Improving Designing Elements to Maintain Radiation Safety of Cobalt^{60} Industrial Irradiator

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Abstract: The main problems of design elements for different irradiators are studied and developed in this work beside their positive design elements to improve quality of irradiation processing and increase radiation safety standards inside and outside a proposed design. A comparison is maintained between different categories irradiators and the new irradiator's models in Brazil leads to increase radiation safety standards for design, operation, and safety. Strike accidents between moveable vertical source racks and metallic containers on the horizontal conveyor system caused very bad effects, firing all different mechanical, electrical systems and bad thermal effects on concrete shielding inside old Canadian irradiators. Also the new irradiator models (Previon) in Brazil will be faced by dinger problems through passing gamma radiation through gaps between the moveable heavy concrete shielding and irradiator concrete shielding and also between rotating concrete door and concrete shielding which were built in 2003 and 2007. Irradiation processing quality inside Pravion irradiators is lower than any old Canadian irradiator. Concrete shielding performance is affected badly by fire through hydration and thermal stress inside irradiation rooms. Radiation shielding penetration and designing engineering sciences are applied to develop old useful designs of Canadian irradiators (wet storage) through preventing dinger stick between radiation source rack components and metallic containers on horizontals mechanical conveyor system. New irradiator designs in Brazil become better safety for operation and radiation through designing and adding new safe concrete mazes in separate lines to operators movement and to trance products containers inside and outside them to maintain the necessity goal through preventing repeating transport big masses of moveable concrete shielding , or rotating concrete door in these new irradiators. The product mechanical systems inside irradiation rooms of new Canadian irradiators will be modified to moveable horizontal mechanical conveyor system of old Canadian irradiator to prevent stick between vertical radiation source rack systems and product containers on horizontal conveyor systems, then new Brazilian irradiators will be modified and become more safe.

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Keywords: Industrial irradiator, concrete shielding penetration, vertical source rack, horizontal mechanical conveyor system, rotating concrete door, moveable concrete shielding, irradiation processing quality and previon irradiator.

1. Introduction

About 200 industrial irradiators using Cobalt-60 irradiator are in operation in many countries for irradiation processing in various fields. Industrial irradiator consists of irradiation room which is surrounded by calculated clean concrete shielding and clean concrete roof to prevent of radiation exposure. The concrete shielding is determined on the basis of maximum foreseen activity and the criterion that the radiation level outside irradiation room remain lower than the maximum safe levels **(1-2).** Cobalt-60 pencils are arranged in a source rack which can be lifted into irradiation room for processing and after words lowered back into a safe position, at the bottom of a storage pool of water of 5-7m depth. During irradiation processing the radiation source is stationary and product boxes are moved on a horizontal mechanical conveyor system around the vertical radiation source rack. Products boxes or product carriers are trance inside irradiation room through a specially designed maze. The personnel maze is strictly controlled **(1-2).** The calculated thickness of concert shielding depends on the activity of radiation source and distance between radiation source rack and irradiator concrete shielding. Must also include multiple safeguards to protect operator health and the community should a natural disaster like an earthquake, fire, or tornado occur **(1-3)** Fig (1).

2. Materials and methods.

The radiation regulation of industrial irradiator depends on the type of radiation sources which are used. Industrial irradiators can treat food and medical products either with radiation sources, such as cobalt^{60} or cesium^{137}, or electrically generated X-ray or electron beams. Industrial irradiators which use radioactive sources must meet the following U.S.

Nuclear Regulatory Commission (NRC) licensing requirements(6-9 and10)

*- a design that incorporates multiple fail-safe measures.

*- extensive and well documented safety procedures.

*- extensive worker training.

The radiation shield is designed to reduce the radiation leakage level from inside to outside industrial irradiator, from 74.4 pbq (2,000,000 ci) source, to an average exposure rate of less than 2.5 µ Sv/h (0.25 mrem/h). This allows a person to work near the shield 40 hours per week and limit their exposure to a maximum dose of 5.0 mSv (500.0 mrem) per year (11-12 and13).

Maximum exposure rates up to 20 µ Sv/h (2.0 mrem/h) are allowed in small areas adjacent to the shield, provided these contributions do not raise the average exposure rate above 2.5 µ Sv/h (0.25 mrem/h) over any surface of concrete shielding (3and14). Stepped concrete plugs located in the roof are removable to allow lowering of the cobalt 60 shipping container into the source storage pool. Personal and product enter the radiation room through a maze design that loss of shield integrity(14 and19). Personal enter through an access door. The product is transported, by the conveyor system, through separate entry (maze) and discharge ports(19) These ports are blocked personnel entry (maze) by metal barriers when no product is present (14 to17).

Cobalt-60 irradiator includes clean safe materials (clean concrete shielding components, safe location, safety measures (before, during and after construction), available for rules U.S. Nuclear Regulatory Commissions, experience, planning, training and supervision [18 to 22].

Work Technique.

Radiation physics science, the environmental impact assessment, engineering of industrial irradiator design and the analysis of nuclear regulatory commission are applied on different industrial irradiators and the new Canadian (Nordon) irradiators which were constructed in Brazil in 2003 and 2007. The work shows a ruling to gain important scientific rules about future problems which will be recorded on the new irradiators in Brazil and the necessity need to design new calculated mazes for operation and products which will lead to develop the design elements of the two new irradiators through preventing transport of very heavy concrete door and concrete wall (rotating concrete door and moveable concrete shielding wall). Also a modified design is maintained depending on positive design elements and development elements of old and new industrial irradiators to prevent stick accidents between vertical radiation source rack system and metallic containers through developing the horizontal mechanical conveyor system to become moveable system to trance far from radiation source rack-by new micro control system that will be attached by control panel outside irradiator.

