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Assessment of Co^{60} Industrial Irradiators According to Basic Design Principles

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ABSTRACT: Ensuring safe and easy operation, providing relative uniform dose in the product and maximizing radiation utilization are the basic design principles for each Co^{60} industrial irradiator to maintain radiation safety. The study shows an assessment for four industrial irradiators to determine which active results were been maintained by using basic design principles. Different designs elements of the chosen irradiators have been illustrated and studied. The study shows that IRASM and ROBO industrial irradiators satisfy all basic design principles. IAEA-NR3772 irradiator maintains only two of the three basic design principles and does not ensure safe operation because radiation leakage from inside irradiator to outside environment due to rotating door. Brevion irradiator satisfies only the principle of relative uniform radiation dose in product. The other two principles had not been satisfied by the effect of sliding door and its batch operating mode. Without affecting radiation safety, this study proposes a new design of the irradiator to maximize energy utilization by adding a new track for low density products and also a static irradiation for cultural heritage beside the main track of high density products.
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Keywords: Ensuring safe and easy operation, providing relative uniform dose in the product, maximizing radiation utilization

INTRODUCTION

Cobalt-60 industrial irradiators have many differences in their main design components, activities, applications, etc. but all of them must satisfy the basic design principles.

Basic design principles of any industrial irradiator depend are:

1. Ensuring easy operation and safe radiation processing,
2. Providing relative uniform dose in the product, and
3. Maximizing radiation utilization.

Cobalt-60 is a radioactive material artificially produced by bombarding a target material, either cobalt-59 or nickel -60, with neutrons. This reaction is produced by nuclear weapons detonations and in nuclear reactors. Its physical half-life is about 5.3 years. [1]

Cobalt-60 activity decreases by about 12% annually, this means that it will decay over time whether it was used or not. Maximizing radiation energy utilization principal is related to the total number of products had 2. been irradiated along with Cobalt-60 life before decayed. Irradiating as much products as possible before Cobalt-60 decaying is a top priority to maximize radiation energy utilization.

A uniform dose is needed to achieve the required effect in the entire volume of the irradiated product. It can be achieved easily along the product's depth by irradiating the product at more than one side. [2]

Safe operation means that the operation satisfies all the radiation safety criteria. Easy operation means that it is done without any complications. The third principle is related to the radiation process done in a smooth way without any serious problems. [3]

MATREIAL AND METHODS

Four different industrial irradiators were shown in the present work (IRASM in Bucharest-Romania, IAEA-NR 3772 in Beijing-China, ROBO in Damascus-Syria, and Brevion in Brazil).

1. **IRASM industrial irradiator:** which was constructed in 1993 in Romania and it is considered to be its first industrial irradiator. Its nominal activity is 2 MCi (74TBq). Fig (2) shows a layout of **IRASM** irradiator. [4]

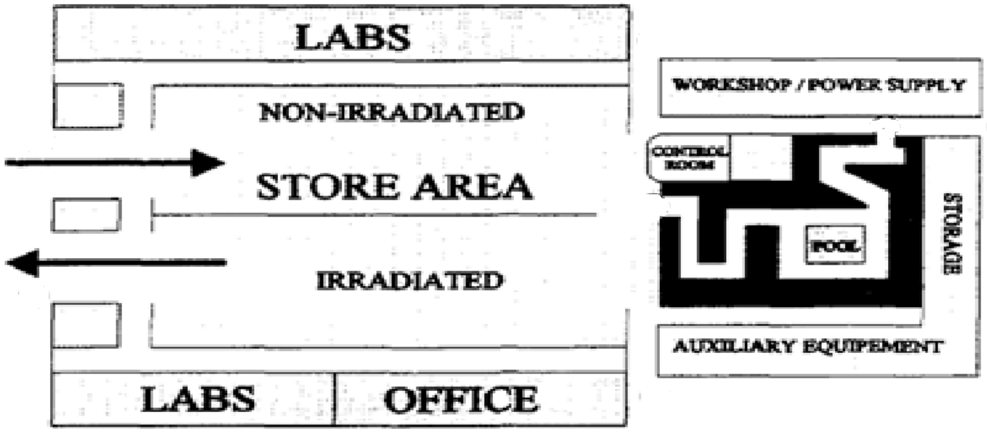

Fig (1) schematic diagram of IRASM irradiator [5]

It uses the free space for irradiating cultural heritage which is varying from paper documents, ancient paintings, wood, textile, etc. An important area was identified near the wall parallel with radiation source, between the personnel and the product entrance (hatched area in Fig (2)).

