Design Assessment 0F Cobalt-60 Irradiator Leads to Prevent Operation Problems and Maintains Development of Radiation Safety

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Abstract: A necessity need to re- assessment dinger stick accidents which were recorded inside industrial irradiators on worldwide through last four decades, causing bad results on their future operation especially overlap metallic container irradiators. Safe operation needs to maintain safe falling for radiation source rack inside storage pool. Operators usually use the gravity (repetition old idea) to raise radiation source rack over irradiator concrete roof and leave it to fall under gravity to strike with plocked metallic container, to free radiation source rack. The work leads to prevent using the gravity idea, to prevent dinger strike between radiation source racks (vertical motion) and an edge of metallic containers (horizontal motion), which leads to repetitions falling cobalt-60 radiation capsules (pencils) from their modules positions, causing very bad results on irradiator systems, environment and also leads to use and new scale small irradiators (Brevion). The work shows a proposed electrical control system P.L.C (programmable logic controller) which is located outside industrial irradiator to operate and control a modified (moveable) mechanical design which is constructed on the mechanical conveyor system inside irradiation room. Any moveable inner shelf was carried by metallic containers and the jammed one (main horizontal motion on conveyor system). The moveable shelve will move far away radiation source rack (vertical motion) caring the jammed container whom will be trance outside irradiator by operators to prevent dinger sticking. And also prevents the dinger repetition falling of cobalt-60 radiation pencils inside storage pool. The work shows also modified designs for (modules, rack and source shroud) to prevent the probability for dinger bending or broking cobalt-60 radiation pencils and also preventing water contamination inside storage pool.

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1. Introduction

Tables (1, 2 and 3) show some recorded radiological accidents occurred in different industrial irradiators (wet storage and dry storage) around the world. These irradiators were manufactured by eastern and western companies and were located in different countries under supervisions of I.A.E.A. (1, 2). Bravon small scale irradiator are designed by Canadian Nordon Company and is constructed in Brazil after stick accidents to prevent bad effects on each of source rack components in industrial irradiators (3, 4).

Cobalt 60 is the main radiation source and are contained by doubly encapsulated stainless steel source pencils approximately 45cm long, with solid stainless steel end caps approximately 1cm in diameter (5-7). Each source pencil is identified by a serial number engraved on an end cap. The radiation source pencils and dummy (non radioactive) source pencils are loaded into source modules in such a way as to maintain a uniform distribution of activity at the irradiation positions (1, 8,9). They are held in place by channels at the top and bottom of the source modules. Fig (3) shows a schematic diagram of source rack pencils.

Vertical and horizontal mechanical systems

The vertical mechanical system (source hoist mechanism)

The radiation source is raised from the storage pool to the irradiation position by pneumatic hoist mounted on irradiator's roof (radiation concrete shield) (10). A stainless steel hoist cable is attached to moveable source rack, and it begins from concrete shield at bottom of storage pool and passes through the roof concrete shield to two sets of sheaves in the hoist cylinder that are moved by pneumatic pusher (3,11).

The source rack movement is guided by two taut guide cables, on at each end of the rack. On being raised, the piston guide of the hoist cylinder actuates a micro switch that mounted on the hoist cylinder to indicate that the source rack is no longer down, thus for any other position of the source rack than fully down, the micro switch should indicate that the source rack is up as shown in Fig (2).

When air is exhausted from the source hoist, the source rack is returned under gravity to the safe storage position in the storage pool. The source rack weight pulls the sheaves in the hoist cylinder back together, and the micro switch is deactivated to indicate that the source rack is down (12,13).

The horizontal mechanical system (product transport mechanism)

The product boxes (metallic containers) are trance inside irradiation room by pushers. They move on roller conveyors. They are irradiated in steps margin in from 35-57 according to the facility design. They are moved by pistons of the product transport mechanism. They are moved around the source rack allowing four rows, two on each side of the source rack, on each of two levels and are raised or lowered from the upper to the lower level by a pneumatic elevator. Steel product guides restrict the movement of product boxes to the path around the source and provide some protection to source rack. The pistons which push the product boxes are located around the mechanical system to control the process sequence by means of a relay logic panel (10, 13,14).

