Co-60 versus Ir-192 in HDR brachytherapy: Scientific and technological comparison

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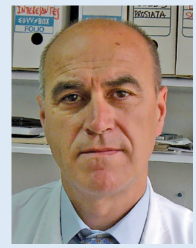

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Comparison motivation and approach

Traditionally, High Dose Rate afterloaders have been based on Ir-192. The high specific activity of iridium allowed very small sources to be used interstitially despite its half-life period. Typically a source exchange is required each 3-4 months to keep the treatment times within the limits required by clinical practice and also because a maximum number of transfers is recommended by the manufacturer. A few years ago, new HDR afterloaders have been introduced in the clinic using Co-60 instead Ir-192; the latest version of these afterloaders are provided with sources having the same size as the Ir-192 ones and have been already implemented in some institutes which shows a clear tendency to increase their number. In fact these sources have been considered in the recent AAPM-ESTRO Report[1] with recommendations about dosimetry methodology, and consensus datasets have been presented for the two commercially existing sources. The Co-60 manufacturer claims important economic advantages because of the larger half-life period and the improved technology which allow for less source exchange frequency.

Within the Medical Physics community there is no clear position on advantages or disadvantages of both HDR modalities, to be taken into account in future HDR facility implementation. To discuss this issue, the *Revista de Fisica Médica* which is the official journal of the *Sociedad Española de Física Medica* (SEFM) promoted a debate on this topic.

To give light on this topic two well-known specialist on this field have been invited, both of them with important roles in their respective companies and directly involved in brachytherapy afterloading research. We appreciate very much that both of them accepted the invitation. In addition to their work on afterloading in

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their companies, they are also involved in several scientific activities on brachytherapy. In favor of the Co-60 will act Michael Andrássy from Eckert & Ziegler BEBIG and in favor of the competitiveness of Ir-192 vs. Co-60 will act Yury Niatsetski from Nucletron, an Elekta Company.

The following topics are the proposed ones to be covered by both competitors:

- Economic aspects (frequency source exchange required, maintenance, facility shielding, self-protection of HDR unit,…).
- Dosimetric aspects on the treatment volume (required S_K for the same dose rate in water, radial dose function and dose rate constant comparison,…).
- Calibration (Accredited labs, well chambers for users, traceability,…).
- Dose to Organs at Risk (OAR) outside of the treated volume.
- Emergency procedures.
- Other issues (i.e. radiobiology, dose rate in function of the useful source period,…).

In favour of Co-60

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The history of radiation therapy has been associated with the use of a relatively limited number of radionuclides. In the 1950-60s, when the production of isotopes by neutron activation became feasible, Co-60 complemented Cs-137 as the standard nuclide in radiation therapy[2]. Its application has been studied in many countries all over the world, and broad clinical experience in teletherapy, as well as in brachytherapy has been gained. All in all, several hundred HDR-afterloader units equipped with Co-60-sources have been utilized in clinics ever since, the majority of them for gynecological applications.

The technical development of sources with higher specific activity was the starting point for HDR remote afterloading. Clinical data and dose delivery concepts to achieve equivalent outcomes in Low Dose Rate (LDR) and HDR-applications had been worked out using Co-60 sources[3]. In the 1970s, the manufacture of miniaturized Ir-192 sources shifted market preference to this nuclide. Smaller size and source diameter allowed new application modalities, e.g. interstitial therapy, as well as dose optimization due to stepping source technology. At the same time, the extrapolation of experience obtained from traditional brachytherapy nuclides to Ir-192 was based on the similarity of physical dose distributions.

Since a few years, Co-60 with enhanced specific activity has allowed the design of miniaturized sources that are equal to conventional Ir-192 sources. Applicators are the same in shape and diameter, and the application techniques are similar in both therapies. Only in the rare cases of applicators with internal shielding, they have to be replaced for Co-60 by other design solutions. The cobalt pellet within the source has dimensions just as the iridium ones have, thereby taking advantage of the higher air kerma rate constant consistent with Co-60. In comparison to Ir-192, the aimed source strength for Co-60 can be achieved with lower activity. (1 GBq Co-60 is equivalent to 2.77 GBq Ir-192).Nominal values of activity currently available on the market are 370 GBq for Ir-192 and 74 GBq for Co-60 (model Co0.A86, Eckert & Ziegler BEBIG). Based on source operation time limited to one half-life for Co-60 and three months for Ir-192, the irradiation time on average is only 1.7 times longer for the cobalt source. This means, prolonged irradiation times in the order of minutes do not seriously extent the overall treatment procedure.