Work idea.

Radiation physics science, the environmental impact assessment and irradiator design engineering are applied on different industrial irradiators and the new Canadian irradiator's designs by (Nordon) which were constructed in Brazil in 2003 and 2007. Important scientific rules about future problems which will be recorded inside Brazilian irradiators and a necessity need to design new mazes for operation and products to develop the design elements of the two Brazilian new irradiators through preventing transport very heavy rotating concrete door and moveable concrete shielding wall. The modified horizontal mechanical designs inside old Canadian irradiator are used also inside new Brazilian industrial irradiators to maintain the best quality of irradiation processing inside new irradiator and also prevent stick accidents between radiation source rack system and metallic containers through developing the horizontal mechanical conveyor system to become moveable system that will be trance far from radiation source rack-by new micro control system P.L.C (programmable logic controller)that will be attached by control panel outside new Brazilian irradiator.

3. Results and Discussion.

Radiation safety standards and safe operation are maintained inside and outside eastern and western industrial irradiators (dry and wet storages), but some negative results were recorded where the stick between cobalt-60 source rack and product containers on horizontal mechanical conveyor system, inside (J.S 6300, J.S 6500 and J.S9500) which recorded very bad results on irradiators different systems, operators,, concrete shielding and surrounded environment. Also the new Canadian design in Brazil will record high concentration of gamma radiation outside concrete shielding which are passed through gaps between rotating concrete door and, radiation concrete shielding or between moveable concrete wall and concrete shielding inside and outside new Brazilian irradiators, and their irradiation processing quality are lower than standards of irradiation processing of old irradiators (8 and19).. There are necessity needs to develop irradiators designing elements of Canadian old irradiators and also must develop the new irradiators in Brazil through designing a new trace (calculated concrete maze) to maintain safe operators movement and trance product containers inside and outside irradiator with not move the rotating concrete door (very heavy weight) or a moveable heavy concrete wall to prevent gamma radiation from leakage to outside concrete shielding through gaps between the moveable concrete shielding and irradiator main concrete shielding.

Fig (1) shows different design elements of a typical panoramic wet storage gamma irradiator J.S-9500 MDS Nordon Canada in different countries.

The main components of cobalt-60 gamma irradiator

Fig. (1). Shows the main components of an industrial irradiator include:

-Concrete shielding storage pool (dry or wet).
-Cobalt-60 radiation source rack.
- Source hoist mechanism,
-Irradiation room is surrounded by calculated concrete shielding.
- Control console (room),
- Product containers (totes),
- Product transport system (mechanical conveyor system through the concrete shielded maze,
– Control and safety interlock system,
– Areas for loading and unloading of products, and
–Supporting service equipment.

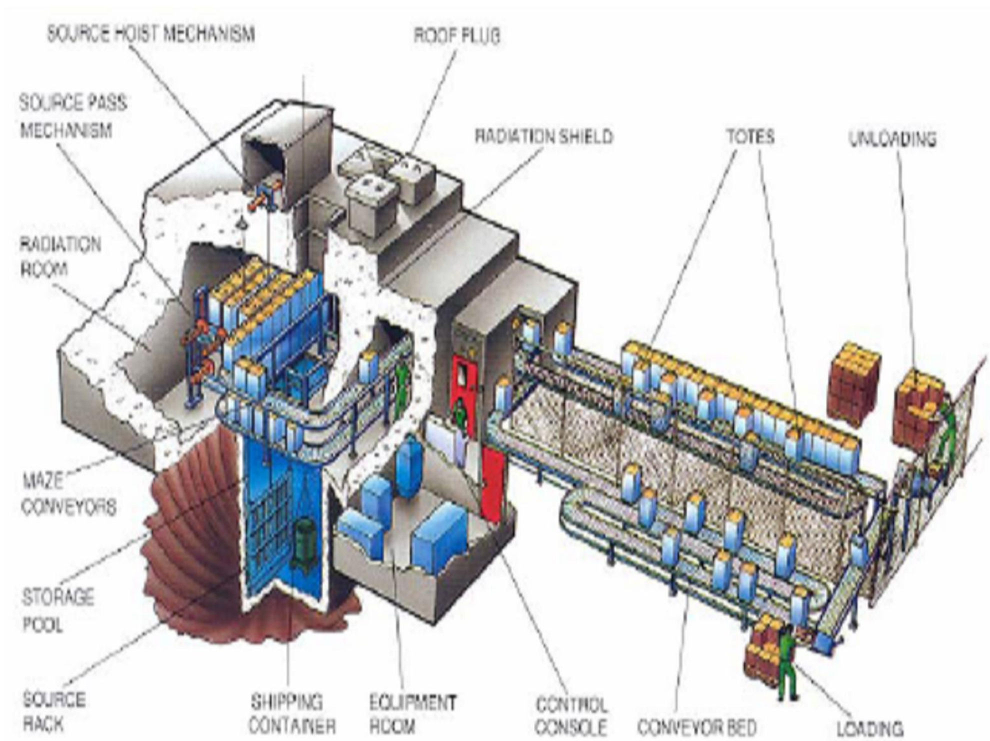


Fig. (1). A typical panoramic wet storage gamma irradiation facility (MDS Nordion, Canada).