(Piston plate is pushed by air pressure) and maintains pushing on a body (product boxes) at rest or moving uniformly will change its state (the product boxes will move on a horizontal straight distance (step) that equal 45cm in the positive direction on the conveyor system (14,15)

2. Materials And Methods

Different products are sterilized inside different industrial irradiators on internal mechanical transport systems which trance product boxes or (metallic containers) in controlled manner, close to an intensely Co-60 radiation source inside industrial irradiator. Different systems are located inside irradiation room which is surrounded by calculated high density reinforced concrete. Dry-storage irradiator has dry storage and wet-storage irradiator has also wet one which is constructed from concrete.

Sticking accident

Following a jam in the product transport systems as a result of sticking between radiation source rack and product metallic container on mechanical conveyor system. The operators entered irradiation rooms (dry or wet) irradiators to clear the faults; at this point, the sources are thought to have been in the safe positions. However, on entering radiation room of an irradiator the operator bypassed a number of safety features and left the controls of control system in a radiation position such that exposure was imminent (16-18).

The source rack becomes exposed (irradiation position) and the operator is irradiated for about 1 minute or more. The operator will be taken into a special medical care. It will been estimated that operator has received a whole body dose more of 10 Gy, with localized areas of up to 20 Gy (19, 20).

When the main door is not opened from outside, casing stick accident(source rack jamming) that leads to bad effects on different operation systems inside irradiation room through firing product boxes (19-23).

Tables (1-3) Sticking Radiation Accidents were recorded on worldwide through last four decades.

Table (1):The recorded radiation accidents through last four decades.

IRRADIATOR ACUTE (Cobalt-60 Sources)		**RADIATION**		**ACCIDENTS SYNDROME**
Year	**Place**	**Irradiator Type**	**Dose (Gy)**	**Death**
1974	**Parsippany NJ, U.S.A.**	**II**	**1.9-4**	**NO (?)**
1975	**Brescia Italy**	**II**	**> 10**	**After 12 days**
1977	**Rockaway NJ, U.S.A.**	**II**	**1.5-3**	**NO**
1982	**Kjeller, Norwway**	**II**	**10**	**After 13 days**
1989	**San Salvador, El Salvador**	**IV**	**8.1**	**After 190 days**
,,	,,	,,	**3.7**	**NO; two legs amputated**
,,	,,	,,	**2.9**	**NO**
1990	**Tel Aviv, Israel**	**IV**	**10-15**	**After 36 days**
1991	**Byelorussia**	**IV**	**10-15**	**After 113days**

Table (2) :Safety conditions upon entry of each irradiator.

SAFTY CONDITIONS UPON ENTRY					
ACCIDENT	**REASON**	**SOURCE INDICATOR LIGHT**	**ALARM**	**DOOR INTERLOCKS**	**ROOM AND MONITOR**
USA 74	JAM?	Shielded	None	None	?
Italy 75	JAM	?	?	?	?
USA 77	JAM	Couldn't see	?	Bypassed	ON
Norway 82	JAM	Shielded	ON	1) Out of order 2)Failed	Out for repairs
ElSalvador 89	JAM	Intermittent	ON	Tampered	Removed
Israel 90	JAM	Shielded	ON	Ok	Ok
Byelorussia 91	JAM?	?	?	?	?

