

# **GEMSTONE DEDICATED GAMMA IRRADIATOR DEVELOPMENT**

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## **ABSTRACT**

The gemstones gamma irradiation process to enhance the color is widely accepted for the jewelry industry. These gems are processed in conventional industrial gamma irradiation plant which are optimized for other purposes, using underwater irradiation devices with high rejection rate due to its poor dose uniformity. A new conception design, which states the working principles and manufacturing ways of the device, was developed in this work. The suggested device's design is based on the rotation of cylindrical baskets and their translation in circular paths inside and outside a cylindrical source rack as a planetary system. The device is meant to perform the irradiation in the bottom of the source storage pool, where the sources remain always shielded by the water layer. The irradiator matches the Category III IAEA classification. To verify the physical viability of the basic principle, tests with rotating cylindrical baskets were performed in the Multipurpose Irradiator constructed in the CTR, IPEN. Also, simulations using the CADGAMMA software, adapted to simulate underwater irradiations, were performed. With the definitive optimized irradiator, the irradiation quality will be enhanced with better dose control and the production costs will be significantly lower than market prices due to the intended treatment device's optimization. This work presents some optimization parameters and the expected performance of the irradiator.

## **1. INTRODUCTION**

The gemstones gamma irradiation process to enhance the optical properties, like the color behavior, is widely accepted in jewelry industry. These gems are processed in conventional industrial gamma irradiation plants, which are optimized to irradiate products in atmospheric environment and stepped linear movement in front of the source rack. The gemstone irradiation use to be made in underwater environment in the bottom of the source storage pool, using narrow box shaped baskets. The product is placed in front of the source rack, with no movement during the irradiation process. The poor results of dose uniformity lead to the need of high overdoses in a substantial part of the product to achieve the proposed modification in most of the irradiated gemstones. Depending on the gemstone characteristics, the resulting rejection rate can be too high.

A new conception design, which states the working principles and geometrical parameters of the device, was developed. The gemstone cylindrical basket planetary movement inside and outside a cylindrical source rack allows a better dose distribution control enhancing the dose uniformity rate (DUR), or the relation between the maximum and the minimum dose rate enhancing inside the irradiation container.

The planetary system was optimized and its expected performance is presented in this work.

## 2. IRRADIATION DEVICE OPTIMIZATION

The optimizations were based on the best throughput, with a maximum dose uniformity rate of 2.5. The operational safety, as long as the baskets were to be handled by the operators, and the device's simplicity, were considered, too.

### 2.1. Basket Length

The dose distribution in a rotating cylindrical basket is radial, with the axial variation depending of the source length and the basket length relation and the distance between their axes. This behavior results in ring shaped isodose curves [1], with the higher doses located in external rings.

Being vertically centered, the axial dose distribution depends mainly on the source length and the basket length relation. The best uniformity in this direction is achieved when the source is slightly higher than the product, since it is intended to have no vertical displacement during the irradiation process.

Adapting the CADGAMMA application [2] to simulate underwater irradiation, the optimized basket length was determined to be 390 mm.

### 2.2. Source Rack, Basket and Translation Orbit Diameters

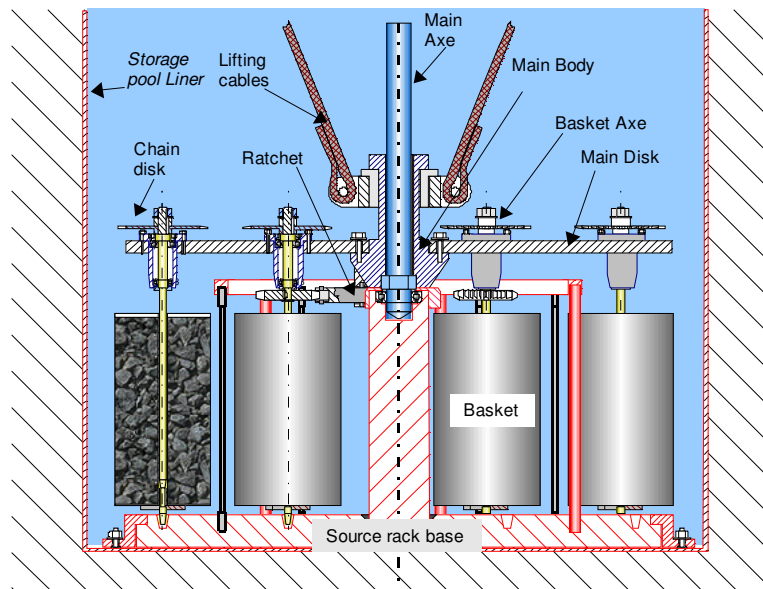
The irradiator is intended to operate with multiple industrial sources, with a maximum  $^{60}\text{Co}$  activity of 37 PBq (1,000 kCi). The real operational load is intended to be 20 to 40% of this limit and it is planned to use sources ranging from 37 TBq (1 kCi) to 50PBq (13.5 kCi). Considering that, a single source rack with 150 source enclosure space will be enough. This observations lead to a designed rack with 740 mm diameter, considering the center of the sources.

Using the CADGAMMA and limiting the dose uniformity rate to 2.5, 210 mm basket diameter was observed as the maximum diameter to be set up in the irradiation device. Due to ergonomic reason to handle baskets loaded with gemstones, the weight of each basket should not exceed 25 kg. The basket filled with gemstones will have, in air, an apparent density of  $1.6 \text{ g/cm}^3$ . A ten liter basket (190 mm diameter) weights 16 kg and the greatest diameter basket (190 mm) will weight 19.5 kg.

