BETA-RADIATION EXPOSURE OF MEDICAL PERSONNEL

Ilona Barth, Arndt Rimpler, Jürgen Mielcarek

Federal Office for Radiation Protection (BfS), Köpenicker Allee 120-130, D-10318 Berlin, Germany
E-mail: ibarth@bfs.de; arimpler@bfs.de; jmielcarek@bfs.de

Abstract. Beta-emitters are increasingly used in medicine in unsealed and sealed form. Therapeutic applications benefit from the fact that the beta-energy can be totally absorbed in a small delimited tissue volume. The occupational beta-radiation exposure was determined for the personnel at different workplaces in the following fields of medicine:

- Radiosynoviorthesis (Y-90, Er-169, Re-186) - a therapy of inflammatory joint diseases
- Preparation and application of Re-188 liquid-filled balloon catheter for vascular brachytherapy
- Use of the Beta-Cath™ system (Sr-90/Y-90) in the therapy of in-stent-restenosis patients
- Change of the P-32-Source at a Galileo™ system for vascular brachytherapy
- Treatment of an eye tumour with Ru-106/Rh-106 eye applicator and

Practices in these fields are characterized by handling high activities, very small distances between source and skin as well as high risk of contamination when using unsealed sources and unsatisfactory area and personal dosimeters. Very sensitive thin-layer thermoluminescence dosimeters (TLD) were used to determine the skin exposure to the hands due to beta-radiation. At some workplaces local skin doses $H_p(0.07)$ at the fingertips due to direct radiation of more than 100 mSv up to about 700 mSv per working day were determined. In addition, exposures in the same order of magnitude were sometimes caused by contamination of the skin. Thus, several simple radiation protection measures have been introduced, leading to a considerable reduction of occupational exposure. Some examples of such measures will be presented. Furthermore, the application of an authorized partial body personal beta-dosemeter with workplace-specific correction factor is proposed.

1. Introduction

Beta-emitters are increasingly used in medicine in unsealed and sealed form. Contrary to most of the gamma-emitters, the energy of beta-radiation can be totally absorbed in a small delimited tissue volume. Thus the exposure can be limited to the tissue to be treated. The higher effectiveness of beta-radiation is reflected by the higher values of the beta-ray dose functions in comparison to the gamma-ray dose coefficients. This leads to dose rates of beta-emitters that are two orders of magnitude above those of gamma-emitters for equal activities and for short distances. That is favourable in therapeutic application, but may cause an increased risk of partial body exposure of the medical staff, especially if high activities are frequently handled in syringes or vials with insufficient radiation shielding.

Often, users are not aware of the risk they are exposed to. One reason for this is the lack of suitable area and personal dosimeters to determine the exposure. Another reason is that estimations of exposure to the hands are not quite easy to perform and therefore these dose assessments are seldom done. In addition, contamination measurements are carried out rarely and often insufficiently. Hence, an investigation has been initiated to analyse the radiation situation and to evaluate the implemented radiation protection measures at several medical workplaces.

2. Measuring quantity and technique

The appropriate measurand for radiation exposure in beta-radiation fields is the personal dose equivalent, $H_p(0.07)$. To determine the local skin dose the equivalent dose is averaged over an area of
1 cm² of skin at a nominal depth of 0.07 mm and at a respective point of interest. Since irradiation of extremities can be very inhomogeneous, it is not appropriate to determine the average dose to the respective extremity but the maximum value.

For the measurement of the local skin dose, thin-layer thermoluminescence detectors (TLD) of the MCP-Ns™ type, made of LiF:[Mg,Cu,P] with an area mass of the sensitive layer <10 mg/cm², were used. The TLD were welded in a PE-bag with a foil thickness of 4-8 mg/cm² and fixed at the measuring point by means of perforated adhesive tape. The tapes were adhered mainly to the fingertips on the palm and on the back of the hands.

For area dose rate measurements, beta-dosemeters DL 1™ and the BD 01™ - both based on an ionisation chamber - were used. Contamination measurements were performed using a monitor of the FHT 111 M™ type with a butane counter.