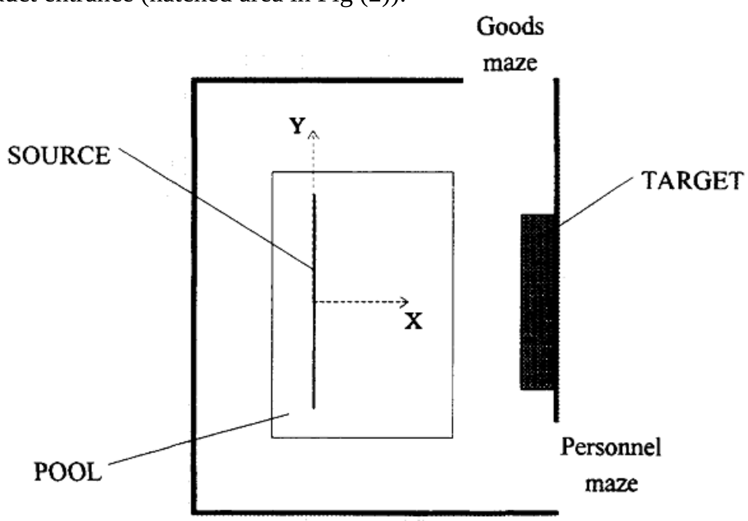

Fig (2) Static irradiation geometry [5]

3. **ROBO industrial irradiator:** ROBO irradiator was constructed in Damascus-Syria. Its nominal activity is 0.5 MCi (18.5 TBq). Fig (4) shows a schematic diagram of ROBO. [6]

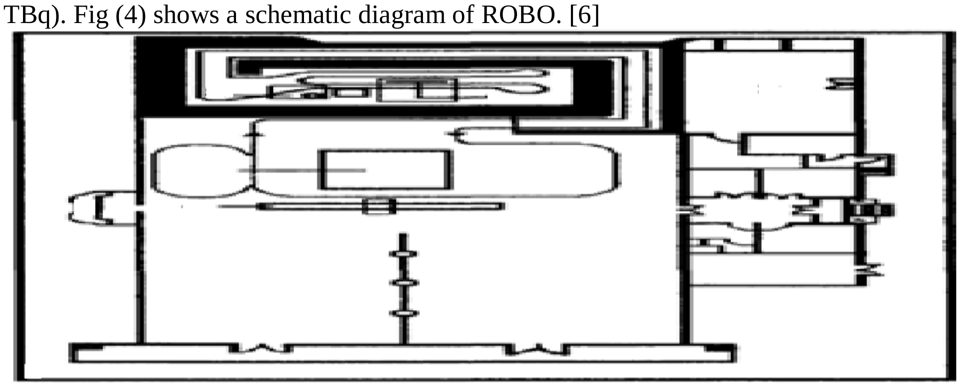

Fig (4) schematic diagram of ROBO [6]

This case study has very important design elements where two storage pool were constructed to maintain safe maintenance for any one of them while radiation source rack will be in safe storage inside the other pool. Fig (5) is a cross section in irradiation room showed the two storage pools (I refers to main pool and 2 refers to auxiliary pool). [7]

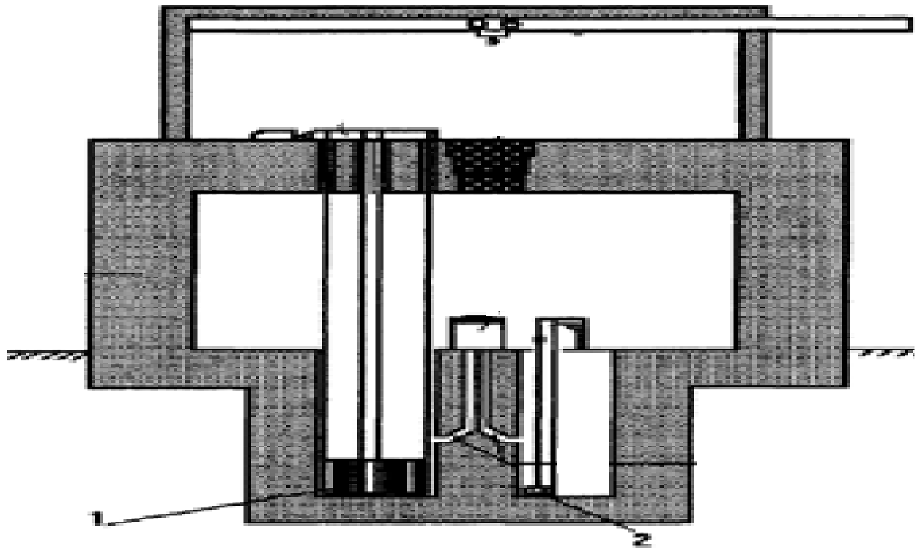

Fig (5) cross section in irradiation room (ROBO) [6]

There is also a 1.5 m safety pit in the end of the first leg of the main maze leading to irradiation room. This pit is closed by push and back plate when the source is stored in the storage pool and opened when the source is raised and in the irradiation position. This pit ensures that anyone cannot enter the irradiation room while the source is in the irradiation position. [7]

4. **IAEA-NR 3772 industrial irradiator:** it was constructed in China and considered one of China's many irradiators (more than 21 irradiators). Its nominal activity is 1MCi (37 TBq). Fig (4) shows a schematic diagram of it. [8]
5.

