

Radioactive sources in brachytherapy

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Background. In modern brachytherapy, a great step forward was made in the 1960s in France with the introduction of new radioactive isotopes and new techniques. These innovations spread rapidly across Europe, though no single dosimetry standard had been set by then. In the new millennium, the advances in brachytherapy are further stimulated by the introduction of 3-D imaging techniques and the latest after-loading irradiation equipment that use point sources. The international organization ICRU (International Commission on Radiation Units) worked out brachytherapy techniques and standardized them in 1985 and in 1997. Due to rapid development of new techniques, the revision is required in order to set new international standards in dosimetry and brachytherapy techniques that will fit to the changed conditions in radiotherapy.

Conclusions. This is an outline of radioactive sources that are currently used in brachytherapy, such as Cs-137, Ir-192, Sr-90, Ra-226, Rn-222, Co-60, I-131, I-125, Pd-103, Tu-106 and Cf-252.

Key words: brachytherapy; radioisotopes; radiation protection

Introduction

In brachytherapy, the radiation dose is applied to tumor by sealed sources. The sources are implanted to the tumor tissue itself or in its close vicinity. The institution in which the therapy is being performed should follow the rules of safe and accurate implantation of the source; this implies that the therapy should be carried out in compliance with interna-

tional regulations on ionizing radiation, thereby also assuring the accuracy of prescribed doses. In all irradiation techniques,^{1,2} the principles of ALARA (*As Low As Reasonably Achievable*) should be observed, indicating that the minimum exposure of the personnel, which may be achieved by the institution at moderate costs, is allowed. In brachytherapy, the patient can be irradiated nonintermittently for several days if the therapy is applied at low dose rate (LDR). Hence, special concern should be focused on the radiotherapists and nursing staff who care for the irradiated patients. The measurements showed that the doses to which the personnel working in a brachytherapy unit is exposed are higher than those that are considered as average rates at other oncology departments.

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Techniques and materials

Radioactive sources Cs-137 and Ra-226, used in brachytherapy, are coated with stainless steel, whereas the iridium wire Ir-192 is coated with platinum alloy that covers the radioactive core. If a crack happens in this shielding coat, there is a great risk of extensive contamination; radioactive material may enter the respiratory and alimentary canals of anyone involved in the treatment process. Therefore, special caution and attention are required from the personnel in charge of regular control of the mechanical and radiation properties of the sources. Safety tests need to be performed especially on the gamma-radiation source as beta-rays are largely absorbed in by the coat of the source while alpha-rays are not applied in brachytherapy. Eye irradiation applicators have beta-source Sr-90 and are applied in the irradiation of superficial tumors of the eye. In this case, a few millimeters of a substance with low atomic number would serve as a protective shield against irradiation. Alpha-particles, emitted by Ra-226 and Rn-222, are absorbed by the coat of such source. Radioactive gas Rn-222 is being accumulated in the source as waste product; therefore, regular tests of Ra-226 sources should be urgently performed. If the coat of the source is damaged, the leakage of radioactive gas can occur. The Ra-226 source is practically not in use any more and is replaced by Cs-137 and Ir-192. These sources are implanted into the patients automatically by remote control, thereby allowing the application of high dose rate techniques at higher activity. The high dose rate (HDR) techniques are those that are performed at dose rates over 12 Gy/h, whereas the low dose rate (LDR) techniques are performed at dose rates below 2 Gy/h. As the high specific activity of the source is required, only Co-60 and Ir-192 can be applied as sources in HDR. The required activity is as high as 370 GBq, which speaks in favor of remote afterloading

of the sources that should be performed in a specifically protected room. In the recent decades, sequential irradiation with Ir-192 as point source, with the activity of 37 GBq, has been widely investigated. This technique is known as pulsed dose rate technique (PDR) and is actually a type of hyperfractionation in brachytherapy. Irradiation restarts every hour for 10 minutes throughout 24 hours. The afterloading equipment allows the interruption of irradiation when necessary, e.g. if patients need nursing care or if they are having a visitor. Statistic analyses have confirmed that the nursing staff at the department where the afterloading irradiation equipment is installed is receiving markedly lower doses. The operating instructions of the irradiation equipment should be accessible to the users and the equipment should be regularly tested for safety reasons.