3. Results

3.1 Radiosynoviorthesis

By application of nuclear medicine procedures in rheumatology and orthopaedics the efficient local treatment of chronic inflammatory joint diseases is possible [1]. In radiosynoviorthesis colloidal radioactive solutions (Er-169, Re-186 or Y-90) are injected into inflammatory joints. Investigations of exposure to the medical staff were performed in 10 hospitals and doctor’s surgeries. Very high local skin doses were measured for both the assistants who prepared the syringes and for the physicians who injected the radiopharmaceutical solutions. Local skin doses were determined up to about 100 mSv per working day for assistants and in some cases up to about 200 mSv per working day for the physicians due to direct radiation [2].

The very high doses were mainly caused for both the assistants and for physicians by holding the upper end of the cannula between thumb and index finger during connecting or separating the cannula and the syringe, or during the injection of the radiopharmaceutical solutions into the joint. The highest exposure occurred by using Y-90 solutions due to the high beta-energy of Y-90. The application of Er-169 has hardly any effect on direct radiation exposure, whereas Re-186 exposure is not negligible. The mean specific dose (local skin dose related to applied activity) added up to about 60 µSv/MBq (ranging from 13 to 233 µSv/MB) for Y-90 and about 20 µSv/MBq (4 - 40 µSv/MBq) in using Re-86.

In some cases a skin contamination of the personnel occurred at a considerable level. Due to the high specific activities of the solutions (e.g., about 500 MBq/ml Y-90) invisible tiny contamination spots may cause high local skin doses. Estimates performed under realistic conditions yielded exposures of
the same order of magnitude as those caused by direct radiation. This result has been found in investigations at several institutions.

The high doses mentioned before are completely unacceptable. Consequently, some radiation protection measures had to be introduced. First of all, the awareness of the personnel regarding high dose levels as a result of touching vessels containing beta-emitters and/or from contamination of the skin had to be stimulated.

The use of appropriate shielding of vials, syringes as well as the application of suitable manipulators (e.g. tweezers, forceps) considerably reduced the exposure of more than one order of magnitude. But the use of forceps for holding the cannula during the injection is not quite easy and is often refused by physicians. To further improve the situation a special plastic protection ring for the upper end of the cannula (Figure 1 and 2) was developed. These rings prevent contacting the cannula with thumb and index finger during the injection (Figure 3) and during the preparation of the syringes (Figure 4). First measurements indicated that the specific local skin dose at the fingertips obtained during the injection of Y-90 solutions into the knees (Figure 3) could be reduced to about 2 μSv/MBq (0.5 – 5 μSv/MBq).

3.2 Preparation and application of Re-188 liquid-filled balloon catheter for vascular brachytherapy

The aim of vascular brachytherapy is preventing restenosis after angioplasty and stenting in patients with severe coronary artery diseases. A possibility to realize this objective is the use of a balloon catheter filled with Re-188 solution. A very high specific activity of this solution (at least 5-10 GBq/ml) and a total activity of 10 – 20 GBq are necessary to achieve a sufficient dose in the stenosed artery wall (30 Gy in 0.5 mm wall depth) in a tolerable time for the patient.

Re-188 is the product of a W-188/Re-188 generator. The concentration of the eluted solution is not yet high enough for this brachytherapy. Thus, the preparation of higher specific activities is necessary. The radiation exposure during this process was investigated in two hospitals. At the beginning of the investigations in both hospitals the local skin dose at the fingertips was about 100 mSv per working day due to direct beta-radiation. In addition, in one case a local skin dose of about 200 mSv was estimated due to contamination at both hands.

For the treatment of patients, the Re-188 solution is filled in a special balloon catheter. After the treatment the catheter is drained by the doctor for nuclear medicine. The removed catheter must be put in a special shielding repository and finally the equipment has to be dismantled and the radioactive
waste disposed. While the cardiologist is injecting the contrast medium, his hands are close to the filled catheter. Thus, both physicians are exposed to beta-radiation.