With regard to the discussion of dose distributions in water according to the TG-43 formalism, differences in the photon spectrum of both nuclides have to be considered. Co-60 is characterized by a higher mean energy (1.25 MeV) in comparison with Ir-192 (0.355 MeV). Consequently, dose deposition in water is based on different contributions from the photoelectric- and Compton-effect. This is illustrated by the different courses of the radial dose functions where Co-60 proceeds up to several percentage points below Ir-192 (model mHDRv2, Elekta Nucletron) for distances of up to at least 20 cm[4,5]. However, the comparison of complete dose distributions of the Co-60- and Ir-192-source does not show any clinical relevant differences, because the $1/r^2$–law is clearly the most dominant physical effect in brachytherapy.

Besides photon interaction in the medium water, comparison of the anisotropy functions reveals less absorption in source core and capsule for Co-60. This effect can be seen as an advantage for Co-60, but has a minor practical effect in relation to the complex treatment planning.

The question whether the higher photon energy of Co-60 might cause higher risk at more distant organs is difficult to access. Based on recent TG-43-data, the dose rate of Co-60, proceeding below Ir-192, shows a cross-over just only at a distance of approximately 25 cm, where it has already dropped to less than 0.2% relative to 1 cm. However, the volume integral remains still below that for Ir-192 up to much larger distances.

The above-mentioned features of Co-60 radiation in absorption and scattering effects have further consequences: In comparison to Ir-192, attenuation effects in applicators or contrast agents are reduced. Moreover, the effect of dose over-estimation by TG-43 when approaching surfaces water-to-air is less for Co-60 than for Ir-192. In relevant cases, we should therefore expect less deviations in treatment planning with software working on TG-43 pre-assumptions regarding reality.

The relation in dose delivery concerning tissue to water demonstrates that there are only minor differences in comparison to Ir-192. For example, dose by Co-60 to adipose tissue is 0.4% higher but 0.8% lower for the rectum. The largest difference is reported for lung tissue (density 0.26 g cm^{-3}) showing a 2.1% discrepancy. Nevertheless, in the practice of radiation therapy such differences are negligible[6].

The main advantage of considering Co-60 afterloading for an extended use in modern brachytherapy are the logistical aspects, as well as the ease connected to the long half-life of Co-60 ($T_{1/2}$=5.27 y), so Eckert & Ziegler BEBIG recommends to exchange those sources at approximately five-year intervals. Based on a useful life of Ir-192 afterloading sources in the order of three months, 20 source exchanges are required for Ir-192, whereas only one is required for Co-60.

The extended use of a Co-60 afterloader source makes higher demands on technology and wear resistance. Eckert & Ziegler BEBIG certifies its Co-60 source integrity in connection with the use of own brand applicators with a reliability of 100,000 transfer cycles. This safety value is based on a successful stress test, which has shown a margin exceeding the latter several times. From past experience, this limit was not reached once during 5 years service life. However, the user is always informed about the actual status, can plan source exchange accordingly but will not be able to start a new irradiation beyond the limit.

In addition to the financial savings, there can be a substantial reduction in efforts for customs clearance, transport, and disposal. Experience in some countries has shown that the import of radiation sources with a precise regular time schedule might be difficult, which is less critical in the case of a Co-60 source.

It should not be concealed that installing a Co-60 unit can require higher investment for radiation safety in the clinic, and pros and cons have to be weighed up in every individual case. However, frequently brachytherapy suites profit from pre-existing basic structure designed for former teletherapy units, accelerators, or even radium applications. In the case of new construction projects, the partial costs for shielding the Co-60 afterloader are moderate or insignificant. From experience of almost 200 installations, the economical balance was always positive and shielding issues have not been a criterion for exclusion.

