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UNDERWATER VERSUS DRY IRRADIATION WITH ^{60}CO, A QUALITATIVE ANALYSIS

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ABSTRACT

The development of gemstone gamma irradiation devices showed that underwater irradiation leads to better results than the irradiation in dry condition. Many reasons may be shown for that behavior. This work intends to analyze qualitatively two of these reasons. The medium discontinuity between the irradiation source, gemstone, and the air inside the irradiation devices, which is minimized in underwater irradiation, is one of them. The other analyzed hypothesis is the differences between the interactions of source's direct radiation and those from the scattered radiation. The numerical study of these hypothesis, as long as some irradiation tests may be presented in future works. The main conclusion of this work is that the absorbed dose may have different behavior view if the depending on the kind and energy level of the absorbed dose. For example, it isn't used to consider what portion of the dose is due to source's direct hit, what part is from ejected electrons with high or low energy and how much high, medium and low energy electro-magnetic quanta hit a portion of mass when determining its radiation dose. To know the total absorbed dose is usually, but not always, enough to explain a material response to radiation.

1. INTRODUCTION

The gemstone irradiation processes showed that underwater irradiations leads to better results than the irradiation in dry conditions. For high dose rates irradiations, like electron beam treatment, the heating may be the key factor for the unwanted results but, with ^{60}Co gamma irradiations, the temperature rise is too low to affect the results [1].

This work intends to analyze qualitatively two of these reasons.

A gemstone portion will contain voids with relative volumes depending on the stone shape. The discontinuity created between the gemstones and the air, with very different densities involved, is one hypothesis. This discontinuity is reduced in underwater conditions, approximating the gemstone and the voids filling material densities.

The other hypothesis is a little bit difficult to explain because it is used to treat the irradiation doses as the total energy absorbed by the material. Although being a fundamental interaction, the direct radiation/secondary radiation quantities rate is only mentioned in the dose buildup definition. The dose buildup may be one of the reasons for better color homogeneity inside the gemstones. And the buildup factor is higher in underwater conditions.

The numerical study or irradiation tests to confirm these hypotheses will not be treated in this work.

The main assumption of this work is that the absorbed dose may have different behavior if the kind and its related energy level groups that compound the dose are considered. For example, it isn't used to consider which portion of the dose is due to source's direct hit, what part is from ejected electrons with high or low energy and how much high, medium and low energy electro-magnetic quanta hit a portion of mass when determining its absorbed radiation dose. To know the total dose is usually, but not always, enough to explain a material response to radiation.

2. MATERIAL DISCOUNTINUITY

The gemstone material density varies with the kind of gemstone but it is usually more than 2.5 g/cm^3 and the air density is about 0.0012 g/cm^3. This difference makes the radiation path in air to be almost free of interactions, if compared to the path inside the stone.

Due to the irregular geometry of the gemstones, the volume occupied by them is about twice their real volume. The voids are filled with air in dry irradiation processes or water in underwater treatment. The Fig. 1 shows the expected behavior of the isodose lines

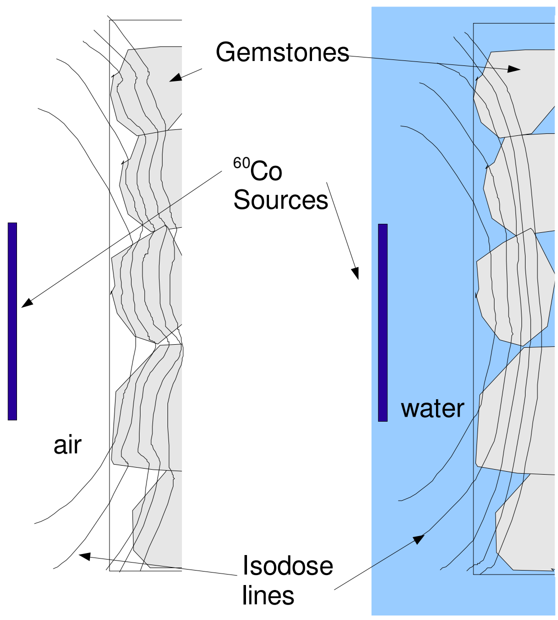

Figure 1: Dry x underwater irradiation (source standing leftside).

The isodose lines in dry irradiations tend to be highly influenced by the voids shape, formed by the shape of the gemstones surfaces and their relative positioning. This influence is more intense for low energy photons and electrons. The resulting isodose lines tend to be very irregular near the gemstone surface, becoming smoother with the penetration.

In underwater irradiation, the density of the voids is not too different from the gemstone density and the isodose lines tend to be more regular than in dry irradiation, with smoother dose distribution inside the gemstones leading to more homogeneous color enhancing.

For those gemstones where the saturation level is not to be reached, the final color uniformity will be better in underwater irradiation, resulting in larger gems with homogeneous color saturation.

Following this assumption, if thin sand is used to fill the voids with the same density of the gemstones, plus the underwater irradiation to fill the resulting very small voids, the resulting dose gradients should be the smoothest achievable. In this case, the bulk density and the gemstone density will be very similar and the results will only depend on the origin of the gemstone.