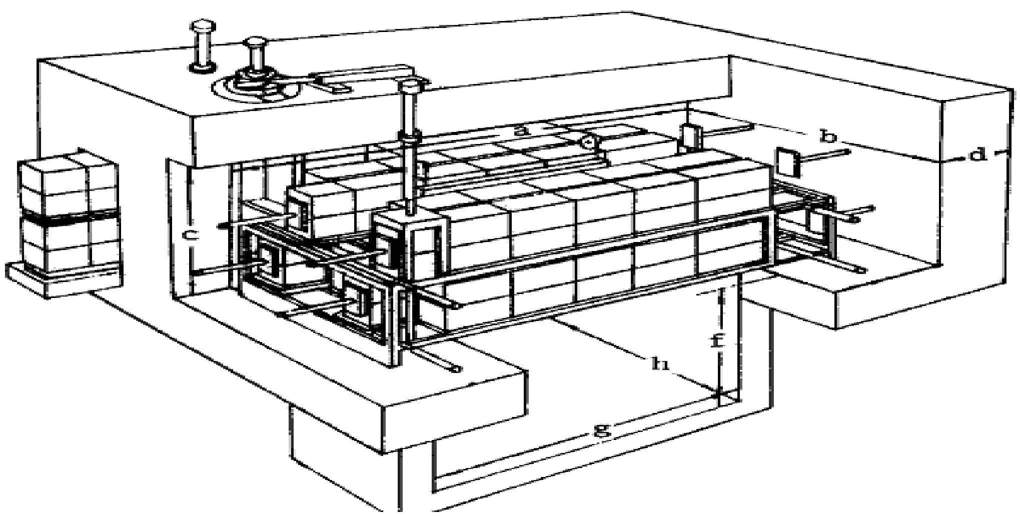

Fig (3) schematic diagram of the IAEA-NR 3772 irradiator [8]

This irradiator has a rotary door for trance the product boxes inside and outside irradiation room. The product boxes enter irradiation room on a mechanical conveyor system through the rotary door that allows passing one product box each time. This irradiator has no maze. [8]

6. **Brevion industrial irradiator:** it was designed for the low-volume irradiation market. This irradiator has a capacity of 1 MCi (37 PBq). Fig (6) shows a schematic diagram of Brevion irradiator. [9]

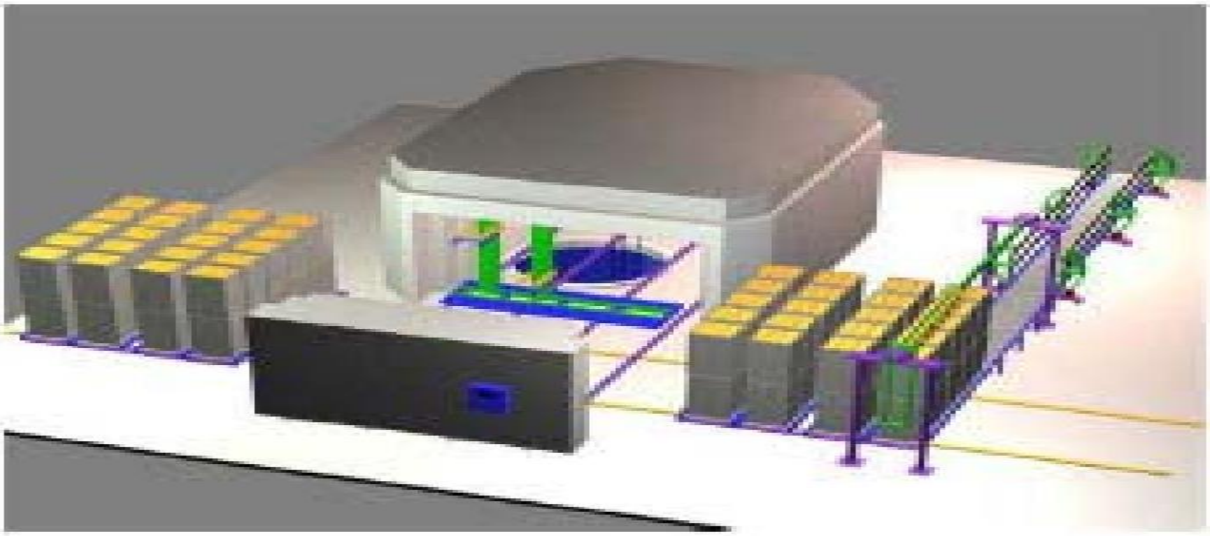

Fig (6) schematic diagram of Brevion irradiator [9]

When product's boxes enter irradiation room, a sliding door (as shown in fig (7)) is trance to close irradiation room and the source rises to irradiation position. After irradiation process, the source lowered to its storage position and the sliding door moves to open irradiation room and unload irradiated products.