The necessity uses of different mazes inside industrial irradiators.

Different designing elements of various industrial irradiators are shown in Fig (2-A and B) where plan and elevation of Byelorussia (dry-storage), a calculated main maze is shown in the plan beside irradiation room, Fig (3-A and B) J.S 9500 (wet-storage) old Canadian irradiator, it has two mazes for operators and products transport inside and outside irradiator and which are attached by irradiation room, Fig (4) plan of Hungarian irradiator where two mazes are shown, Fig (5) plan of Russian irradiator (wet storage) where main maze is shown that look a like Byelorussia irradiator where they are attached by their irradiation rooms, and Figs (6-A, B and C) show Bravion irradiators with their rotating concrete door in the first design or moveable concrete wall in the second. There is not any operators maze or product containers maze inside designs of Bravion irradiators which recorded very bad results on irradiator different systems, operation and environment.

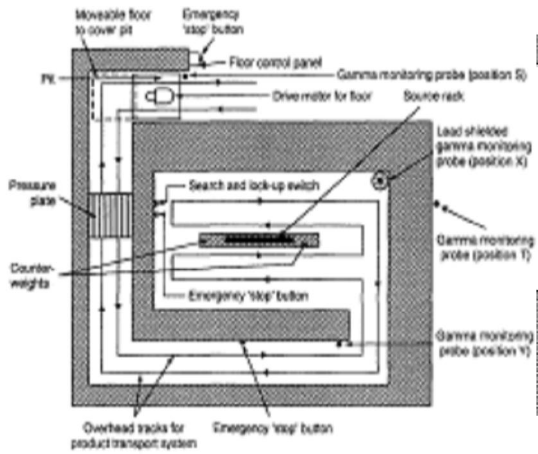


Fig. (2-A): Plan of Byelorussia dry-storage irradiator.

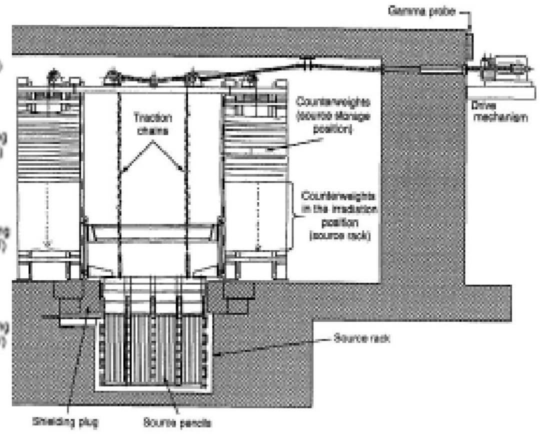


Fig (2-B): Elevation of Byelorussia dry-storage irradiator.

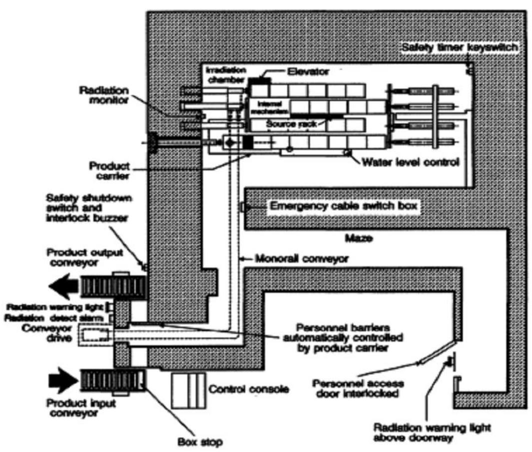


Fig (3-A): Plan of J.S 9500. Wet storage Canadian irradiator.

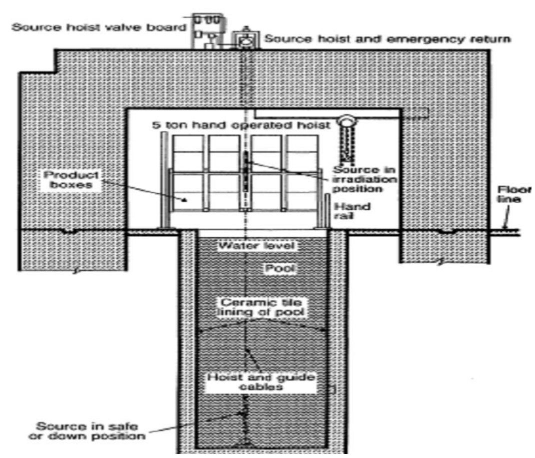
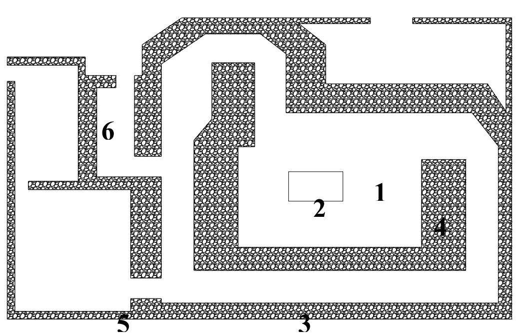


Fig (3-B): Side view of J.S 9500. Wet storage Canadian irradiator.



1=Irradiation room
2=Storage pool
3=Main maze
4= Concrete shield
5=Main opening
6=Product maze

Fig. (4) Plan of Hungarian irradiation facility (wet storage).

