RADIATION PROTECTION PROCEDURES AND DOSE TO THE STAFF IN BRACHITHERAPY WITH PERMANENT IMPLANT OF THE SOURCES

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1. INTRODUCTION

The treatment of intracapsular prostate cancers with the permanent implantation of low energy sealed radioactive sources (^{103}Pd – ^{125}I) offers the same probability of curing the tumour as surgery and external-beam radiotherapy, with a minimum incidence of unwanted side-effects. (1)The first attempts of using sealed sources for treating prostate cancers go back to 1917, when Barringer (2) reported the results obtained with the implant of ^{226}Ra needles. Beginning from that period the interest for prostate brachitherapy has shown a "fluctuating" trend, due especially to the technological possibilities and to the status of the alternative treatment modalities (surgery, external radiotherapy). The main reason of the substantial failure of brachitherapy as compared to the two other treatment modalities had two main causes: the energy, too high ($\overline{E}$ 840 keV), of γ-radiation emitted by ^{226}Ra in equilibrium with its decay products and the lack of *imaging techniques* able to visualize with sufficient accuracy both the prostate and the arrangement, inside it, of the radioactive sources.
The employ of low energy γ-emitting radionuclides began in 1974, when Whitmore et al. (3) working at the Sloan Kettering Memorial Cancer Hospital of New York suggested the use of ^{125}I sealed sources for the realisation of interstitial permanent implants. Also this attempt, though reducing the side effects typical of the surgical intervention (incontinence, impotence), did non give the expected results in terms of local control of the disease and, as a consequence, of the survival's length. This partial failure was attributed to the fact that, in most cases, the dose distribution inside the target volume was not homogeneous, due to the inadequacy of the available imaging techniques used for checking the real position of the sources, during their manual insertion in the tissues.
In the last ten years, however, great progresses have been made in the US-imaging techniques, in the manufacture of suitable sealed sources of ^{103}Pd and ^{125}I , in the development of computer programs able both to acquire US-images and to calculate and display in real time the dose distribution. In selected cases, the permanent implant of such sources has demonstrated of being alternative to the surgical intervention and even to external conformal radiotherapy.

2. MATERIALS.

Physical, geometrical and dosimetric characteristics of the sources. The physical characteristics of the sources employed for the permanent implants, that must be taken into consideration also from the point of view of radiation protection, are listed in Table 1. The structure of the seeds is shown in Fig. 1 and 2.

Radionuclide	**Type of decay**	**Production Process**	**$T_{\frac{1}{2}}$ (days)**	**Energy of γ-radiation (keV)**	**HVL (mm Pb – mm of tissues)**
Pd-103	EC – 100%	^{102}Pd(n,γ)^{103}Pd	17	21	0.008 - 23
I-125	EC - 100%	^{124}Xe(n,γ)^{125}Xe → β^- (18 h) ^{125}I	60.2	28	0.025 - 37