This sliding door is constructed, mainly, from concrete and the plug between the sliding concrete door and the irradiation room is in a tooth shape which is bending on right angle to ensure no radiation leakage from irradiation room to outside environment. There is no maze in this irradiator. [10]

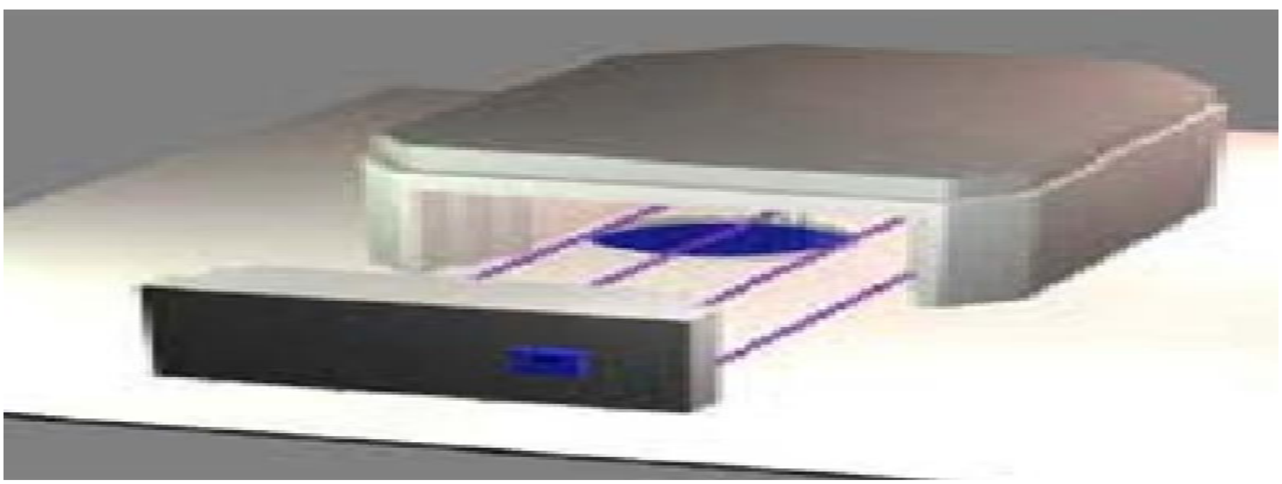

Fig (7) Brevion's unique door design [10]

RESULTS AND DISCUSSION

Table (1) illustrates the main elements of design the four case studies (nominal activity, application, mechanical transport system, operating mode, irradiation room dimensions, etc.). [4-10]

Table (1) the main design components of the four case studies

No.	Element / Irradiator	IRASM	IAEA-NR 3772	ROBO	Brevion
1.	Country	**Romania**	**China**	**Syria**	**Brazil**
2.	Nominal Activity (MCi)	2	1	0.5	1
3.	Application	Multi-purpose	Multi-purpose	Multi-purpose	Multi-purpose
4.	Mechanical Transport System	Tote-box Conveyer	Tote-box Conveyor	Carrier Suspended	Tote-box Conveyor
5.	Container dimensions(cm)	90 x 24 x 46	50 x 50 x 90	40 x 40 x 50	80 x 60 x 40
6.	Product/source overlap	Product overlap	Product overlap	Source overlap	Product overlap
7.	Operating mode	batch /continues	Continuous	Batch /continues	Batch
8.	Irradiation room dim.(m)	10 x 6 x 3	5.3 x 5.7 x 3	12 x 6.6 x 5	12 x 8
9.	Radiation shielding	concrete	concrete	concrete	Concrete
10.	Shielding thickness (m)	1.7	1.9	1.7	1.8
11.	Maze form	Z-shape	No	U-shape	No
12.	Maze wide (m)	1.7	No	1.7	No
13.	No. of rows/side	2	4	1	2
14.	Storage of source	Wet	Wet	Wet with 2 pools	Wet
15.	Depth of storage (m)	5	5.5	4.8 (for both)	5
16.	Ventilation system	Yes	Yes	Yes	Yes
17.	Static irradiation	Yes (culture heritage)	No	No	No
18.	Stationary irradiation	No	No	No	Yes
19.	Push- back plate with pit	No	No	Exist	No
20.	Maze door	Exist	No	Exist	No
21.	Rotating door	No	Yes	No	No
22.	Sliding door	No	No	No	Yes

The results of comparing between the four irradiators' main component according to basic design principles are:

1. Ensure safe and easy operation:

i. Easy operation means that it is without any complications

There isn't any complication related to operation for the four irradiators. But complications expected for Brevion, because of the sliding concrete door and its friction with the irradiation concrete shielding, and also for IAEA-NR 3772, because of the rotating concrete door and its friction with the irradiation concrete shielding.

As an additional defect for Brevion, the sliding door consumes energy when opening and closing due to its huge weight. This sliding door is constructed, mainly, from concrete with 4.0 m (length) × 4.0 m (height) × 2.45 m (width) with concrete density (2350 kg/m^3). [11]

∴ The weight of this sliding door = 4.0 × 4.0 × 2.45 × 2350 = 92120 kg ≅ 92.1 tons

This weight consumes huge energy and complicates radiation operation.