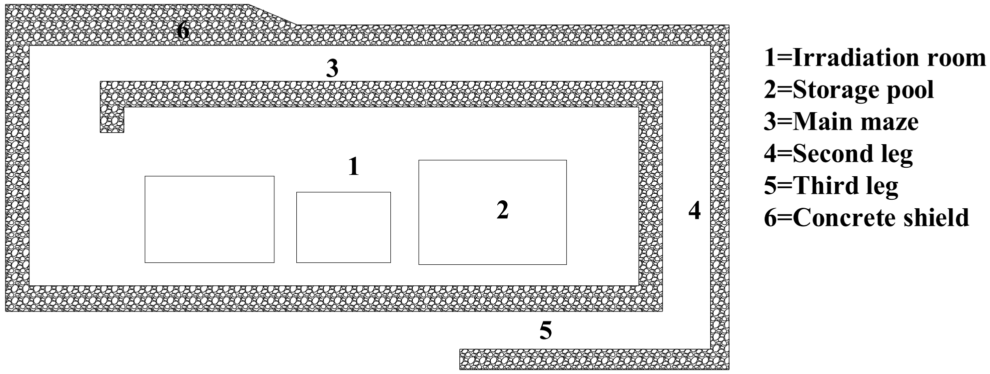


Fig. (5) Plan of Russian irradiator (wet storage).

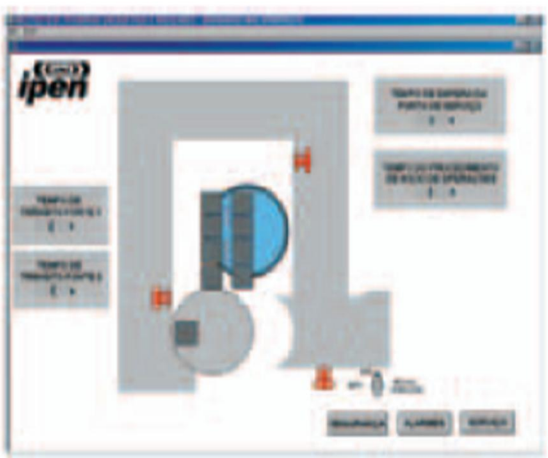


Fig (6-A) plan of Pravion new irradiator.

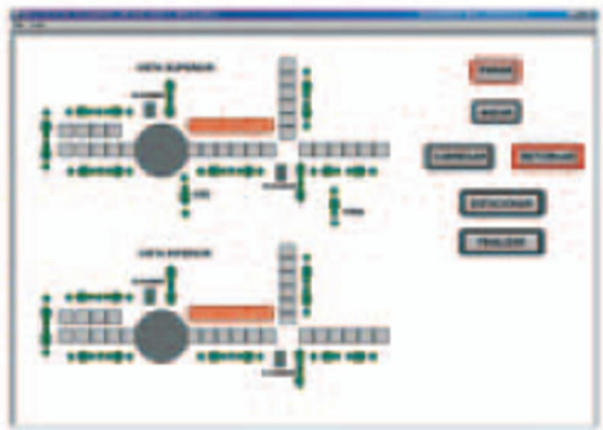


Fig (6-B) loading/unloading new Pravion irradiator.

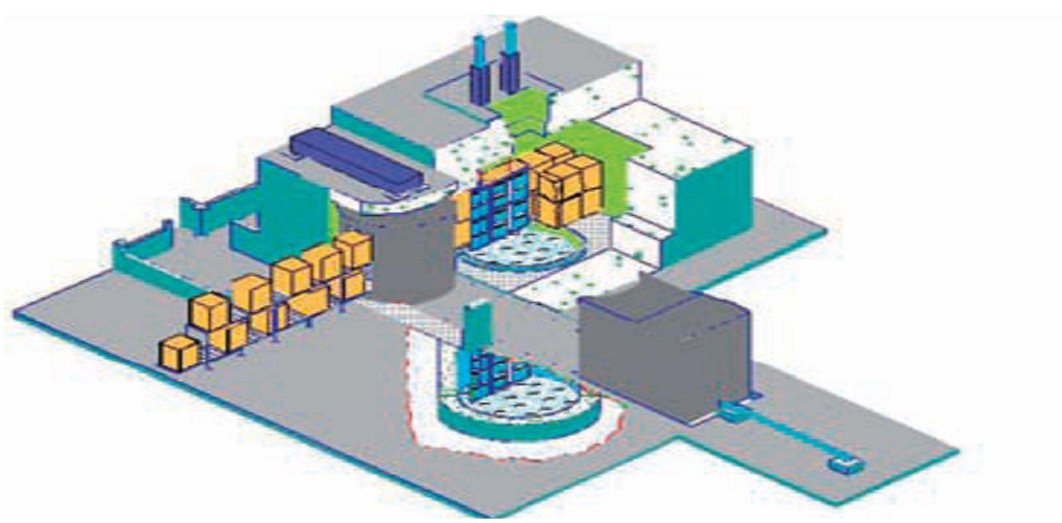


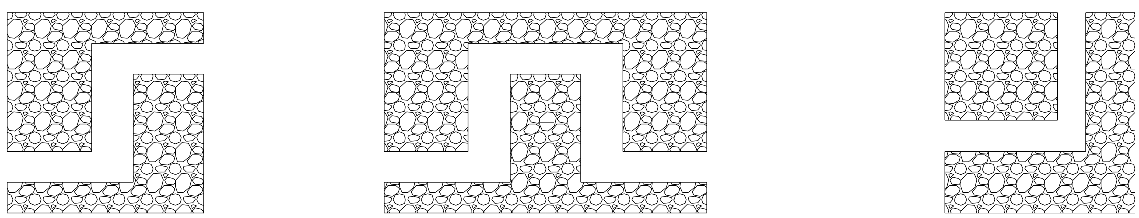
Fig. (6-C). New design of Bravion irradiators in Brazil by M.D.S Nordon CANADA.