To confirm this hypothesis, tests with well known gemstones and very sensible color saturation in small portions of gems apparatus should be performed. The difference between underwater with and without the thin sand may be too small to eliminate all the influences of the other variables.

3. BUILDUP EFFECT

During the underwater irradiation the interaction with the surrounding water increases the number of the photons and electrons that hit the target, although decreasing their average energy. The material ionization is more random and, even with lower average radiation penetrations, the number of chemical bonds affected can be high enough to maintain the uniformity. The Fig. 2 shows the expected behavior of electrons and photons irradiation that leave a gemstone volume and hit other gemstone. The Fig. 3 shows the same in underwater irradiation. Both show the direct hits paths (1.17 MeV or 1.33 MeV gamma from ^{60}Co) in blue and the secondary radiations hit paths (from Compton ejected electrons and lower energy photon) in red.

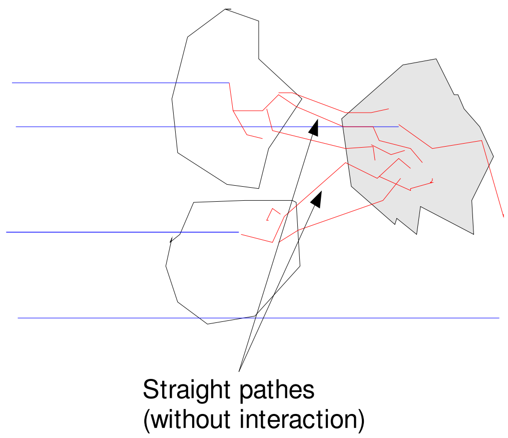

Figure 2: Dry irradiation

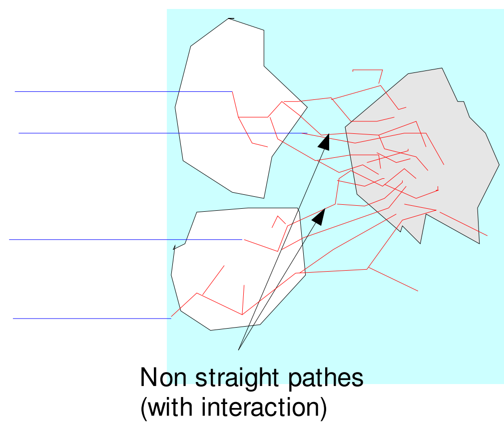

Figure 3: Underwater irradiation

Most of the interactions with electromagnetic waves generated by ^{60}Co irradiation are Compton. The ejected electron may initiate a small cascade until it looses all the energy and the scattered photon may also generate other Compton interactions or a photoelectric interaction.

The interaction of a radiation element (an ejected electron or a photon) with the color center precursor forming [2] depends on the energy of this element in relation to the bond energy of the ejected electron. As the bond energy level is about some electron-volts, also considering that the interaction probability of a lower energy radiation element increases, it is logical to suppose that for an energy flux of 1 MeV, the ejection of an electron probability of a particular bond, forming ions, is higher for a hundred 10 keV particles hitting the region than for an unique 1 MeV particle.

The dose calculations consider the total amount of energy absorbed in the material, no mater how much hits or the average energy of the particles that interacts with that portion of mass. In the Monte Carlo method, most of these lower energy particles are considered, but the result doesn't show their influence. In the Point Kernel methods, the energy absorption in a particular position is treated as the portion of energy from original photons multiplied by the buildup factor [3], which is always higher than the unit.

For deep irradiations, the buildup factor may be beyond one hundred, meaning that more than 99% of the absorbed dose, disregarding the fact that it is very small, is due to low energy electrons or photons. The buildup factor of 2 is available with less than 11 cm of water, meaning that, beyond this distance, the presence of water ensures that at least half of the energy absorbed is from the secondary radiation. In the dry irradiation, this buildup begins to form virtually in the outer surface of the basket.

Other behavior of the secondary radiation is the random direction of the radiation elements. The bigger is the flux of the secondary radiation in a point, the more random is the direction where the radiation particles come from.

Actually, the total energy absorbed in a portion of mass decreases with the penetration, but it is not sure that the flux of particles capable to ionize the color center precursor is reduced in all penetration deeps.

The conclusion of this hypothesis is that radiation dose, as it is defined, simulated and measured, may not explain all the behavior of the gemstone color center precursors formation by irradiation. In this particular case, the underwater irradiation seems to show better relations between distance from the source, dose penetration and buildup effects, if compared to dry irradiation.

4. CONCLUSIONS

According to the above considered suppositions, underwater irradiation shows better color distribution in gemstones than dry irradiation due to these two reasons:

- Better dose distribution, with smoother isodose lines; and
- Better relations between distance from the source, dose penetration and buildup effects, compared to dry exposure, particularly with more scattered radiation, which improves the number of ionizing photons or electrons that hits the gemstone.

To know only the total absorbed dose in the gemstone mass is not enough to explain the better results in underwater irradiation than in dry conditions. The absorbed dose may hide the effective number of color center precursor ionizations as it considers the total absorbed energy, which includes converting radiation energy to heat, the major part of it.

As intended, this work presents only qualitative discussions on these hypotheses. New practical and numerical works may be developed from these discussions.

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