Table (3): Operators actions to enter irradiation room during each radiation accident

WORK ACTION TO ENTER ROOM				
ACCIDENT	**Dosimeter**	**ALARM**	**DOOR INTERLOCKS**	**PORTABLE MONITOR**
USA 74	?	?	N/A	NO
Italy 75	?	?	?	NO
USA 77	?	?	N/A	NO
Norway 82	YES	Turns off	N/A	NO
ElSalvador 89	NO	Turns off	Bypasses (cable hoist)	NO
Israel 90	NO	Turns off	Bypasses (Disconnects room Rad Monitor)	YES (out of order)
Byelorussia 91	NO	?	?	NO

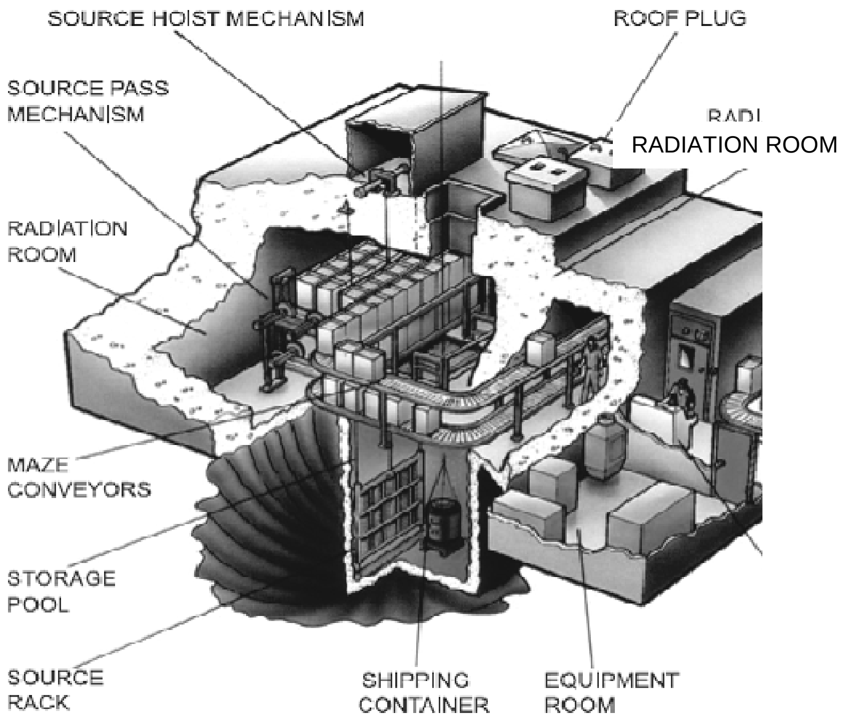


Fig (1) :Schematic diagram of a typical panoramic, wet storage irradiator.