Table (1). Comparison of four industrial irradiation designs by Co ^{60} irradiator

No	Element	Western		Eastern	
		J.S.6500	Bravion	Russian	Hungarian
1	Activity	1.000.000 curies	2.000.000curies	1.000.000 curies	2.000.000 curies
2	Biological shield	Concrete	Concrete	Concrete	Concrete
3	Storage of source	Water pool	Water pool	Water pool	Water pool
4	Coating of storage pool	Tile	Stainless Steel	Stainless Steel	Stainless Steel
5	Poll number an d depth	1-4.5 m	1-4.5 m	2-4.5 m	1-7.0 m
6	Interior height	3 m	4 m	5 m	4 m
7	Source rack, number	1 3 x 2	1- 3x2	2 1 x 2 2 x 2	1 3 x 2
8	O_3 ducts, intake number	1 1x1	1 1x1	2 1x2	1 1x2
9	Concrete shielding, penetration	Three closed/ lead	No	No	No
10	Maze and form	2 Z	No	1 U	2 U
11	Dose rate receive 40h/week	2.5 mSv/h	2.5 m.Sv/h	2.5 mSv/h	2.5 mSv/h
12	Ventilation system	20 air change/H	20 air change	40 air change/H	40 air change/H
13	Boxes transport in /out	Maze boxes	Boxes on railway	Maze carrier	Maze product
14	Roof plug	No	No	Three	Three
15	Door	Four	Moveable concrete wall	One	Four
16	Research track	No	No	No	No
17	Product opening	Two Exist	Moveable wall	Through main maze	Two
18	Push- back plate with pit	No	No	Exist	Exist
19	Emergency stop cable	Exist	No	No	No
20	Power failure	Exist	No	No	Exist
21	Maze door		No maze	No	Exist
22	Source rack		Exist	Exist	Exist
23	Source rack guide cable	Exist	Exist	Exist	Exist
24	Temperature sensing device	Exist	Exist	Exist	Exist
25	Conveying system	Exist	No	Exist	Exist
26	Source inter lock	Exist	Exist	Exist	Exist
27	Side boxes changer	No	No	Exist	Exist
28	Camera holes	No	No	Exist	Exist
29	Counter weight	No	No	Exist	Exist
30	Pool water level (guide)	No	Exist	Exist	Exist
31	Source Hoist/Alarm	Exist	Exist	Exist	Exist
32	Air pressure		Exist	Exist	Exist
33	Start up safety daily timer	Exist	Exist	Exist	Exist

Table (1) shows four different irradiators (wet storage) where radiation safety limits of international basic safety standard for protection against ionizing radiation of safety series 115. International basic standards for protection against radiation sources, 1995 are maintained (2, 3 and 13). Some different design elements are recorded on each one of the showed irradiators. The eastern radiation designs have several active features such as the thickness of concrete shielding which are bigger than (J.S 6500), interior dimensions, O_3 ducts numbers and intakes(lower and upper intakes) and maze dimensions (width, height and length) beside the maze legs are longer than the western irradiator (5, 14 and18)where radiation safety standards are maintained more than western irradiators, but the vertical motion of radiation source rack components system and the horizontal motion on mechanical conveyor system inside western irradiators are more simple than the eastern irradiator systems but dinger stick accidents were recorded inside western irradiators more than eastern irradiator where a necessity need to develop western irradiators which were fabricated by Canadian company (Nordon) to prevent this very dinger (stick) problem(19-20 and21).. **1-** Generally Radiation sources are removed from the irradiator to suppliers (Nordon or high voltage) when the radioactivity falls to approximately 6% and 12% of the initial level. Cobalt-60 sources decay to 50% in about 5.3 years and to 6 to 12% of their original radioactivity in about 16 to 21 years(8-10 and 14).

2-Under normal operating conditions, operators and public are protected by clean calculated concrete shielding, detection systems, and maze design and maze safety procedures Fig(2). Irradiator designs include redundant levels of monitoring and safety devices to protect personnel from radiation exposure. A system of interlocks prevents unauthorized (Fig.7) entry (maze components) systems into an irradiation room when the source is not exposed and Fig (3 and 4) show (maze) entry procedure for category IV Hungarian irradiator. And operators maze in Canadian wet storage J.S 6500 .Worker safety is also dependent upon strict operating procedures and proper training. In most countries, regulations require periodic inspection of industrial irradiators to ensure compliance with the terms of operating licenses. The Occupational Safety and Health Administration are responsible for regulating operators' protection. The Nuclear Regulatory Commission or an appropriate state agency must license food irradiators which use cobalt-60 irradiator, as their radiation source.



Z- Shaped duct **U- Shaped duct** **L- Shaped duct**

Fig (7) Schematic diagram of Bent duct and maze design.