As an additional defect for IAEA-NR, the rotating door consumes energy when opening and closing due to its huge weight. This sliding door is constructed, mainly, from concrete with 2.65 m (diameter) × 4.0 m (height) with concrete density (2350 kg/m^3). [8]

∴ The weight of this sliding door = $\pi\,(\frac{2.65}{2})^2 \times 4.0 \times 2350$ = 51866 kg ≅ 51.9 tons

This weight consumes huge energy and complicates radiation operation.

ii. Satisfying radiation safety criteria:

IRASM and ROBO satisfy all radiation safety criteria. ROBO has three more additional safety features more than other irradiators, which are:

1) It has only one entrance for both product and personal. This entrance is designed to decrease the penetration of irradiation room for assuring more radiation safety.
2) An auxiliary pool to maintain a safe storage to source.
3) A safety pit to ensure forbidding any unauthorized human entrance to irradiation

room when radiation source is in irradiation position.

Both IAEA-NR 3772 and Brevion did not satisfy all radiation safety criteria.

As for IAEA-NR 3772, the rotary door will record high concentration of gamma radiation outside concrete shielding which passed through gaps between rotating concrete door and radiation concrete shielding. Repeated friction, as a result of continuous entrance of product boxes through the rotating door, may lead to radiation leakage to outside environment. With the absence of maze, the leakage radiation may harm operators outside irradiation room.

Brevion irradiator records very dinger and important notice where the plug between the sliding door and the irradiation room can be damaged by the repeated friction as a result of continuous opening and closing of the sliding door. It may lead to irradiation leakage to outside environment. With no maze, the leakage radiation may harm operators outside irradiation room directly.

2. Provide relatively uniform dose in the product:

A uniform dose is needed to achieve the required effect in the entire volume of the irradiated product.

There is another irradiator, named ROBO, was built in Lama-Peru. There are some design modifications between the two irradiators in connection with the location of the carriers with respect to the source rack and also to each other. Fig (8) shows the irradiation arrangement of carriers around the source rack where first irradiator is Syrian ROBO and second irradiator is Peruvian ROBO. The dimensions are as follows:

For Syrian ROBO : A = 10 cm, B = 40 cm, C = 16.5 cm

For Peruvian ROBO : A = 6 cm, B = 40 cm, C = 12.0 cm

Similar dosimeter commissioning experiments were carried out for both ROBO irradiators to illustrate the effect of these construction modifications. The results indicate that uniformity dose was not conflicted with the distance between the carrier and the source rack (8).

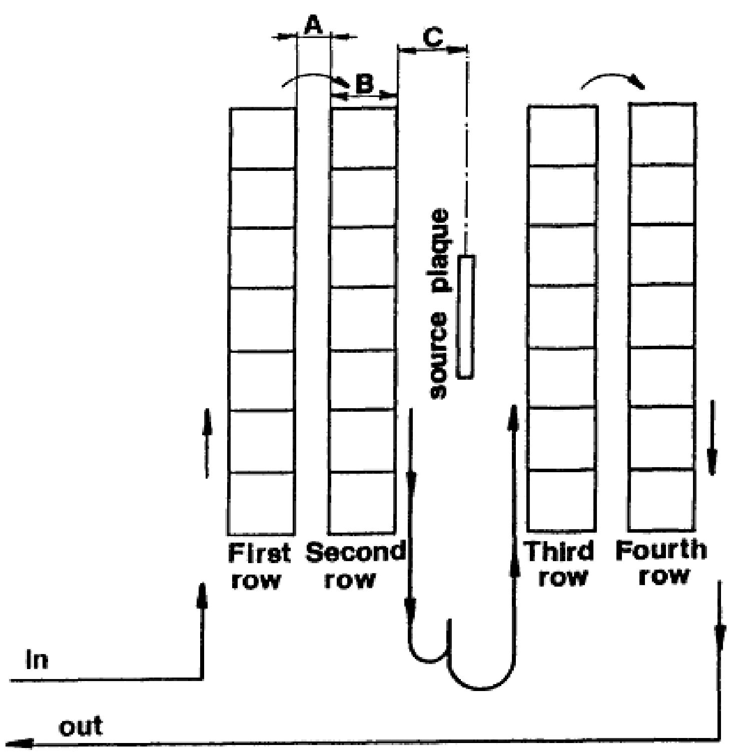

Fig (8) Irradiation arrangement of carriers around the source rack [6]

There isn't any other parameters related to uniformity differs from the one irradiator of the four from the others. Thus, the four irradiators satisfy uniformity principle.

3. Maximize radiation energy utilization:

The most important parameter related to this principle is the quantity of products irradiated by the radiation source in its active period before decaying. Thus,

a. Continuous operating mode is better than batch mode: because it covers more products in the same time interval. According to table (1), IRASM, IAEA-NR 3772, and ROBO designed to be continuous operating mode while Brevion is designed to be batch operating mode only.

b. Scheduled maintenance: it must be predictable and can be planned to be done in as short time as possible. Unexpected problems can stretch time of suspension of the radiation source. Avoiding these problems maximize utilization of the radiation source.

c. Products quantity/source active life: Radiation source activity must be proportional to products to be irradiated (quantity – density) to not waste the radiation energy. Developments must be made for irradiators to maximize radiation energy utilization.

d. Make benefit of free space: There is an extensive space in most irradiation rooms. These spaces must be considered to be used in irradiating products. IRASM is the only irradiator of these four irradiators which make benefit of this free space. It gives an additional utilization of energy emitted from cobalt-60 source by making a static irradiation for cultural heritage.