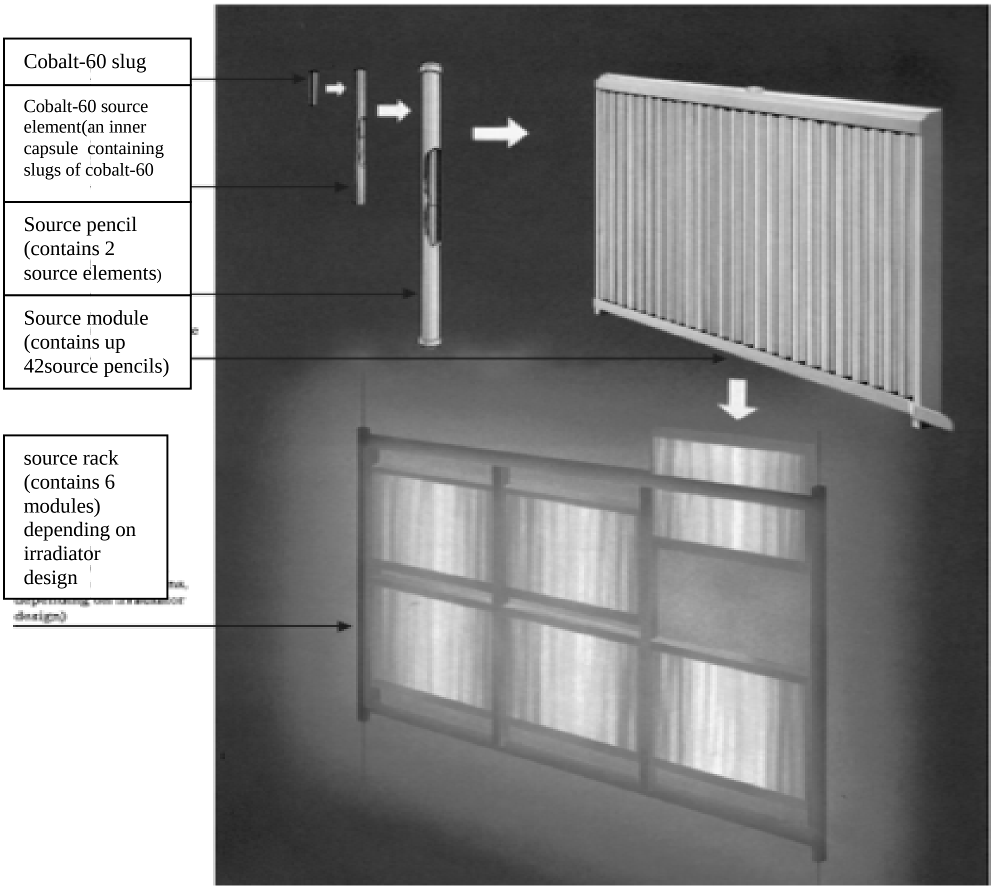
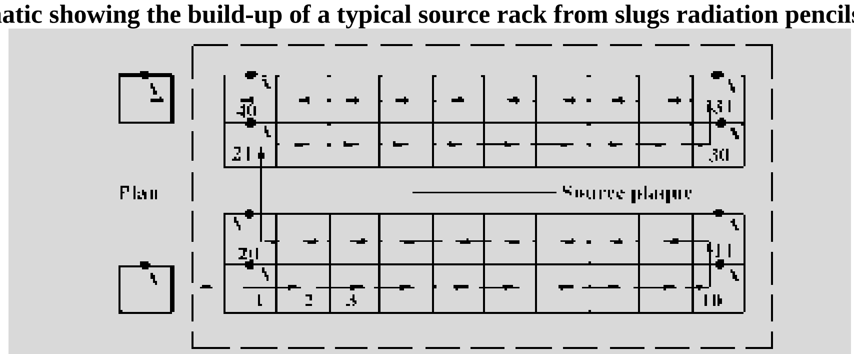
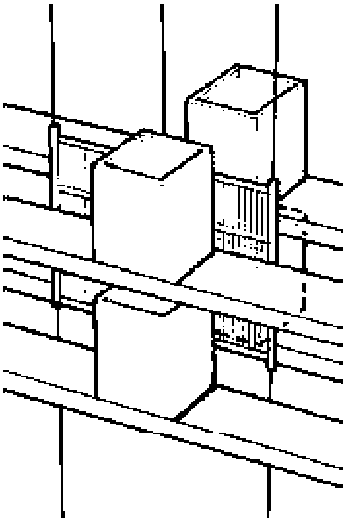


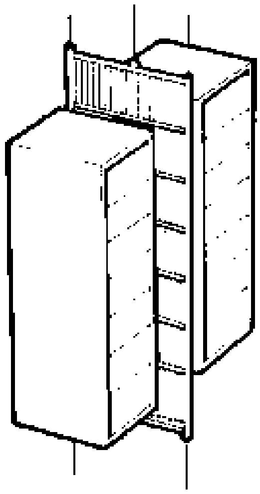
Fig (2): Schematic showing the build-up of a typical source rack from slugs radiation pencils and modules.



Irradiation chamber

Fig (3): A sequence of irradiation for a shuffle-dwell irradiator for 4 passes, single level. Each product container occupies each of the 40 positions in sequence before exiting the irradiation room. (A) is a fixed point on the side surface of the container, which indicates the orientation of the container with respect to radiation source rack (plaque) as the container passes around radiation source where, each container is irradiated twice from each of two sides.