Development of vertical and horizontal motion systems to prevent stick accidents inside Canadian old irradiators like J.S 6300, J.S6500 and J.S 9500 which recorded very bad results for operators and irradiators. So the reaction effect is more than radiation source rack weight and more than the two bodies' weights (product metallic containers) that leads to stick radiation accident (20 and21).

The source rack was stopped after impacting at a distance of 5 cm (20 and 21). The pusher's pressure pushes the product containers on its conveyor of the four mechanical conveyors system, which are located on the two sides of radiation source rack to bulge burst and disrupted product container boxes the adjacent conveyor. Pushing the product boxes which are protruded towards the radiation source rack.

- The overdose timer detected the jam and the source rack began to descend but the source rack was blocked by a product box on the inner conveyor which was protruding under the upper edge of the source rack. The product box on inner conveyor hindered the descent of radiation source rack causing the stick
- Releasing and also fitting the steel guide bars, and leading to the stuck of the radiation source rack.
- The safe allowing distance between the radiation source rack and each shroud sides is 2.5cm, because the (horizontal) distance between the two vertical sides of the protective shroud is 10.0 cm, and the source rack's width is 5.0 cm.
- Product box jam interferes with the movement of the source rack whom is prevented of falling to the safe down position inside the storage pool causing the most dangerous irradiation accidents inside old Canadian irradiators which need to prevent these accidents by modifying the horizontal mechanical conveyor design.

The work shows a modified design of the horizontal mechanical system that allows to trance away two shelves of the four shelves (2 upper shelves and 2 down) which are carried by the product boxes (stick product box) far away the two sides of the source rack. The radiation source is prevented of jamming by this modified design that allows falling cobalt-60 source rack to its shielded position inside the storage pool, then the main door will be opened from outside irradiator. The jammed box will be trance outside irradiation room and the moved parts (New design) will be returned to its normal position on the main shelf (Fig 7).

The mechanical system will be returned to the normal irradiation position (Figs 7 and 8). Radiation source is raised to safe irradiation position by control panel depending on (cobalt-60 irradiator requires pneumatic facilities with a minimum capacity of 35.5 cubic feet per minute free volume of air based on free air at 7.0 atmospheres. A 7.5 hp compressor with a reservoir of 20 cubic feet capacity is recommended).Main problem of old Canadian irradiators (the best designs) are solved through this development.

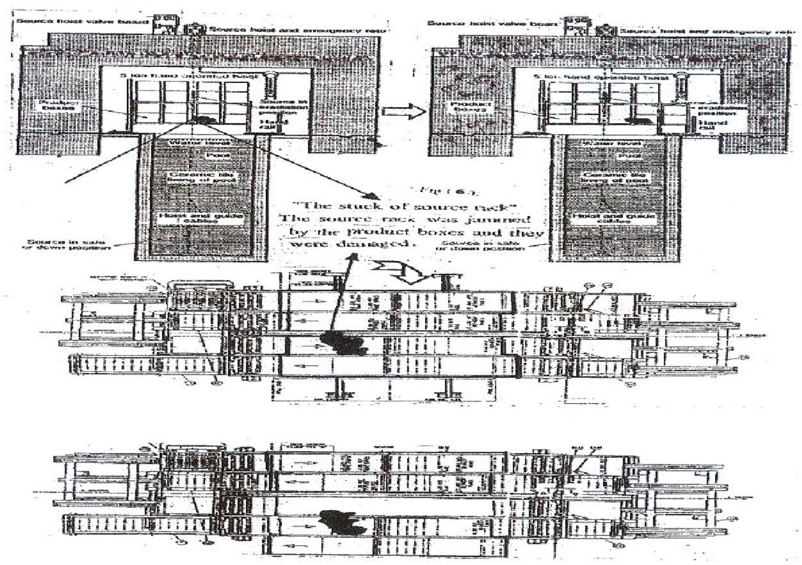


Fig. (8). Mechanical conveyor plan and side view after modification.

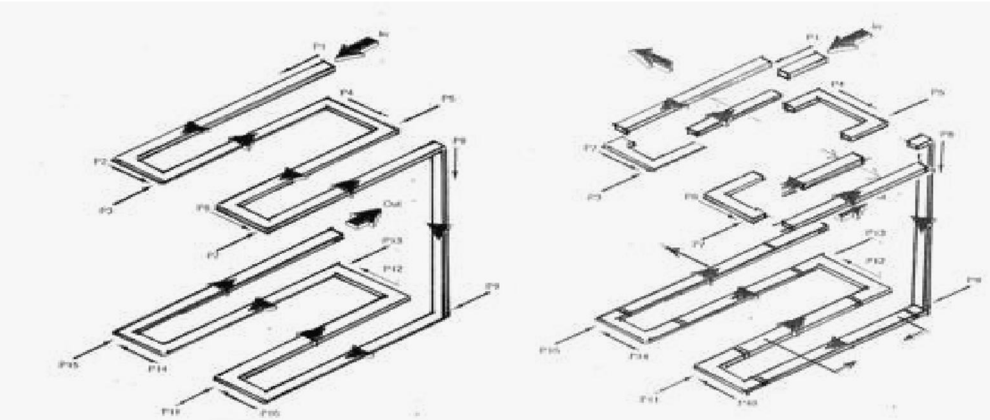


Fig (9) Schematic diagram of the transport of product boxes on the fixed conveyor system before modification.

Fig (9) Show the moved part of mechanical system to trance the jammed boxes far away from the radiation source system.