Irradiation with radioactive sources

The brachytherapy irradiation dose is defined as the ratio between activity of the source, irradiation time, and distance from the source. The total air KERMA_{dose} is computed from the equation

$$K_a = \frac{\dot{K}_r * t}{r^2}$$

in which t denotes the irradiation time and r the distance between the source and irradiation point. \dot{K}_r is the reference air KERMA rate, measured in $\mu\text{Gy/h}$ at the distance of 1 m. Activity of the source is measured in MBq. The effect of the source coating on the dosage around the source is taken into account by the correction factor. Photons get absorbed also into the tissue of the irradiated patient, which is expressed by the transmission factor, depending on the duration of transit passage of the photons through the tissue, on the electron density of the tissue, and on the energy of gamma rays. Figure 1 shows a graphi-

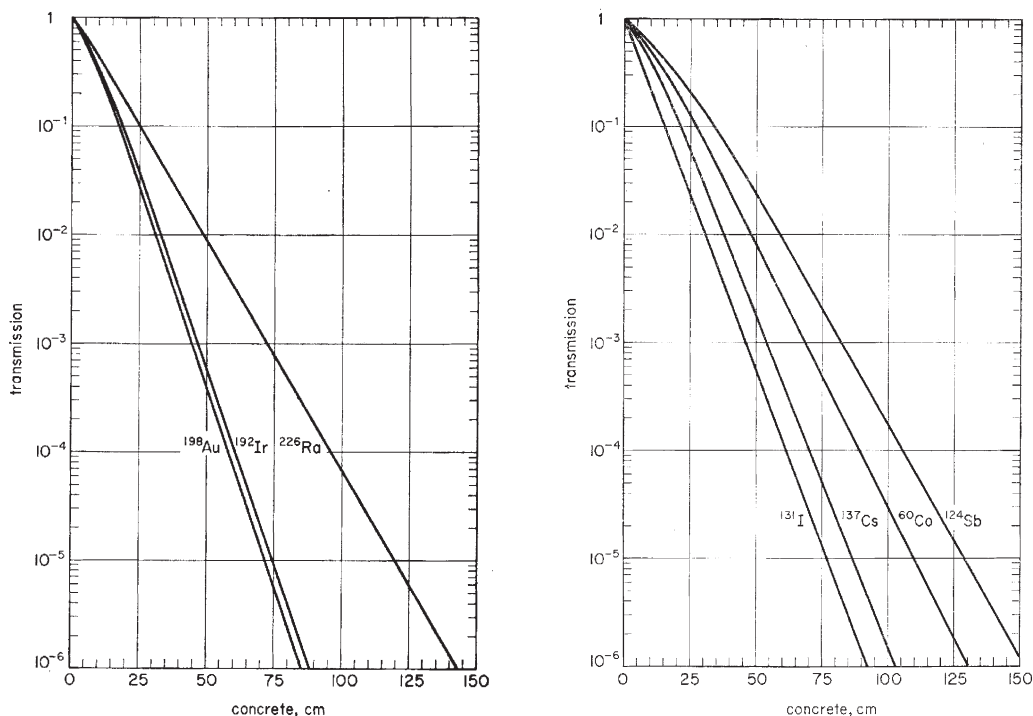


Figure 1. Transmission factors for concrete:

- y axis: transmission factor
- x axis: concrete (in cm)

cal presentation of the transmission factor of concrete.⁴ Transmission factor is the percentage of photons (axis of ordinate y) that reach at a particular depth of a substance (axis of abscissa x). An important data required for radiation protection is half value layer (HVL). This is the depth at which gamma ray loses one half of its initial intensity. A similar defi-

nition was adopted for tenth value layer (TVL). This is the depth of the absorption substance at which γ -ray loses one tenth of its initial intensity. Table 1 is a collection of all key data that are relevant for the radiation protection against the isotopes most frequently used in brachytherapy. The worker who is in charge of the preparation of the

Table 1. Data relevant for radiation protection in brachytherapy

Nuclide	Mean energy (in MeV) of emitted photons	Half life	First HVL in Pb (in mm)	TVL in Pb (in mm)	TVL in concrete (in cm)
^{198}Au	0.42	2.7 day	2.5	9	18
^{60}Co	1.25	5.3 years	13	45	27
^{137}Cs	0.66	30 years	6.5	21	22
^{125}I	0.029	60 days	0.025	-	-
^{103}Pd	0.021	17 days	-	-	-
^{192}Ir	0.35	74 days	2.5	11	19
^{226}Ra	0.78	1620 years	12	45	25

sources to be implanted into the patient must strictly follow the following basic rules that are imperative:

- to minimize as much as possible the time spent in the area of radiation exposure;
- to maximize the distances from the sources;
- to minimize the activity of the sources

Even though the staff is capable of handling the sources safely, the risk of contamination at the department storing up and applying radioactive material is not excluded. If it does happen, it spreads over the objects and the staff. The most exposed parts of the body are the skin, respiratory and alimentary tracks. The contamination of other organs depends on the chemical properties of the source, *e.g.* Sr-90 affects the bones. The decontamination should be carried out strictly according to the prescribed regulations. After each application of radioactive sources, the irradiation levels should be necessarily tested by radiation detectors and remove eventual residual radioactive substance in compliance with the standards. Throughout the year, regular testing of the sources should be carried out following manufacturer's instructions. Handling with radioactive sources should only be entrusted to specifically trained personnel, who have obtained the required knowledge and skills of radiation protection and who regularly attend refreshment courses on radiation protection as prescribed by law.

Handling with radioactive sources

Radioactive sources are kept in safety box, made from radio-protective material. At the distance from the box of 10 cm, the exposure should not exceed 1 $\mu\text{Sv/h}$. The safety box and the shelter where it is kept under lock should be tagged with noticeable radiation warning label. A record book, keeping records of implanted and returned radioactive sources, should necessarily be kept beside the safety box. The shelter in which the

safety box is stored should be equipped with ventilation system that provides good airing to the room as gas products may be generated due to radioactive decay of the sources. Regular checking and cleaning of the sources should be performed in an area shielded by a lead wall and using a system of mirrors in order to avoid direct strike of photons on the eye lenses. The sources should be transported by special carriage under radiation protection from the shelter to the patient. The eventual leakage on the surface of the transport trolley should not exceed the value of 2 mSv/h. If the implantation of the source is not carried out manually, but mechanically with the after-loader, the radiation protection is much safer. The source can be automatically removed out of the patient whenever nursing personnel is entering the room. The communication between the patient and nursing staff should be provided through audiovisual media in order to allow the patient to ask for help or for service, whenever necessary. No visitors are allowed during irradiation and the cleaning-up of the patient's room is reduced to a minimum. After the therapy is completed, the whole room, including bedclothes, should be examined for eventual contamination with radioactive substance. The risk of contamination is particularly high if irradiation is performed with unsealed radiation sources, such as I-131 that is administered in pills. The sources permanently implanted into the prostate, such as the seed sources I-125 and Pd-103⁵, do not require special protection because these are the sources with low energy, *viz.* 29 keV and 21 keV, for I-125 and Pd-103, respectively. Upon discharge from the hospital, the patients with implanted sources receive the necessary instructions on radiation protection and are also warned that the first few days after the implantation there is a risk of losing the implanted source with the secretion of the urine. If this occurs with the implanted I-125 with the half-life period of 60 days, special protection instruction should be

followed. If the patient dies the first year after the implantation, cremation of the body is not allowed. The isotope Sr-90 applied in the irradiation of eye malignancies is currently by and large replaced by beta-radiant, e.g. Ru-106. The highest beta-energy that strontium (Sr-90) emits is 2.3 MeV, which means that it can penetrate 12 mm deep into the water. The beta-energy generated by ruthenium (Ru-106) amounts to 3.54 MeV; this implies that application of Ru-106 requires more severe safety measures. The safety containers are therefore made of substances with low atomic number in order to avoid braking radiation. Alpha-radiants are not used in brachytherapy. If the source emits them, as it is the case with Ra-226 and Rn-222, their particles are completely absorbed in the wall of the safety coating. Radium is a highly radioactive element with an immensely long half-life period of 1620 years. The contamination with this isotope poses a serious problem because decontamination is very costly and demanding as all the surfaces that were contaminated need to be completely and permanently removed. Californium (Cf-252) is one of the few neutron radiation sources whose application in brachytherapy is still restricted as long we are not able to yield a higher radiobiological effect in poorly oxygenated tumor tissues. In radiation protection, particular concern should be paid to neutrons as their biological efficiency, at the same dose as in photons, is ten times that of photons. Therefore, the containers where Cf-252 is kept should be extremely carefully protected. Primary shielding should be made of a substance with high atomic number, e.g. lead (Pb), which is additionally layered with a substance with low atomic number, e.g. polystyrene.

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