Table 1. Physical characteristics of the radionuclides ^{103}Pd and ^{125}I

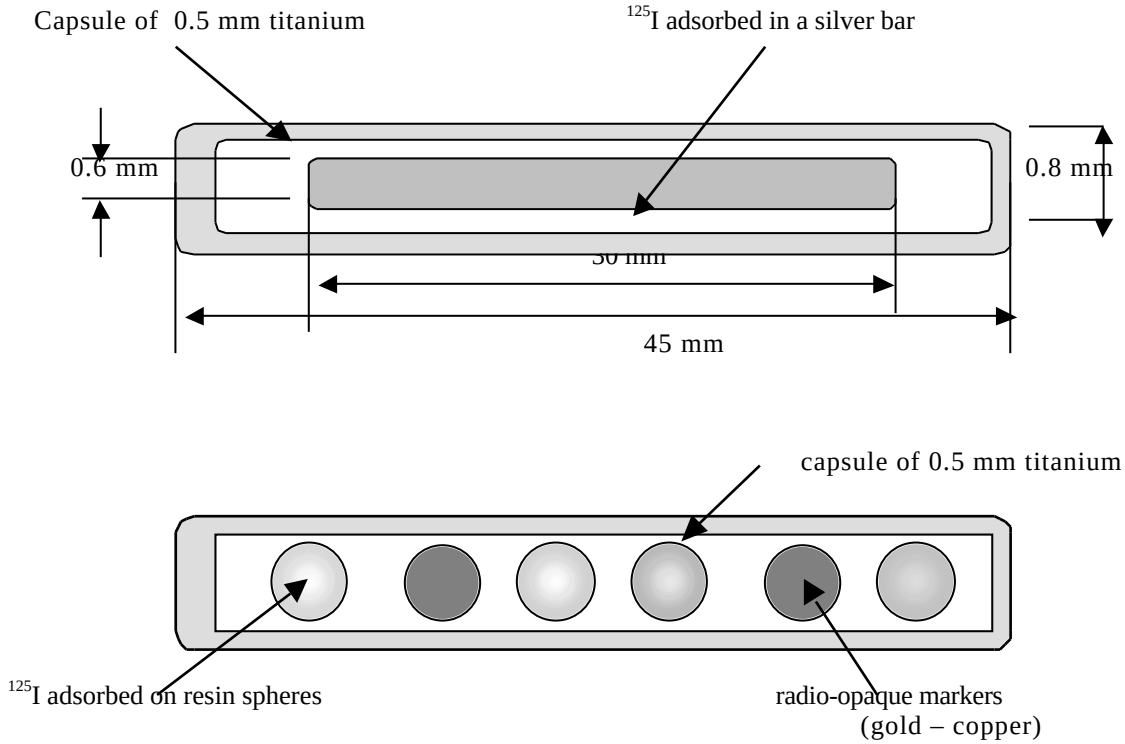

Figure 1. Geometrical characteristics of the ^{125}I sources (mod. 6711 in the upper part of the figure, mod. MED3631-A in the lower part)

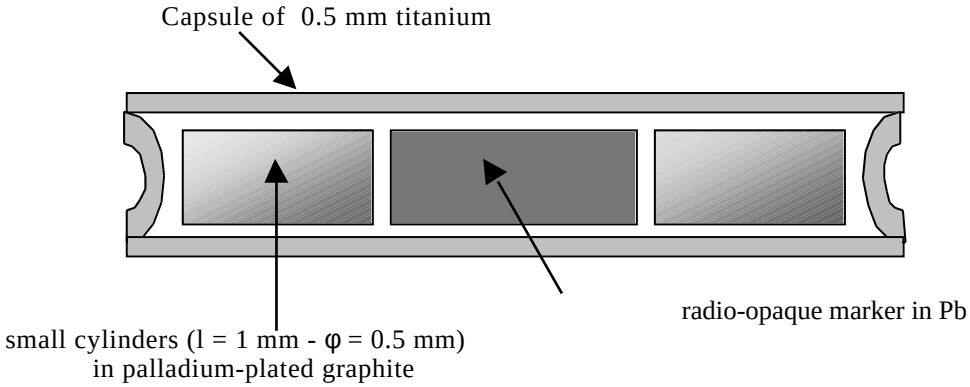

Figure 2. Geometrical characteristics of the ^{103}Pd sources

The dose distribution around both type of sources is characterised by a strong anisotropy, which is taken into consideration for the treatment planning by introducing a so-called "anisotropy factor" or a so-called "anisotropy function" $F(r,\vartheta)$, but which can be neglected from the point of view of radiation protection. The dosimetrical parameters to be employed for calculating the dose distribution around the sources have been defined by Group n. 43 of AAPM (American Association of Physicists in Medicine).(4) In our protocols, the activity of each iodine and palladium sources is "standardised": 13.32 MBq (0.36 mCi) for ^{125}I "seeds" and 51.8 MBq (1.4 mCi) for ^{103}Pd seeds. In order to achieve at the periphery of the prostate capsule the *prescribed dose* (*"minimum peripheral dose"*) of 145 Gy when ^{125}I seeds are used and of 125 Gy when ^{103}Pd seeds are used, some tens of seeds must be implanted, the exact number depending on the size of the prostate. The ranges of the number of implanted seeds and of the corresponding total activity values are listed in Table 2.