Quality of irradiation processing standards inside Previon models (Canadian irradiators) before and after irradiator development.

Product boxes are trance on railway system inside irradiation room of Brazilian irradiators, they are not trance around cobalt-60 radiation source racks on four upper shelves or on four lower shelves on mechanical conveyor system and also their positions around radiation source racks are not changed causing bad irradiation processing. Figs (8 and 9) show good irradiation processing around irradiation source racks maintaining very good irradiation processing inside old Canadian Irradiators, and the new mechanical transport system inside new Canadian irradiators (Pravion in Brazil) recorded bad irradiation processing as a result of bad distribution of gamma radiation which penetrated product boxes inside these new irradiators..

Irradiation processing standards by Brevion (new Canadian irradiators) are lower than the Canadian old irradiators because old irradiators maintained the best irradiation processing standards through good transporting of the product boxes on conveyor system around cobalt-60 radiation source rack where gamma radiation distribution are better than Brazilian irradiator figs (8,9,10 and11).

During a radiation process, gamma radiation interacts with the product through several types of atomic interactions, such as Compton scattering, photoelectric effect and pair production [12]. Through these and subsequent interactions, it imparts energy and, thus, radiation dose to the product. As radiation proceeds through the product its intensity decreases, resulting in the decrease of dose with depth. This is referred to as depth-dose distribution (see Fig (10 and11) and curve 'a' or 'b'). The rate of decrease depends on the composition and density of the product, as well as the energy of the gamma radiation. Besides the variation of dose with depth, there is also dose variation in the lateral direction. This variation depends on the geometry of irradiation. Both types of dose variation contribute to the non-uniformity of the dose delivered to the product. Variation in dose in the irradiated product is unavoidable. One accepted method of describing this non-uniformity of dose is the concept of dose uniformity ratio (DUR), which is the ratio of the maximum dose in a product container to the minimum dose in the container. This ratio increases with the density of the product as well as with the size of the container (see Fig.10).

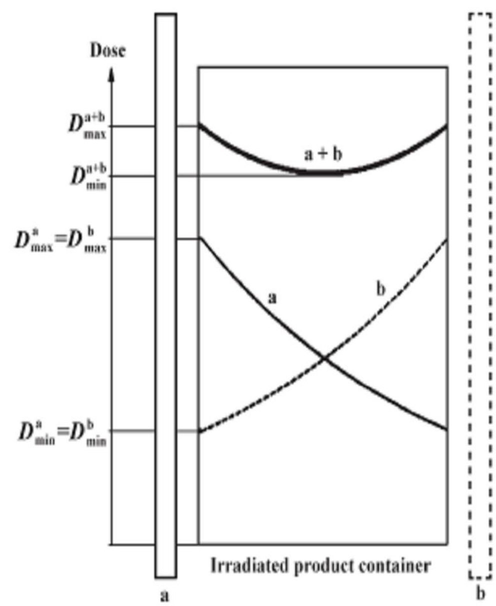


Fig. (10). Depth-dose distribution in a product container irradiated from two sides with a cobalt-60 source. The curve 'a' represents the depth-dose distribution when the product is irradiated from one side only (source is at position 'a'). Similarly, when the source is at position 'b', the dose distribution is represented by the curve 'b'. The total dose due to irradiation from two sides is then shown as the curve 'a+b'. Notice that this total dose is much more uniform than that which is due to single-sided irradiation (curve 'a' or 'b').

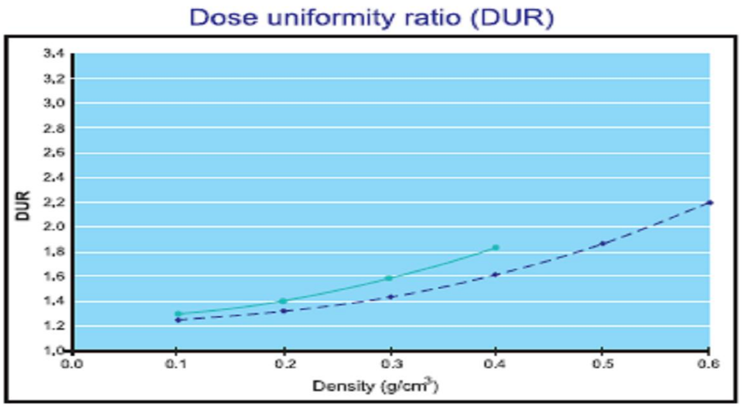


Fig. (11). Dependence of dose uniformity ratio (DUR) on product density for two different irradiator designs (MDS Nordion, Canada).

This ratio should be close to unity (for example, less than 1.05) for radiation research samples, where the research objective is to correlate radiation effect in the sample to the dose. This is generally achieved by reducing the size of the sample. For commercial operation, this is not possible for economic reasons. A typical product container can be 60 cm × 50 cm × 150 cm, and some irradiators are designed to irradiate entire pallets of product, 120 cm × 100 cm × 150 cm. The dose uniformity ratio would be significantly larger than unity for such large containers. However, for a large majority of applications, there is fortunately a wide window of dose that is acceptable to achieve the desired effect without detrimentally affecting product quality. For example, the dose limit ratio is between 1.5 and 3 for many applications, and sometimes even larger, depending on the product and the process.