Culture heritage by gamma radiation in IRASM doesn't add quantity of products to the main products because the main products track stops when irradiating culture heritage. It's related to (value/utilization) ratio rather than (quantity/utilization) ratio. These culture products are considered to be very value to the human kind.

e. Multi-uses irradiator: without affecting radiation safety, another track can be added to irradiate low density products. These low density products can be irradiated in the new track while the main track irradiate high density products. This increases (quantity/utilization) ratio.

As for IAEA-NR 3772 and Brevion, a new track cannot be added because there isn't any maze in them.

As for IRASM, fig (9) shows a suggested design for the new track. This design suggested a new entry (number 2 in the figure) for low density products beside operators' door entry. This new track is suggested to be a carrier type suspended from the roof to avoid interfering between the carriers and operators.

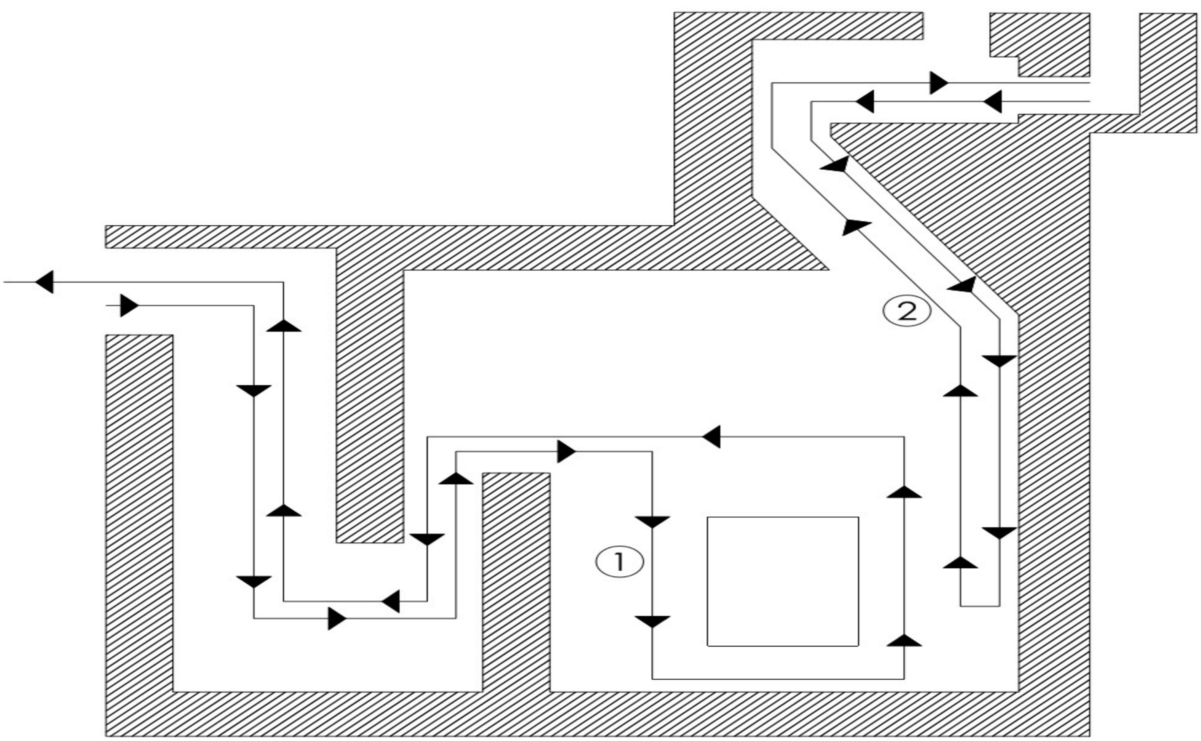

Fig (9) IRASM suggested design for the new track

As for ROBO, fig (10) shows a suggested design for the new track. This design suggested a new entry (number 2 in the figure) for low density products by adding a new maze. This new track is suggested to be a carrier type suspended from the roof.