Product overlaps **Source overlap**

Fig (4):Types of irradiation geometry product overlap and source overlap. The product-overlap arrangement, the combined height of two containers is more than the height of the source rack and each container travels at two levels. For source –overlap arrangement, the height of the source rack is more than that of the product container and each container travels at one level only.

2. Work Ideas

1-The dynamical Mechanic laws are used to calculate the value of falling force of cobalt-60 source rack under gravity effects depending on some main elements (24-29).

2-The using of a proposed micro control system or P.L.C which is located outside an industrial irradiator to operate a proposed moveable mechanical system.

3-The proposed (moveable) mechanical system will be moved far away stick radiation source rack carrying jammed metallic container far from stick radiation source which will be free from sticking by metallic container and also will fall safely inside storage pool .Stick accident will be solved and main door will been opened safely from outside irradiator to repair and jammed metallic container will trance outside irradiator.

4-The proposed P.L.C (programmable logic controller) will use also to return the proposed moveable mechanical system to normal operation position inside irradiator, and irradiation processing will been contained by control panel (25-30)..

3. Work Technique

It depends on three main proposed stages, where the first depends on dynamical calculation for falling force of source rack by gravity and its dinger strike between source rack components and metallic container edge. The first design is a new (moveable) mechanical conveyor system that will be sited inside an irradiation room. When radiation source rack falls (by gravity) it will been stick by a product metallic container (that will be noticed from outside irradiator by control panel and continues sound from irradiator ring).Through using the second proposed design (the proposed control system), the moveable part of mechanical conveyor system will been moved far from radiation source rack and caring jammed metallic container, then radiation source rack will be free and will trance safely to safe position inside storage pool (jamming stick accident will been solved). The main door will open safely from outside to repair through changing and trance the jammed metallic container outside irradiator.

3. Results and Discussion

Proposed Electrical control system and proposed mechanical control system are used to develop industrial irradiator (J.S9500) wet storage, which leads to prevent dinger stuck accidents between radiation source rack system and metallic container system.

Electrical Control system:

It consists of a video display, keyboard, printer (data logger), and a proposed programmable logic controller (PLC). The control system, its functional operators and indicators ensures that the irradiator operates safely and efficiently. A video display and printer provides the operators with complete irradiator status including safety and different logic conditions. The Programmable Logic Controller (PLC) controls irradiator's operation through using solid state relays, switches. Micro switches and various input and output devices. A cabinet located outside irradiator in control room which houses (contained) the PLC interfacing terminals and different relays. Operating Controls – Timer Controls- Master Control Timer- Overdose Control Timer- Under dose Control Timer- Off Tute Timer – Indicator Lamps-PLC control Panel-Machine Key switch.

The proposed programmable logic control system

The proposed electrical control design (Micro Control or P.L.C or modern control system) will allow from outside an industrial irradiator to control and operate (the new proposed moveable mechanical conveyor system)whom is located inside irradiation room. Two proposed moveable shelves of conveyors system will be moved where the inner one of them has been carried by jammed metallic containers (horizontal motion) far away radiation source rack (vertical motion) to prevent dinger stuck accidents between these developed systems. Active results will maintain through using these two modified designs where the source rack components will trance safely by gravity inside the storage pool with not each of dinger stacking and jamming with metallic container, with not dinger falling cobalt-60 radiation pencils and not bending or not broking cobalt-60 radiation pencils. The main door will open safely from outside and operators will enter irradiation room to trance jammed metallic container outside irradiator. The new modified control system will be used also to return the moveable (modified) mechanical system to the safe operation system. Sticking and jamming are prevented and irradiation processing will start by main P.L.C.