Measurements were performed in a catheter laboratory in one clinic only. First results revealed extremely high exposures. The local skin dose at the fingertips of the doctor for nuclear medicine amounted to almost 500 mSv at the left thumb due to the treatment of one patient only. In this day all activities (preparation, application, waste management) of the doctor for nuclear medicine resulted in a total dose at the thumb of about 700 mSv. Consequently, the annual limit of the skin dose of 500 mSv was already exceeded in one day. At the fingertips of the cardiologist a local skin dose of about 30 mSv was measured.

First of all, these high exposures can be reduced by consequent shielding of all activity containing vials, syringes, little hoses, and ion exchange cartridges. Moreover, the use of a semi-automatic preparation facility is beneficial. Along the lines of radiosynoviorthesis, the use of manipulators and thus preventing the personnel to touch the containers filled with activity (e.g. syringes, vials, hoses) was also very effective to reduce the doses. Additionally, exposure during the waste management was lowered to a negligible level by storing the contaminated equipment for about 10 half lives before dismantling.

After introducing these measures the exposure could be decreased considerably. Measurements have shown that the doctor for nuclear medicine got a dose of about 30 mSv due to all activities at a day. The exposure of the cardiologist still reached almost 20 mSv. But at this day one patient was treated only.

In a third verification measurement the local skin dose of the cardiologist could be reduced to 7 mSv although two patients were treated. He kept a longer distance to the filled catheter. The doctor for nuclear medicine got a maximum local skin dose of 42 mSv due to preparation, two applications, and waste management at this day. After the first treatment he shortly touched the cannula to separate the catheter with his fingers, resulting in a dose of 18 mSv at the thumb.

Currently very few institutions in Germany have the licence for medical research with the Re-188 brachytherapy system.

3.3 Vascular brachytherapy with the Beta-Cath™ system

Another way for treating in-stent-restenosis is the application of sealed sources. For this aim the Beta-Cath™ system was developed. It consists of a radiation source train (Sr-90/Y-90, about 2 GBq), transfer device and delivery catheter.

The beta-radiation exposure of the personnel was determined in two catheterization laboratories [3]. During the investigations the applied beta-doses at the vascular wall of the patients were 19 Gy and 23 Gy, respectively.

The local skin doses at the fingertips of the medical staff was lower than 1 mSv per treated patient. Only in one case 1 mSv was measured at the fingertips of the cardiologist. It was assumed that the cardiologist held unintentionally his hand above the delivery catheter while the source train was ejected. At the surface of the transfer catheter a dose up to 24 mSv was determined during the therapy of one patient at normal operation. As a result of a mistake during an operation a dose of 52 mSv was found. It must be pointed out that it is not required to hold the catheter in the hands during the treatment of patients.
3.4 Change of P-32 Source at a Galileo™ system

An afterloading device for endovascular brachytherapy is the Galileo system with a sealed P-32 source (10 GBq). The source delivery unit is designed to calculate precise treatment time and to allow delivery of the source wire.

The procedure of source exchange including the subsequent quality assurance was investigated with regard to radiation exposure of the personnel. Because of the short half life of P-32 (14.3 days) the source must be exchanged by the medical physics expert on site in the hospital after a short period of time; two half lives are recommended.

The local skin dose to the hands of the medical physics expert was lower than 0.1 mSv for all worksteps. At the surface of the shielded delivering catheter, also a dose below 0.1 mSv was measured after two passages of the source wire. For comparison, the dose at the unshielded catheter amounted to about 200 mSv.

3.5 Treatment of eye tumour with Ru-106/Rh-106 eye applicator

Beta-radiation is also used for therapy of special types of eye tumours. For this purpose Ru-106/Rh-106 eye applicators are available. These applicators must be stitched at the eyeball by an ophthalmologist.

Measurements of exposure to the hands from preparation of an applicator (type: COB, 6 Gy/h at surface) by the medical physics expert as well as from stitching the applicator at the eyeball by the ophthalmologist were carried out for one patient. This operation was a very difficult one because of the location of the eye tumour. So it lasted longer than usual.

The personnel used strictly forceps and tweezers to avoid handling close to the applicator. Thus the exposure of the hands was low. The maximum doses of the medical physics expert and the ophthalmologist added up to lower than 1 mSv per treatment.