This next point may be of particular interest for clinics with very busy workloads: Afterloader availability is higher and physics support time is reduced with Co-60 in comparison to Ir-192 for QA procedures requested for source exchange. It has been estimated that 40% more physics support time is required for Ir-192 compared to Co-60[7].

Concerning the availability of equipment for quality assurance, there is no difference in practice with Ir-192. Detectors can be calibrated for both nuclides, Co-60 and Ir-192, with traceability to the appropriate primary standards of PTB, Germany or NIST, U.S.A. Co-60 calibration factors presently stated by ADCLs are based on Ir-192 measurements using appropriate radiation quality corrections.

In conclusion: The recent introduction of miniaturized Co-60 sources by Eckert & Ziegler BEBIG represents a renaissance for this nuclide in HDR-brachytherapy. Clinical specialists evaluate the use of Co-60 in modern afterloading equipment as an equivalent to Ir-192. Their research shows that, in typical brachytherapy applications, there are no significant differences between the two isotopes with respect to dose prescribing, treatment planning, or resultant isodose distributions to target coverage or OAR doses. Beyond that, there are economical aspects making this nuclide an interesting option for clinics all over the world.

In favour of the competitiveness of Ir-192 vs Co-60

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Both Co-60 and Ir-192 sources are in use for HDR brachytherapy for many years.

The first publication on the use of Co-60 sources, in the form of radioactive needles, was in June 1948 by William Myers[8,9]. Iridium has been used in brachytherapy since 1958 as seeds by Ulrich Henschke and then, from the early 1960s, mainly as wires[9]. Both isotopes were later used in the sources for remote afterloaders, having different shapes (pellets, seeds, wires, etc.). Because of the high specific activity[9], Ir-192 has become the most popular radionuclide in brachytherapy, especially after the first remote afterloaders with the miniature HDR sources were introduced on the market. This invention made it possible to apply brachytherapy not only in intracavitary but also in interstitial treatments. Recently, a remote controlled HDR afterloader with a Co-60 source has been introduced in the market with identical geometrical dimensions as HDR afterloaders with Ir-192 sources[4] offering the same possibilities for brachytherapy treatments.

Here the miniature HDR sources of both isotopes will be compared, related to the use of the remote controlled afterloaders with these sources.

The maximum specific activity of Co-60 (41.91 GBq/mg) is much lower than that of Ir-192 (340.98 GBq/mg)[9], therefore the activity of a Co-60 source of the same mass is lower than that of an Ir-192 one. Typically, Ir-192 sources, as supplied by the manufacturer, have an initial activity of 370 GBq (10 Ci), while Co-60 sources have only 74 GBq (2 Ci). The air-kerma rate constant of Co-60 is higher than that of Ir-192 (0.306 vs. 0.110 μGy·m^2/h/MBq)[9], so the difference in source strength is smaller: 22,645 vs. 40,820 cGy·cm^2/h. Thus the treatment time for the same treatment plan with a Ir-192 source is about 1.8 times shorter than that with a Co-60 source, both sources having their initial source strength.

Both, Co-60 and Ir-192 sources are high-energy photon-emitting brachytherapy sources[1]. However, they have a different energy spectrum with mean photon energy of 1.253 MeV and 0.355 MeV, respectively[9]. This difference has first of all an influence on radiation protection. The higher the photon energy, the thicker the protecting material that is required to shield the treatment room and the treatment unit itself. Thus, a treatment unit with a Co-60 source requires a much heavier source safe. HVL (half value layer) and TVL (tenth value layer) values are used to describe the shielding capabilities of a certain material. The HVL of lead is, for example, 4 times larger for Co-60: 12.0 mm vs. 3.0 mm for Ir-192[9].

A recent publication of the GEC-ESTRO BRAPHYQS workgroup[10] provides detailed information on shielding materials for brachytherapy facilities, taking into account oblique incidence of radiation to the walls and door, spectral variation with barrier thickness, and broad beam conditions in a realistic geometry. The results are expressed in terms of HVL_e (equilibrium) and TVL_e values additionally to the traditional HVL_1 (first) and HVL_1 values for typical shielding materials, as well as graphically for calculation of the material thickness needed to provide the necessary protection level. The thickness of the shielding materials for Co-60 sources is much larger than for Ir-192 sources. For example, TVL_e values (in mm) for concrete are 210 vs. 139, and for lead glass 74 vs. 47, respectively. In general, treatment rooms designed for Ir-192 afterloaders are not necessarily suitable for Co-60 afterloaders and might need additional shielding and, thus, additional investment.