Different development engineering stages are used-to prevent dinger stuck between radiation source rack and metallic containers on the four inner-shelves of mechanical conveyor system inside irradiation room (31-34)

1-The dynamics laws of Mechanic science are applied to deal with moving systems (bodies) which are (radiation source rack and product boxes) under the action of some forces which were caused by a pneumatic hoist and air pressure pushers leading to dinger stick and jamming between them. Calculation the value of falling force of source rack under gravity depending on the relative velocity, straight motion with uniform acceleration, vertical motion under gravity "g = 9.8 m/sec2" (Newton's laws of motion) to calculate the falling force value of source rack under gravity(24).

I – Motion of the source rack without jamming (general cause)

∴ The mass of radiation source rack = 200 Kg

Vertical (distance) between the source rack and water surface is = 1 m.

Storage pool depth is = 4.5 m.

Before impact (normal case)

∴ Calculation of the velocity of the source rack before impacting by the water surface of storage pool.

$V^2 = U^2 + 2gs$ (6) (Newton's laws)

$V^2 = Zero + 2x9.8x1$

$\therefore V = 2\sqrt{5}$ m/sec down wards 1

After impact

$V_1^2 = U^2 - 2aS \quad a = \frac{U^2}{25} = \frac{20}{2x4.5} = \frac{20}{9}$

$\therefore a = 2.2\ m/s^2$ -----> 2

The acceleration is in the opposite direction of the source rack velocity.

Then: the force causes the acceleration up Towards also like the acceleration direction.

Force cause acceleration

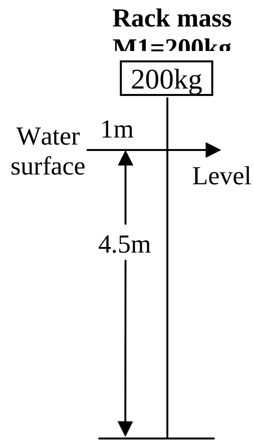
= liquid "water" resistance – weight.

∴ F = R - ma (Newton's laws)

From 2

∴ 200 x 2.2 = R - 200x 9.8

∴ R = 200 (2.2 + 9.8) ∴ R = 2400 Newton



Secondly impact case.

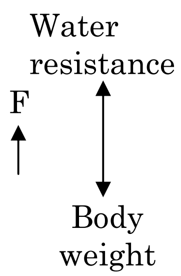
The radiation source jamming

"**The stuck of radiation source rack**".

The radiation source rack

Falls down gradually under the gravity effect.

It was jammed by the product box at distance = 0.1 m



From its normal irradiation position. The two bodies (radiation source rack and product box) move down as one stuck body for small distance = 5 cm (before impacting and jamming).

$\therefore V_1^2 = U^2 + 2gS$ (6)

V^2 = zero + 2 X 9.8 X 0.1 $\therefore$ V = 1.4 m/sec

Source rack velocity before impact = v = 1.4 m/sec

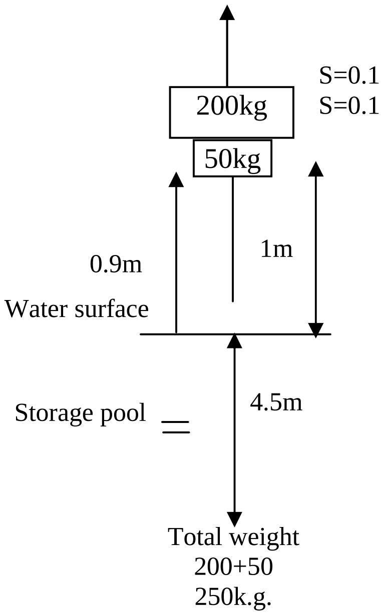
m1v1 + m2vx = (m1 + m2) V

200x1.4 + 50 x zero = (200+50) V $\therefore$ V = 1.12 m/sec

Velocity of the two bodies after impact.

$V_1^2 = U^2 - 2aS \quad 0 = (1.12)^2 - 2\,a x 0.05$

$$\therefore a = \frac{(1.12)2}{2x0.05} = 12.544 \text{ m/sec}$$



B – Jamming of radiation source rack

and product box on lower shelve.

