# Shield Calculation Design for Gamma-Ray Sterilizer Plant

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## Abstract

The present calculation covers the building shield during irradiation process and under water storage of three million curries Cobalt-60 radiation source. The calculation results in a design requirement of 8 m depth of water in the source storage pool so that the dose rate on water surface will be $2.8458\times10^{-15}$ Sv/hr, and the Dose rate on the surface of reinforced concrete of 1.70 m thick will be $2.42040\times10^{-8}$ Sv/hr as a maximum and of 1.90 m thick will be $6.6453\times10^{-10}$ Sv/hr as the minimum on the outer surface of the irradiation room building. The entrance doors need to be manufactured of lead of 0.10 m thick so that the maximum dose rate will be $1.3105\times10^{-7}$ Sv/hr and of 0.25 m so that the minimum dose rate will be $8.2307\times10^{-12}$ Sv/hr on the outer surface of lead door .


## 1. Introduction

The gamma strilizer technique is one of high throughput sterilizer for food and medical products sterilization. A plant of such technology needs to consider many different mechanisms of engineering and nuclear science aspects such as in particular a radiation shield [1, 2]. In general, the plant includes major components such as a radiation shield, a Cobalt-60 gamma radiation source, a source operating mechanism, a source pass mechanism, maze conveyors, input and output conveyors, and supporting services equipment [3].In the present work, a radiation shield calculation of three million curies Cobalt-60 gamma source is carried out for installation food and medical sterilization lant n raq. he calculation covers the determination of the dose rate of a radiation source in case of in and out of the water storage pool.

## 2. Theory

The main concern in shield calculation is on the physical properties and related parameters of both the radiation source and/or the shield materials.

### 2.1. Radiation Source

The present three million curies radiation source is Cobalt-60 source which emits two photons with energy $E\gamma1$ =1.17MeV and $E\gamma2$=1.33 MeV, respectively. This sterilizer radiation source consists of a flat vertical plaque carrying Cobalt-60 "Pencils" and it is the form of a rigid rack which contains eight modules. There are 42 source pencils in each module. The total weight of Cobalt-60 per pencil is 112

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gm.The Cobalt-60 is doubly encap-sulated in AECL Type C-188 stainless steel pencils with active length of Cobalt-60 equals to 40.64cm.
The overall length of each pencil is 45.1500 cm and with end caps diameter equals to 1.11cm.
Using the above information, the volumetric radiation source is calculated from the formulated relation as:

$$Sv = 1.31258\times10^{13}\, E\gamma \qquad (1)$$

where,
Sv is the volumetric radiation source in [MeV/cm$^3$.sec], and $E\gamma$ is the emitted gamma-ray energy from the Cobalt-60 source in [MeV].
The total generated heat rate in three million curies is calculated from the following formulated relation:

$$Q = 5.0964\, E\gamma \quad \text{Kcalories/hr} \qquad (2)$$

where,
Q is the total generated heat source in [Kcalories/hr] and $E\gamma$ is the total emitted gamma-ray energy from Cobalt-60 in [MeV].

### 2.2. Gamma-Ray Flux and Dose Rate

The gamma-ray flux photons/cm$^2$.sec due to Cobalt-60 radiation source at any point in the shield is obtained as a result of application of point kernel technique and may be written as [4]:

$$Q\gamma = \frac{S_v}{2m_s} \times \alpha \times e^{-b_1} \times \left[1 - e^{-\mu_s R_s}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where:
$b_1 = \sum_{i=1}^{n} \mu_i d_i$ is the linear attenuation coefficient of the core region, $d_i$ is the width of the i$^{th}$ shield component and $\alpha$ is the average building factors parameter for shield [$\alpha$=B($\mu$r)/$\mu$r]. $\mu_s$ is the linear attenuation coefficient of the source region and $R_s$ is the equivalent source radius; B is the buildup factor.
The dose rate due to the gamma-ray at specified point in the shield is given as [4]:

$$D = F\gamma Q\gamma \quad \text{mrad/hr} \qquad (4)$$

Where, $F\gamma$ is the conversion factor (photon/cm$^2$.sec)$^{-1}$ ×(mrad/hr).

## 3. The Shield of Sterilizer Plant

The reinforced concrete is mainly used as a shield for Cobalt-60 gamma-ray source during irradiation process.The source is kept in water storage pool and can be raised from the storage as needed for irradiation. The dose rates on the surface of the water and/or the reinforced concrete are calculated in order to be in accordance with IAEA recommendations. High concern on safety aspects of personal and equipments is given a priority in shield calculations before and after the use of the source in irradiation process for food and/or medical products.

### 3.1. Water Storage Pool

A water-filled pool is provided in the floor of the irradiation chamber for storage and replenishment of the Cobalt-60 source pencils. The pool water is subjected to certain specification in order to be used as a shield and as a heart removal through a pool water chiller which has a capacity of removing 12.741 Kcal/hr.
The linear attenuation coefficient of water at $E\gamma$=1.33 MeV is $\mu$=0.0612 cm$^{-1}$ and the buildup factor can be calculated by ***Taylor's*** formula [4]:

$$B(\mu r) = Ae^{-\alpha_1 \mu r} + (1-A)e^{-\alpha_2 \mu r} \qquad (5)$$

where, A=17.2949, $\alpha_1$ = -0.0781 , $\alpha_2$ = 0.0232 for water at $E\gamma$=1.33MeV.

The air layers facing the Cobalt-60 radiation source during irradiation process have very low contribution in attenuating of the present intensive gamma-ray source. However, the air is considered as one of the shields media and its linear coefficient at $E\gamma=1.33$ MeV is calculated as $\mu=6.7857\times10^{-5}$ $cm^{-1}$ and the buildup factor is calculated from the following relation [5]:

$$B(\mu r) = 1 + k \times (\mu r) \qquad (6)$$

where , k = 1.1891 at $E\gamma=1.33$ MeV.