The difference in mean photon energy between Co-60 and Ir-192 is not significant when the dose distribution is calculated according to the AAPM TG-43 formalism in terms of dose to water in water[11,12]. This has been demonstrated for a single source and for a typical GYN applicator[13]. However, for shielded applicators, designed for a Ir-192 source, the shielding effect will be lower if such applicator is used with a Co-60 source. Thus, shielded GYN applicators must be redesigned for such use. The same is valid for shielded skin applicators (of Leipzig and Valencia type). Their shielding capabilities are not sufficient for use with a Co-60 source. Their wall thickness may become too bulky when adapted to Co-60, making these applicators much heavier.

It should be noted that dose calculation with correction for (i) inhomogeneities in the patient body, (ii) lack of scatter due to missing tissue near to the patient surface, and (iii) applicator and shielding material will only be possible by following the recently published AAPM TG-186 recommendations for model-based dose calculation algorithms[14]. A comparison of typical clinical plans for different body sites using one of the model-based dose calculation algorithms or Monte Carlo simulation should be performed in order to evaluate more precisely the differences between these two sources.

For estimation of the integral dose values to organs far away from the target volume, Venselaar *et al.*[15] investigated the dose values at large distances from different brachytherapy sources including Co-60 and Ir-192. For distances up to 20 cm, dose values from Ir-192 source are slightly higher (ratio of 1.14 at 10 cm and 1.05 at 20 cm), but for distances larger than 25 cm, dose values from a Co-60 source are higher (ratio of 1.16 at 30 cm, 1.68 at 45 cm, and 2.57 at 60 cm). That suggests higher integral dose for Co-60 sources, so additional attention should be paid when estimating the dose on distant organs at risk.

It is clinical routine to replace an Ir-192 source after one half-life, because the source strength becomes too low and treatment times too long. As already mentioned earlier, the initial strength of a Co-60 source is about equal to that of an Ir-192 source at time of exchange. Thus, replacement of the Co-60 source every 2 years, after which the source has still 77 % of the initial source strength left, is to be considered. For the same initial source strength, one (1) exchange of a Co-60 source after one (1) half-life equals 26 (i.e. 5.27 x 365.25 days / 73.83 days) exchanges of a Ir-192 source. As an Ir-192 source has almost twice the initial source strength, one (1) exchange of a Co-60 source after one (1) half-life equals 13 exchanges of an Ir-192 source in clinical practice. A Co-60 source exchange every 2 years is equivalent to 7 Ir-192 source exchanges, when the initial source strength of the Ir-192 source is twice that of a Co-60 source and the exchange source strengths are equal for both sources.

A certain number of source transfers are guaranteed by the manufacturer. For an Ir-192 source, that number will not be approached, even when the source exchange is done after 6 months. For a Co-60 source, this is also not a matter of concern for a hospital treating just a few patients a week. However, for a busy hospital treating many patients per day with 3-20 catheters per fraction with Co-60 source, it becomes very relevant. Assume 8 patients per day with an average number of 9 channels per fraction are treated (mixture of gynecological and prostate HDR treatments). Thus, 72 source transfers per day, about 21,600 transfers per year (300 days), and 108,000 transfers in 5 years, which exceeds the guaranteed maximum (currently 100,000 transfers). To stay within 100,000 source transfers in 5 years, an afterloader can treat 24 fractions per day for a typical GYN treatment (3 channels) and 4 fractions per day for a typical prostate treatment (18 channels). A solution to this reaching the maximum number of source transfers could be to exchange the Co-60 source more often, e.g. every 3-4 years. The availability of the information about the number of source transfers for the user is essential.

In conclusion: Currently, the great majority of interstitial, intraluminal, and intracavitary brachytherapy treatments, performed by HDR remote controlled afterloaders, are delivered with the use of Ir-192 sources. All recent clinical data is obtained from treatments with an Ir-192 source.