3.6 Radioimmunotherapy with Zevalin™

Zevalin™ (Y-90-ibritumomab tiuxetan) is the first radioimmunotherapy agent for compassionate use in Germany. It is administered for the treatment of patients with relapsed and refractory non-Hodgkin’s lymphomas. Zevalin™ consists of an anti-CD20 monoclonal antibody linked to the radioisotope Y-90. The monoclonal antibody component enables radioimmunotherapy to be targeted towards malignant cells expressing CD20 antigen only. The beta-radiation of Y-90 kills the target cell and other malignant cells in the surrounding area.

Immediately before administration, the antibody component must be radiolabelled with Y-90 on site. Activities of about 2 GBq are handled in this procedure. Thus considerable partial body doses to the medical personnel may occur, if adequate radiation protection measures are not considered. In cooperation with the provider of Zevalin™, the experience gained at workplaces described above were already considered at the first application. Thus the Y-90 delivery vial, the radio-labelling vial as well as the syringes were adequately shielded by polymethylmethacrylate (PMMA) protectors. Nevertheless, the maximum local skin dose at the fingertips of the doctor for nuclear medicine amounted to 25 mSv during the radio-labelling and administering the therapeutic dose of Zevalin™ to the patient.

It can be assessed that the skin dose can be reduced by practising the specific worksteps with inactive solution to gain experience. Further investigations will be carried out.
4. Conclusions

Local skin doses to the hands of the personnel can reach very high values due to the exposure of beta-emitters during their use in medicine. In one case (preparation and application of Re-188 liquid-filled balloon catheter for vascular brachytherapy) the measured dose per day at the fingertips of a doctor for nuclear medicine exceeded considerably the legal annual limit for skin dose (500 mSv). In other cases (radiosynoviorthesis) it was estimated that the skin dose limit was also exceeded by direct radiation due to the expected use of beta-emitters within a year. In use of unsealed sources, additional exposures must be considered following a possible contamination of the skin that can also be notable.

The doses of beta-radiation that the staff is exposed to during their working hours are mostly not reflected adequately with the dosemeters used up to now. If finger ring dosemeters were worn, they were usually calibrated for photons. Thus, the staff did not get any information about the high skin exposure at the hands due to insufficient response to beta-radiation. Therefore, the person gets a deceptive impression of very low exposure. Suitable area dosemeters are rare and not commercially available. Other precautions, e.g. calculations of the exposure were not done or not properly done.

As a result of the findings, lots of information about the high exposure risk were disseminated under the affected personnel and the responsible authorities. Especially for radiosynoviorthesis a leaflet about radiation protection measures for beta-radiation was distributed.

Drastic dose reductions can be achieved by an increased awareness of the problem. By using appropriate shielding (plastics, e.g. PMMA) and manipulators (e.g. tweezers and forceps) to avoid touching the unshielded cannula during the radiosynoviorthesis the specific dose at the fingertips of the doctors could be decreased to about 1 µSv/MBq. But it is not quite easy to hold the cannula with forceps during the application. That’s why a special cannula ring made of plastic was developed. This ring can already be used during the preparation of the syringes to avoid touching the cannula for separating the filled syringes by assistants.

During the preparation of the Re-188 solution and its application in endovascular brachytherapy appropriate PMMA shielding and use of forceps led to significant reduction of radiation exposure, too.

In general, the staff needs more practice in handling the beta-emitters as well as in the use of radiation protection measures. A stricter regime for the measurement and removal of contamination must be implemented at workplaces where unsealed sources are used. Furthermore, radionuclide-impermeable gloves must be worn. In some cases latex gloves were not tight enough.

The radiation exposure at workplaces, where sealed sources were used, was low during normal operations. But the dose can considerably increase, e.g., when the cardiologist holds the delivery catheter in his hands during the transfer of the source train. It is a mystery to use and a wrong example that a producer of a brachytherapy device distributed brochures with a picture where the cardiologist holds the catheter between the hands during the treatment of a patient.

In Germany, the introduction of official beta-finger ring dosemeter has started recently. Since the spot where the dosemeters can be worn deviates normally from the spot of the expected maximum dose, correction factors must be applied. Further investigations are necessary to evaluate the doses determined with these dosemeters and to deduce the correction factors.

References