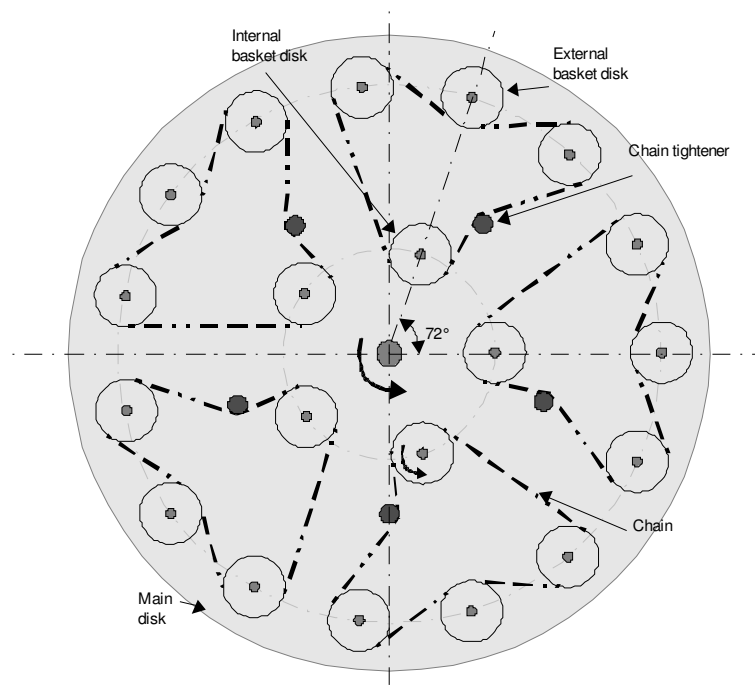
The Table 1 shows the possible diameter and number of the baskets, with internal and external translation orbits.

The operational safety led to the choice of the 210 mm internal baskets and 190 mm external baskets. This will ensure gaps enough to avoid operators hand catch. This choice makes easier to control baskets rotation, tying three external baskets to each internal one.

The Fig. 1 shows the irradiation device, side view cut, and the Fig. 2 shows the basket distribution in the orbital arrange.



**Figure 1: Irradiation device**



**Figure 2: Orbital arrange**

**Table 1: Diameter and number of internal and external orbit baskets**

| Orbit    | Basket Diameter | Quantity | Orbit Diameter | Gap Between Baskets | Device Circumference Diameter* |
|----------|-----------------|----------|----------------|---------------------|--------------------------------|
| Internal | 190             | 6        | 430            | 25.0                | -                              |
|          | 200             | 5        | 420            | 46.9                | -                              |
|          | 210             | 5        | 410            | 31.0                | -                              |
| External | 190             | 15       | 1050           | 28.3                | 1240                           |
|          | 200             | 15       | 1060           | 20.4                | 1260                           |
|          | 210             | 14       | 1070           | 28.0                | 1280                           |

\* Internal baskets do not influence in the device circumference diameter.

Simulating external 190 mm diameter baskets and internal 210 mm diameter baskets in their orbits and the average dose during irradiation processes, the minimum dose rate (close to the basket axe) resulted to be statistically equal. The average distance of each source and the basket is larger for external baskets than internal ones and it compensates the larger layer to irradiate the center of the basket, the minimum dose rate point, in the 210 mm diameter device.

The IPEN's compact size multipurpose industrial irradiator [3] source rack was used to perform basic tests to determine the dose rate in the gemstones, in underwater slow spinning basket. These tests, made with 190 mm and 210 mm diameter baskets, showed that using 7.4 PBq of  $^{60}\text{Co}$  load, in the proposed device, more than 54,000 kg per year of gemstones can be irradiated to a minimum dose of 600 kGy in one year [1].

### **3. EXPECTED ECONOMICAL PERFORMANCE**

The irradiator plant implementation costs, including the irradiation device, source storage pool, water cooler, water deionizer and radioprotection tools is estimated to be about US\$ 150,000.00, without the sealed sources. The 7.4 PBq (200 kCi) of  $^{60}\text{Co}$  sources load costs US\$ 400,000.00.

The system can be loaded with up to 37 PBq (1.000 kCi) of  $^{60}\text{Co}$ . The performance data was made with 7.4 PBq (200 kCi), considering it as initial load.

The amount of 600 kGy, required to treat many gemstones in the existing industrial irradiators, is adopted as a reference dose in this work. With the better dose control and uniformity, less than 600 kGy of minimum dose will be required, and using the commercial value of US\$ 10.00 per kg of irradiated gemstones, the annual income of US\$ 540,000.00 may be exceeded.

To maintain this production, the operational cost, using the method presented by Morrison [4], is about US\$ 171,250.00, where US\$ 50,000.00 is for source replacement and

US\$ 121,250.00 for other expenses, resulting in a US\$ 3.17/kg of treated gemstone. Doubling the  $^{60}\text{Co}$  load, the annual throughput may double, with the source replacement doubled in the overall costs and almost no increase in the other expenses.

The demand for gemstone irradiation is limited and higher initial load at the beginning of the irradiator's operation may be too risky. But as the irradiation process becomes cheaper and the irradiation quality is enhanced, more gemstone producers can adopt this technique and new kinds of gemstone irradiation may become to be technically or economically available, enlarging the gemstone irradiation service market.

#### 4. CONCLUSIONS

The irradiator with 7.4 PBq (200 kCi) of  $^{60}\text{Co}$  sources can treat more than 54,000 kg per year of gemstones which absorbing 600 kGy as a reference dose. Many gemstones need less than this dose to get the desired change, increasing the annual throughput.

With a capital investment of US\$ 550,000.00, the annual liquid income may be beyond US\$ 350,000.00, with 7.4 PBq load.

The gemstone irradiation market may grow with lower irradiation prices and better color enhancement results.

#### REFERENCES

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