated that the multipurpose irradiator of the IPEN-CNEN/SP, projected and constructed by a totally national technology, presents excellent performance and is extremely competitive when compared with the compact and large size irradiators of the MDS Nordion Sterilization Technologies, largest and more traditional gamma irradiators manufacturer in the international market.

The Safety Analysis Reports: Previous Approval, Authorization for Construction, Authorization for Operation and Transport Plan applied and already approved by the CNEN; Enterprise Characterization Memorial and Request of Dismissal of Installation Certification demanded and already approved by the Company of Environmental Sanity Technology (CETESB) and the Ambient Licensing for Transport of Radioactive Material demanded and already approved by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) confirm the rigorous criteria of the project and the safety measures adopted in the multipurpose irradiator, which does not present risks to the surrounding communities and to the IPEN-CNEN/SP itself.

To complete the qualification program of the multipurpose irradiator, it is necessary to carry out the dose mapping of two products, at least, with apparent densities between 0.20 g/cm³ and 0.40 g/cm³.

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