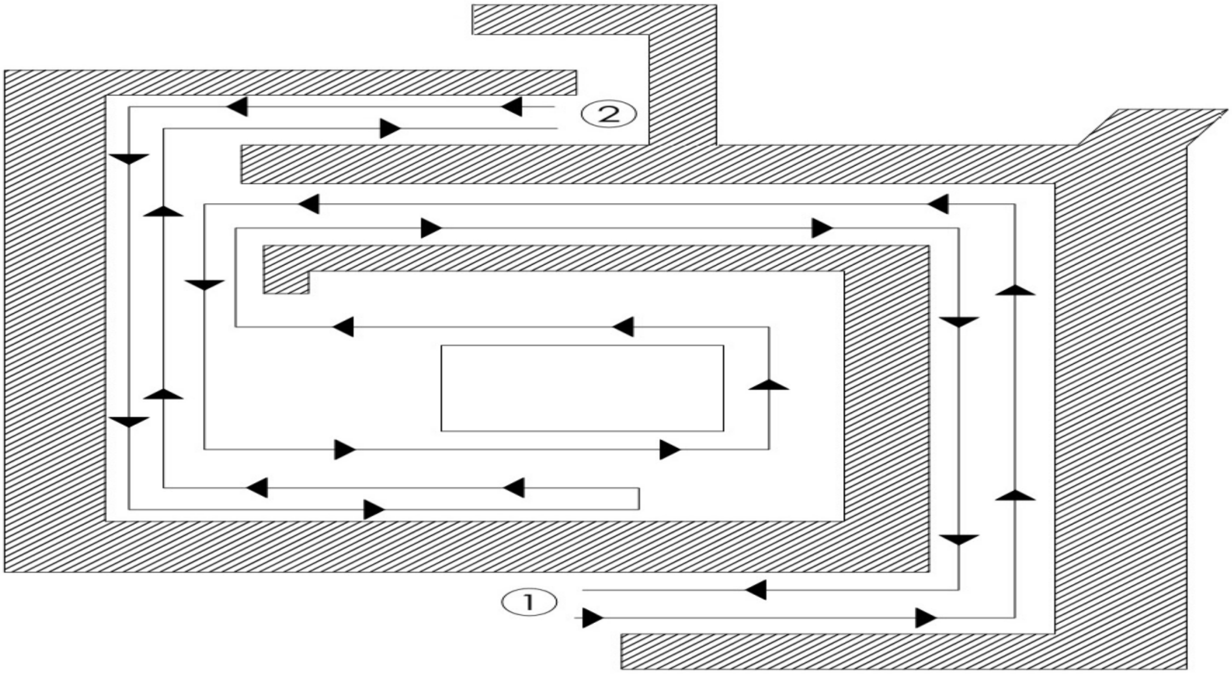

Fig (10) ROBO suggested design for the new track

4. Satisfying Basic Design Principles:

A study of design elements of the four different case studies and table (1) shows that IRASM, ROBO, are satisfying all the basic design principles. But IAEA-NR is satisfying only two of the three principles: maximizing energy utilization and providing uniform process on the product.

Brevion irradiator does not satisfy two out of the three principles which are: ensuring safe and easy operation, as a result of using a sliding door, and maximizing energy utilization (batch operating mode). The only principle that was satisfied is providing uniform process. Table (2) shows the relation between the four irradiators and the three basic design principles.

Table (2) Relation between irradiators and basic design principles

	Ensuring safe and easy operation	Providing relative uniform dose in the product	Maximizing radiation utilization
IRASM	✓	✓	✓
ROBO	✓	✓	✓
IAEA-NR	×	✓	✓
Brevion	×	✓	×

5. A proposed irradiation room:

Adding static irradiation for cultural heritage and new track for low density products for an irradiator maximizes energy utilization of the irradiator. Figures (12, 13) show a plan and side view, of a proposed irradiation room where:

1) The main irradiation track for high density products,
2) New track for low density products, and
3) Static irradiation for cultural heritage.