When for HDR afterloading a Co-60 source is used, the following considerations must be taken into account:

- The initial source strength of a Co-60 source is about equal to that of an Ir-192 source at the time of exchange. Thus, treatment times will become longer.
- The maximum number of source transfers for the commercially available Co-60 afterloader is guaranteed to a value of 100,000. A Co-60 source can reach this value before the exchange at 1 half-life. So, the total number of source transfers must be restricted by the afterloader to the maximum allowed number. In the light of increasing treatment times and the large number of source transfers, it may be wise to replace a Co-60 source after 2-3 years.
- Shielded applicators designed for Ir-192 sources must be redesigned for Co-60 sources, if the same dose reduction must be achieved. This may not be possible for the shielded skin applicators because of excessive wall thickness.
- The shielding of the treatment room must be adapted to the much higher energy of Co-60 sources.

In light of the above remarks, using a Co-60 source may be considered in order to reduce the number of source exchanges, thus the operational cost, by accepting longer treatment times, and to simplify the logistics for radioactive material transportation and regulatory issues.

Conclusions and remarks

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In the previous sections, both authors have clearly stated the arguments for both HDR solutions. These are well known issues in clinical practice. Also issues are presented that require further research.

It is shown that economic aspects make HDR Co-60 an option to be considered for brachytherapy applications, with the same technical performance as in HDR Ir-192.

Among the most important points, where differences could be significant, are the economical versus clinical requirements. The economic efficiency is different if a new facility is planned, or if an existing one is modified, even when an existing bunker for external radiotherapy is dedicated to HDR. The arguments of both authors show that the economical advantages of Co-60 versus Ir-192 should be weighed against the clinical workload requirements, taking into account the half-lives of these sources, the longer treatment times with Co-60, and the permissible number of source transfers.

Within the treatment volume, both sources give similar dose distributions, thus existing optimizations and inverse planning tools give similar results. The clinical impact on non- TG-43 dose formalisms assumptions needs to be assessed. Modern dose calculation algorithms for Treatment Planning Systems (TPS) must be able to predict the resulting dose distribution according to the TG-186[14] recommendations. More research is needed in this area for better understanding of the deviations from measured or MC calculated data. At the moment there is only one commercial TPS on the market with only one Ir-192 HDR source model that is able to perform adequate calculations taking into account scatter defect, tissue inhomogeneity and shielding.

Outside of the treated volume, dose comparisons in peripheral organs at risk show opposite behavior (Ir-192 doses > Co-60 doses) at shorter distances from the treated volume in contrast to the behavior at larger distances (Ir-192 doses < Co-60 doses), as presented in the study of Venselaar *et al*[15]. In a recent study of Candela *et al*[16] organ doses on a reference male phantom have been calculated for a typical prostate HDR implant using MC; For the nearest organs considered, equivalent doses given by Co-60 were smaller (8%-19%) than for Ir-192. However, as the distance increases, Co-60 deliver higher equivalent doses. The overall results is that effective dose per clinical absorbed dose from a Co-60 source is about 18% lower than from an Ir-192 source.

Of course, the properties of shielding elements in an applicator are different between Co-60 and Ir-192, because of the higher energy of Co-60. In some cases, the peripheral dose should be decreased to such extent that a new design of the applicator is needed. It could be less relevant, e.g. for a shielded colpostat, because these are becoming of limited use due improvements on dosimetry, applicator capability (adding of an interstitial component), and MR image-based techniques.

Quality assurance instrumentation used for HDR Ir-192 is compatible with HDR Co-60. Currently, source calibration traceability is well established (Accredited Laboratories to User chain) for HDR Ir-192. For the case of Co-60, a solution is made available by the current HDR Co-60 manufacturer and the German metrological institute PTB, to provide traceable calibrated well chambers to Users at Hospital level. Newer recommendations from societies, such as the AAPM and the ESTRO, will be complemented regarding HDR Co-60.

We thank both, M. Andrássy and Y. Niatsetski, and their companies, Eckert & Ziegler BEBIG and Nucletron, an Elekta Company, for their work on this topic, which will be quite helpful for the brachytherapy community to select the HDR isotope for clinical implementation.

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