Source	Minimum peripheral dose (Gy)	Total number of seeds	Total activity (MBq – mCi)

Pd-103	145	60 – 120	799.2 – 1598.4 21.6 – 43.2
I-125	125	50 – 100	2590 – 5180 70 – 140

Table 2. Ranges of the total number of seeds and of the corresponding total implanted activity /treatment

3. METHOD.

The technique used for the treatment is based on the following steps:

- Preliminary evaluation of the size and of the shape of the prostate by trans-rectal echotomography, with acquisition and storage of a series of axial images 0.5 cm apart from each other
- Computerised simulation and theoretical optimisation of the treatment, based on the stored images, enabling to evaluate both the number and the arrangement of the seeds inside the prostate (*pre-planning*)
- Insertion of the seeds into a series of hollow long needles, ready for being inserted into the prostate of the patient
- Implantation of the seeds into the prostate of the patient, by trans-perineal way and under trans-rectal real-time US-guidance (performed exactly in the same geometrical conditions, as the preliminary echotomography) in order to release the sources as near as possible to the planned positions (for this aim a "template" equipped with a series of holes is used and the US images are superimposed to a suitable grid, having steps of 0.5 cm)
- Optimisation of the arrangement of the seeds by a (real-time) computer program and a fluoroscopic control of the real positions reached by each seed, which, due to local anatomical conditions, can differ from the planned ones.

In the following Fig 3. the positions of the seeds and the corresponding isodose curves in an axial plane are shown. In Fig. 4 the 3D reconstruction of the implant is displayed.

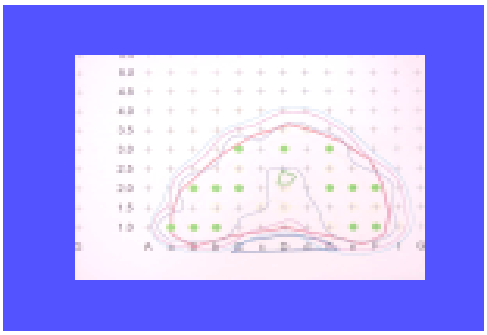

Figure 3. Position of the seeds in an axial plane and corresponding isodose curves

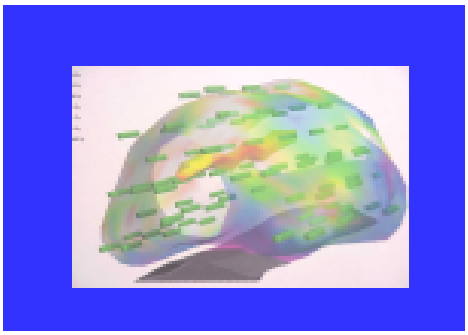

Figure 4. 3D reconstruction of the implant

4. RADIATION PROTECTION PROBLEMS.

The whole procedure of implantation of the prostate with the radioactive seeds (that is generally performed under spinal anaesthesia) involves different operators (radiotherapist, urologist, anaesthetist, radiation technician, medical physicist, nurses, etc.), each having a specific task. In Table 3 the phases of the procedure involving radiation protection problems are reported.

Phase of the procedure	Operator
1. Opening of the transport container and of the stainless steel cases containing the seeds (s. Fig. 4)	1. Radiation technician
2. Check of the number/activity of the seeds	2. Radiation technician / medical

			physicist
3.	Insertion of the seeds into the hollow needles	3.	Radiation technician
4.	Implantation of the charged needles in the patient	4.	Radiotherapist / urologist
5.	Medical assistance of the patient during the implantation	5.	Anaesthetist / nurses
6.	Possible real time computer evaluation and optimisation of the implant	6.	Medical physicist / radiotherapist
7.	Environmental monitoring during the implantation	7.	Medical physicist
8.	Final monitoring of the implanted patient	8.	Medical physicist