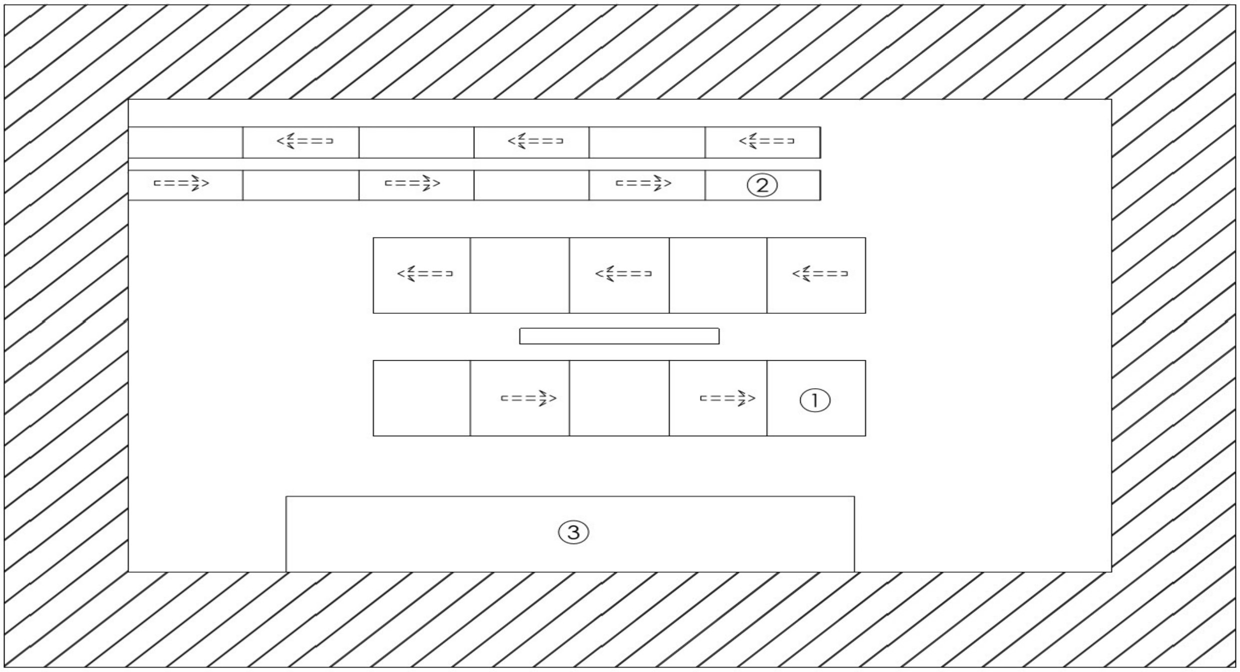

Fig (12) plan for suggested ideal irradiator

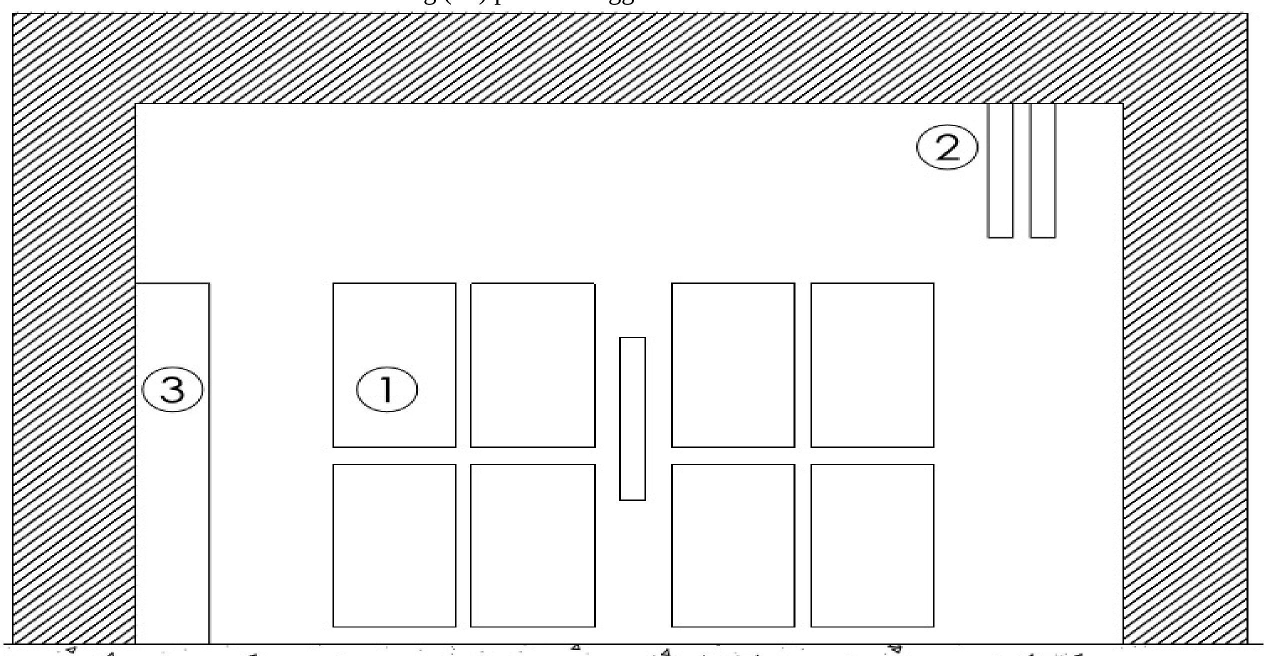

Fig (13) side view for suggested ideal irradiator

CONCLUSION

IAEA-NR industrial irradiator satisfies two of the three principles and doesn't satisfy radiation safety principle where it has bad rotating door and probability of radiation leakage outside irradiation room will be maintained.

Brevion irradiator does not satisfy two out of the three principles where sliding door and probability of radiation leakage outside irradiation room, and maximizing energy utilization due to batch operating mode which limits the quantity of products irradiated over source active life.

IRASM and ROBO satisfy all the basic design principles. ROBO industrial irradiator has additional positive safety features for its design maintaining best irradiation for its category IV. It has an auxiliary wet storage pool, and a safety pit. ROBO irradiation room has the biggest volume among the four case studies where future development designing works are easy done to change to big industrial irradiator.

Without affecting radiation safety, this study proposes adding another track to irradiate low density products while high density products are irradiated in the main track. This study proposes a new design of the irradiator to maximize energy utilization by adding a new track for low density products and a static irradiation for cultural heritage beside the main track.

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