Force cause acceleration =

Reaction of jammed box-total weight.

$\therefore$ total weight = radiation rack weigh + jammed product box.

= 200+ 50 = 250kg

$\therefore$ 250x12.544 = Reaction R- (250x9.81)

$\therefore$ R = 5586 Newton = 570 Kg.

Important: the reaction effect is more than the source rack weight and more than the two bodies' weights (radiation accident).

The source rack was stopped after impacting at a distance of 5 cm.

2-Determining the dinger position of radiation source rack

When source rack was blocked by an edge of metallic container and was prevented to trance to safe position inside storage pool causing stuck accident (24).

- The pusher's pressure pushes the product boxes (metallic containers) on its proposed (moveable) conveyor of the four mechanical conveyors which are located on the two sides of the source rack to bulge burst and disrupted product boxes the adjacent conveyor. Pushing the product boxes which are protruded towards the radiation source rack causing dinger effect.
- The overdose timer detected the jam and the source rack began to descend but the source rack was blocked by a metallic container (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 the source rack system causing the rack releasing and also fitting the steel guide bars, and leading to the stuck of the radiation source rack that prevents safely falling of source rack.
- The safe allowing distance between the radiation source rack system 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.
- Metallic container (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 radiation accident (Fig. 6).

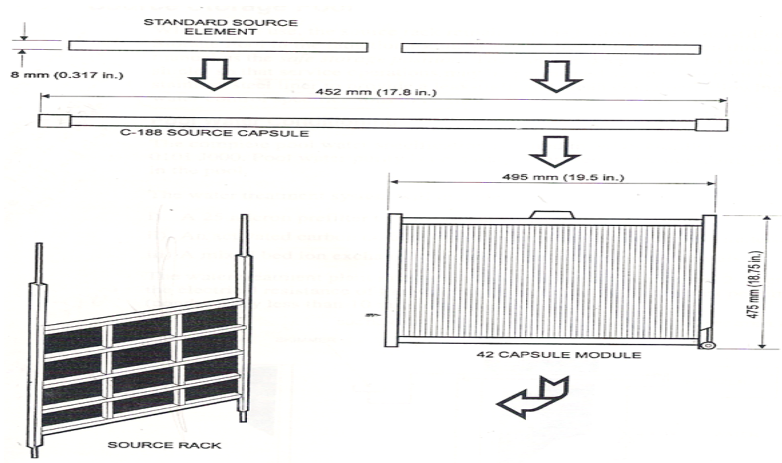


Fig (5) radiation source racks components.

3-An operator must go on irradiator concrete roof to notice the microswitch was out of adjustment and did not actuate reliably when the roller moved out of the indent. It was concluded that the adjustment of the microswitch did not allow sufficient over travel when the source rack was raised, and the switch consequently continued to indicate that the source rack was down. As is discussed in this work, there are other safety systems to prevent access while radiation source is exposed, and these would have called into question the validity of radiation source down indication from the microswitch. In such a situation, an operator with knowledge of maintenance procedures could go to the concrete roof to check whether the roller was in its indent. That the roller was not in the indent would indicate that the source rack was not safely down (jammed).

4- The operators rise radiation source rack and must use the modified P.L.C to move the proposed (moveable) conveyer system (horizontal motion) far from radiation source rack (vertical motion). Radiation source rack system become free and it will trance safely inside storage pool and all its important components are safe and bad effects are not recorded on them (Fig 6).

5-The main door will open safely from outside by control panel, operators will enter irradiation room to trance the jammed metallic container outside irradiator. 6- The proposed P.L.C will been used to return the modified (moveable) mechanical system to its safe operation position on the conveyor system. Irradiation processing will start by normal operation through using P.L.C. which located outside industrial irradiator beside control panel.