The included doors in plant building adjacent to the irradiation room are made of lead which has a linear attenuation coefficient $\mu=0.6245cm^{-1}$ at $E\gamma=1.33MeV$ and the buildup factor is calculated using ***Taylor's*** formula [ Eq.5 ] but with A = 3.7883 , $\alpha_1$ = -0.03495 , $\alpha_2$ = 0.10480 at $E\gamma=1.33MeV$

**3.2. Reinforced Concrete**

A special type of reinforced concrete is considered on basis of mixing specified amounts of ordinary concrete and iron . the mixing process is based on calculating the volume fraction of ordinary concrete and iron using the following relations :

$$\sum_{i=1}^{n} f_i = 1 \quad ; \quad \sum_{i=1}^{n} f_i \rho_i = \rho_{mix} \qquad (7)$$

where, $f_i$ and $\rho i$ (i=1,2,3,4, ..............n) represent the volume fractions and densities of reinforced concrete constituents, respectively .

The linear attenuation coefficient of reinforced concrete is calculated using the computed volume fractions of the ordinary concrete and iron that is :

$$\mu = \sum_{i=1}^{n} f_i \mu_i \qquad (8)$$

The buildup factor for reinforced concrete is calculated using ***Taylor's*** formula [Eq.5] with A=22.9357, $\alpha_1$=-0.0611 , and $\alpha_2$=0.0158 at $E\gamma=1.33MeV$ . These constants are calculated considering both the volume fraction of ordinary concrete and iron as calculated by [ Eq.7 ].

## 4. Results and Discussion

The shield calculation covers different layers in shield media such as water storage pool , air - reinforced concrete combinations , and lead doors . The shield physical parameters and constants are calculated using interpolation at $E\gamma=1.33$ MeV as indicated in the above section [6,7].

The gamma-ray flux and the dose rate at any point in the shield have been calculated using [Eqs. 3-4], respectively .The calculated results of the dose rates for water storage pool , irradiation room , and lead are listed in Table 1 .

## 5. Conclusion

The calculation results exhibit good accuracy as compared with the reported work [3]. The present calculation procedure may be adopted for shield calculation using another gamma source instead of Cobalt-60 such as Cesium-37 gamma source , [$T_{1/2}$ =30.0 year with $E\gamma=0.656$ MeV (85%)].

Table 1 : The calculated dose rates in different shield media such as water storage pool, irradiation room , and lead doors .

| Water Storage Pool | Water Depth | | | | |
|---|---|---|---|---|---|
| | 4 m | 5m | 6m | 7m | 8m |
| Dose Rate (mrem/hr) | 3.5504×10[illegible] | 9.84617×10[illegible] | 2.9687×10[illegible] | 9.120×10[illegible] | 2.8458×10[illegible] |

| Irradiation Room | Reinforced Concrete Thickness * | | |
|---|---|---|---|
| | 1.70m | 1.80m | 1.90m |
| Dose Rate (mrem/hr) | 2.42040×10[illegible] | 4.00693×10[illegible] | 6.64653×10[illegible] |

| Lead Door | Lead Door Thickness ** | | | |
|---|---|---|---|---|
| | 10cm | 15cm | 20cm | 25cm |
| Dose Rate (mrem/hr) | 1.3105×10[illegible] | 4.9659×10[illegible] | 1.9902×10[illegible] | 8.2307×10[illegible] |
| Lead Door Weight "Tons" | 2.268 | 3.402 | 4.536 | 5.670 |

*Reinforced concrete of density ρ=3.50 $gm/cm^3$ with ordinary concrete of density ρ=2.35$gm/cm^3$ and volume fraction = 0.7913 and iron of density ρ=7.86 $gm/cm^3$ and volume fraction = 0.2087 .

** Suggested lead door dimensions 100 cm width , 200 cm height , and thickness s n ccordance with the selected dose rate in the above table. Lead density ρ= 11.35$gm/cm^3$ permissible dose rate equals to 2.50 mrem/hr.

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# حساب الدرع الواقي لمحطة تعقيم بواسطة أشعة كاما


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الخلاصه

يغطي الحساب الحالي بناية الدرع الواقي إثناء عملية التشعيع وكذلك حالة خزن مصدر إشعاعي من الكوبلت – ٦٠ نشاطه الأشعاعي ٣ مليون كوري تحت حوض من الماء. تضمن الحساب تصميم حوض ماء لخزن المصدر الأشعاعي بعمق ٨ متر كي يؤول المعدل الزمني للجرعة الأشعاعية على سطح الماء $2.8458\times10^{-15}$ سيفرت\ساعة، و ان المعدل الزمني للجرعة الأشعاعية على سطح الخرسانة المسلحة بسمك ١,٧ متر سيؤول $2.42040\times10^{-8}$ سيفرت\ساعة كنهاية عظمى و عندما يكون السمك 1.9 متر سيؤول الى $6.6453\times10^{-10}$ سيفرت\ساعة كنهاية صغرى على السطح الخارجي لبناية غرفة التشعيع . تصنع أبواب المدخل من الرصاص الذي سمكه 1.10 متر لكي تؤول النهاية العظمى للمعدل الزمني للجرعة الأشعاعية $1.3105\times10^{-7}$ سيفرت\ساعة وبسمك 0.25 متر لكي تؤول النهاية الصغرى للمعدل الزمني للجرعة الأشعاعية $8.237\times10^{-12}$ سيفرت\ساعة .