There are necessity needs to develop Pravion new irradiators through improving their designing elements and also use the modified Canadian old irradiators where the vertical motion system of, cobalt-60 radiation source rack and product transport system (the developed horizontal mechanical system to prevent stick accidents with radiation source rack inside old Canadian designs) that is considered the first development to site inside Previon irradiation room where the product containers are trance safely on modified (moveable conveyor system) for irradiation processing with calculated dose of gamma radiation to maintain the best irradiation processing with not dinger stick.. The major designing elements of new modified industrial irradiator include.

-Irradiation room has interior dimensions = width X length X height = 6 mX 8m X 4 m.

-Calculated clean concrete shielding.

-Calculated concrete mazes for different irradiation uses.

-Concrete shielding storage pool (dry or wet)

-Cobalt-60 radiation source rack.

- Source hoist mechanism,

-Irradiation room is surrounded by calculated concrete shielding .without moving any concrete shielding wall, where moveable concrete shielding and rotating concrete door will be modified inside new modified Pravion Irradiators...

- Control console (room) that will be modified through adding (P.L.C) micro programmable logic controller system to move the modified moveable horizontal conveyor system far from radiation source rack to prevent stick between radiation source rack and metallic product containers (totes) inside irradiation room.,

- Product transport system (mechanical conveyor system through the necessary concrete shielded mazes which will be designed in Pravion irradiator .to trance products inside and outside the modified irradiator.

The development stages of new Canadian irradiators (Pravion) in Brazil.

The sciences of shielding penetration and design engineering are used to design new separate traces (new calculated mazes) inside new Brazilian irradiators (Previon) through penetrating calculated concrete shielding depending on maze legs and bend on more than right angle bend where Fig (6) show Pravion irradiators without any maze. Each closed new irradiator is modified by adding new calculated mazes for operator's movement and irradiation mass production to verification does attenuation in two-legged concrete ducts for gamma radiation. A new calculated trace (maze) is designed to pass product containers inside and outside each Brazilian new irradiator during irradiation processing, and. moveable concrete shielding wall and rotating concrete door are prevented from their motion (movement). Fig (12) shows the developed design of Pravion new irradiator leads to maintain radiation safety standards inside and outside it. Radiation safety is maintained for operators, irradiation processing and radiation environment outside the modified new design depending on different maze designs (shaped ducts) are shown in fig (7). Also it must use the modified Canadian old irradiators where the vertical motion system of, cobalt-60 radiation source rack and product transport system (the developed horizontal mechanical system to prevent stick accidents with radiation source rack inside old Canadian designs). That is considered the second development to construct inside modified Previon irradiation room where the product containers are trance safely on modified (moveable conveyor system) for irradiations processing with calculated dose of gamma radiation and with not trance. The heavy concrete wall (moveable concrete shielding) is prevented to move and leads to maintain the best irradiation processing. Fig (12).shows radiation room (1) dimension (6X8X4) m, operators and products main maze (3), the second products maze (4) ,storage pool (2) and irradiation room (1).

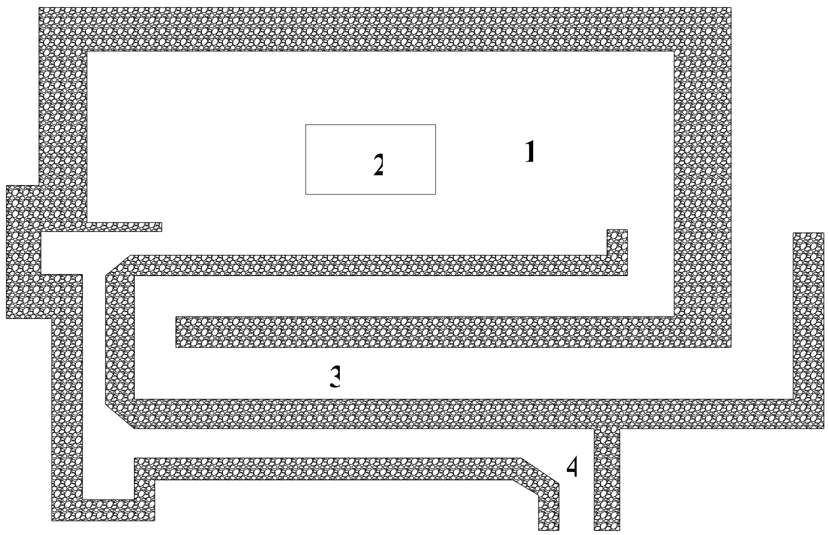


Fig. (12). New Brazilian irradiator (Pravion) is modified to multi uses irradiator. [1]

3. Conclusion.

New irradiator models (Previon) in Brazil are developed to become multi uses irradiators by designing new different maze designs to improve different operation systems, radiation safety and irradiation processing. Irradiation processing qualities inside Pravion irradiators are increased by using the modified design of the horizontal mechanical conveyor system (which were modified in old Canadian irradiators) to trance product boxes around irradiation source rack to maintain the best irradiation exposure. Radiation shielding penetration and designing engineering sciences are applied inside new irradiator designs(Pravion) in Brazil to maintain the necessity goal through preventing transport big masses of heavy moveable concrete shielding , or rotating concrete door and prevent probability of gamma radiation leakage through gaps between moveable concrete shielding components which were built in 2003 and 2007. Stick accidents between vertical radiation source rack systems and product containers on horizontal conveyor systems of old Canadian irradiators are prevented through modifying horizontal mechanical conveyor systems to become moveable and are used in Brazilian designs. New Brazilian irradiators are modified and become safer.

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