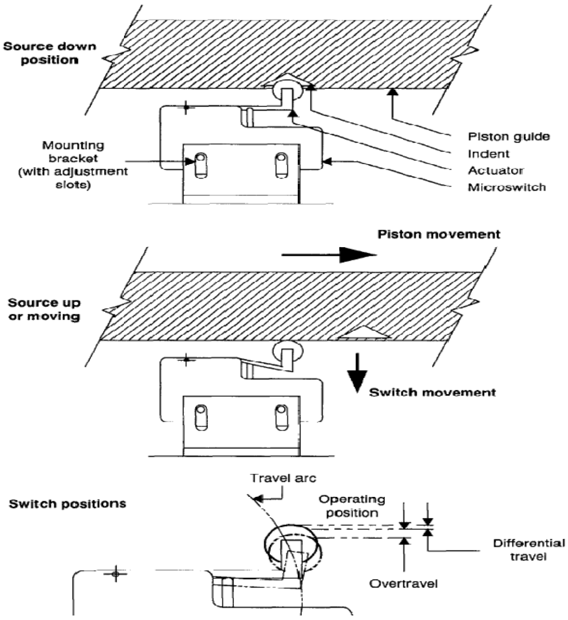


Fig (6): Diagram shown the working of the L.S-109 limit microswitch mounted on the hoist cylinder to indicate when the source is down.

There is necessity needs to increase interior dimensions of irradiation room for any new western irradiator to maintain development because dimensions of western irradiation room are smaller than the eastern one for the same category and activity. Irradiation room of western irradiator needs to maintain development through increasing its interior aria to maintain easily different developed mechanical system.

This work shows also developed designs for steel product guides, source shroud, modules, and rack farms to prevent continuous falling of radiation pencils from modules of source racks inside storage pool as a result of repetition sticking between source rack and metallic container causing very dinger effects inside irradiator. Steel product guides on mechanical conveyor system restrict the movement of product boxes to the path around radiation source rack and will provide active protection to source rack through increasing the thickness of the steel guide to increase the empty calculating distance between radiation source rack and metallic container that will lead to prevent stuck between radiation source rack (vertical motion) and metallic container (horizontal motion).

-Development of stainless steel modules and stainless steel rack that will been maintain by constructing two small metallic guides on upper and lower edges for each modules row on source rack frame, which will lead to prevent the dinger falling for cobalt-60 radiation pencils inside storage pool and will prevent bending or broking cobalt-60 pencils.

Modified metallic container.1- A modified aluminum container is a solid metal more than carton boxes which were used before and very bad effects are recorded on source rack components (Rack- modules- cobalt-60 radiation pencils and stainless steel dummy pencils). The metallic container needs to maintain a new design by modifying its surrounded envelope that was located on outer container edge and will lead to prevent repetition strike with source rack and to prevent distortion each of source rack components envelope and outer envelope of metallic container edge. The repletion falling cobalt-60 radiation pencils from its positions inside different modulus will be prevented.

Conclusion and Recommendations

Increasing radiation safety of cobalt-60 industrial irradiators (overlap metallic containers J.S9500) are maintained in this work through preventing dinger strike between radiation source racks (vertical motion) and an edge of metallic containers (horizontal motion) which lead to prevent repetitions falling cobalt-60 radiation capsules (pencils) from their modules causing the best results of (J.S9500) irradiator systems, environment and also prevent using new small irradiators(Bravion small scale) in mass production. The work shows also a proposed electrical control system P.L.C (programmable logic controller) which is located outside industrial irradiator to operate and control a modified (moveable) mechanical design which is constructed on the mechanical conveyor system inside irradiation room. Any moveable inner shelf was carried by metallic containers and the jammed one (main horizontal motion on conveyor system) will move far away radiation source rack (vertical motion) caring the jammed container by proposed P.L.C. The jammed container will be transported outside irradiator and irradiation processing will be started..

The work shows also modified designs for (modules, rack and source shroud) to prevent the probability for dinger bending and broking cobalt-60 radiation pencils and also may preventing water contamination inside storage pool by effect of broken cobalt-60 radiation pencils.

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