Table 3. Tasks involving the possibility of external exposure of the operators

For the opening of the transport container and of the cases containing the seeds a mobile shield, equipped with a 0.5 mm Pb thick lead glass (corresponding to 20 HVL for the radiation emitted by ^{125}I) is available (s. Fig. 5). Moreover, during this phase, as during the check of the number and of the activity of the seeds, the operators wear a lead-rubber apron (0.25 mm Pb equivalent), 0.10 mm Pb equivalent gloves and 0.25 mm Pb equivalent lead glasses. The same protective devices are worn by the radiotherapist/urologist who implants the charged needles. The other operators present in the operating room during the implantation, for whom the risk of exposure of the hands and of the eyes is negligible, wear only the lead-rubber apron, that is necessary for shielding not only the radiation field produced by the sources, but also the scattered X-radiation produced during the fluoroscopic control of the position of the implanted seeds. Radiation technicians, medical physicists and radiotherapists were provided with the following personal dosimeters:

- Film badge, for the evaluation of the effective dose
- TLD dosimeters, for the evaluation of the doses to the hands and to the eyes.

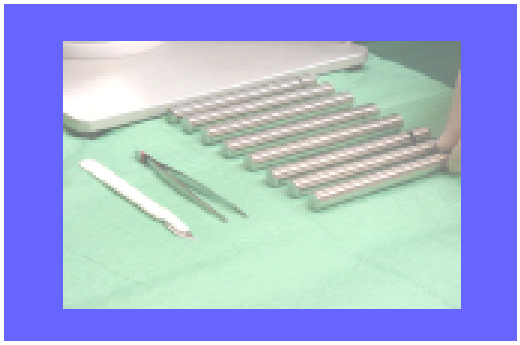

Figure 4. Stainless steel cases containing the seeds

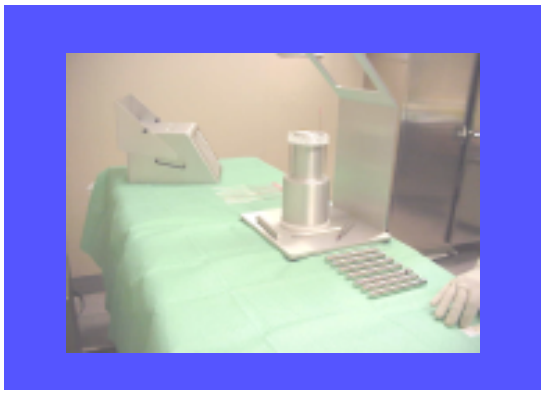

Figure 5. From left to right: box for transporting the charged needles from the preparation room to the operating room, needles, shielded container and screen, stainless steel cases containing the seeds

RESULTS. Brachitherapy of prostate tumours with permanent implant of radioactive seeds (^{103}Pd at the beginning, and now only ^{125}I) started in october of 1999. Since then, 140 patients have been treated, with results very satisfactory from the clinical point of view. Also the radiation protection procedures adopted have been very effective; the more exposed workers have been the radiation technician entrusted with the loading of

the needles and the radiotherapists performing the implant. The doses received in one year by such workers are listed in the following Table 4.

Category of operator	Effective dose (mSv)	Dose to the eyes (mSv)	Dose to the hands (mSv)
Radiotherapist n. 1	0.080	0.025	1.35
Radiotherapist n. 2	0.075	0.025	1.05
Radiation technician	1.0	1.30	4.35

Table 4. Doses received in 2001 by the operators (56 patients treated)

The intensity of the radiation field around the implanted patients depends on the following parameters:
- Radionuclide employed (^{103}Pd/^{125}I)
- Number of implanted seeds
- Size and anatomy of the patient and of the implanted region

The ranges of the air kerma rates measured around the patients are listed in Table 5

Radionuclide	Air kerma rate (μGy/h) at different distances from the patient		
	0 cm	20 cm	50 cm
103-Pd	4 - 30	2 - 10	1.5 – 5
125-I	15 - 100	4 - 50	2 - 10

Table 5. Air kerma rates at different distances from the implanted patients

The data reported in Tables 4 and 5 demonstrate that:
- as regards the workers, the radiation protection measures taken are adequate and effective and the whole procedure can be considered as completely safe from the point of view of radiation protection
- as regards the general population, the implants are completely compatible with a normal relation life of the treated patients.

5. REFERENCES

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