APPLICATION OF THE ALARA PRINCIPLE IN MINIMIZING THE EXPOSURE OF OPERATORS OF RADIOTHERAPY CO-60 UNITS

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Abstract

The paper presents the results of mapping stray radiation fields in three different radiotherapy treatment rooms equipped with three different Co-60 machines. Based on the distribution of the ambient dose equivalent rate, the effective dose to the personnel under various scenarios has been assessed with regard to their movement and position in the room during the preparation of the machine and the patient for treatment. Analysis of the results showed that by using an optimum scenario taking into account the actual distribution of the radiation level in the room, exposure of the personnel may be reduced considerably.

Key words

Radiotherapy, Co-60, personnel, exposure, ALARA

1. Introduction

Powerful sealed gamma sources are widely used in various medical and industrial applications. There is always some radiation level around sealed gamma sources even if they are stored in a container or transferred into a so-called OFF position when not being used. One type of high-activity source which is still used at radiotherapy departments and clinics especially in developing countries is the radionuclide Co-60. Although during the OFF mode the source is kept in the shielded position within the treatment head, some photons, leakage photons, penetrate through the shielding material and appear outside the cobalt unit head. The leakage photons may further scatter and then, as a stray radiation, contribute to the radiation field in the room and thus expose operating personnel while they are preparing the patient and the machine for treatment procedures.

The radiation field formed in the treatment room is generally not homogenous because of the asymmetrical shape of the source shielding as well as the effect of various surrounding materials and accessories which may scatter photons unevenly in different directions. The leakage and scattered photons result in some exposure to the personnel which may vary throughout the room. Consequently, the radiation field shows unpredictable variations with respect to the spatial distribution of the ambient dose equivalent rate. This is why the exposure received by personnel in the room may to a certain extent be affected by their actual specific movement and position in the treatment room. Once this radiation field is known, one can optimize the behaviour of the operators taking into account the specific radiation situation and reducing their exposure in line with the ALARA principle, which is one of the basic elements of radiation protection recommended by the International Commission on

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Radiological Protection (ICRP) [1,2]. The ICRP has continually promoted the philosophy of such protection, where in normal or controlled situations the exposure should always be not only below dose limits set by the regulator, but also all possible measures should be taken to reduce this exposure to a minimum, taking into account relevant factors such as social aspects and economic aspects.

2. Radiotherapy facilities

Monitoring and analysis of leakage and scattered gamma fields in treatment rooms of different Co-60 units installed in three hospitals were performed. Two of these hospitals were in Prague while one was located in the nearby city of Kladno. Each of these facilities was unique because not only due to different irradiators but also because of differences in the treatment rooms. This surely affects the distribution of the radiation field in any of these installations with respect to the fluence rate due to the leakage and scatter gamma photons.

Faculty Hospital Královské Vinohrady in Prague

In addition to a linear accelerator, the Radiotherapy and Oncology Clinic of this hospital operates also a Co-60 machine a Teragam K-2 unit delivered by UJP Praha (Czech Republic) [3]. The machine was put into operation in 2001 and the activity of the most recent source was 301 TBq (2 Aug. 2006). The treatment room with the machine installed is shown in Figure 1.

Figure 1. The Co-60 machine Teragam K-2 installed in the Faculty Hospital Královské Vinohrady in Prague.

General Faculty Hospital in Prague

The Oncology Clinic of the General Faculty Hospital in Prague uses a Theratron 1000 Co-60 machine manufactured by Nordion in Canada [4]. The unit was reloaded with a source with the activity of 477.6 TBq on 11 Nov. 2008. The treatment room with this machine can be seen in Figure 2.

Figure 2. Teletherapy Co-60 irradiator Theratron 1000 used at the General Faculty Hospital in Prague.

Regional Hospital at Kladno

A new Terabalt ACS 100 machine produced by UJP Praha [3] was installed in the Oncology Department of the Regional Hospital at Kladno in 2009 with the initial activity of the source 371 TBq (26 Nov. 2009). The treatment room with the machine is illustrated in Figure 3.

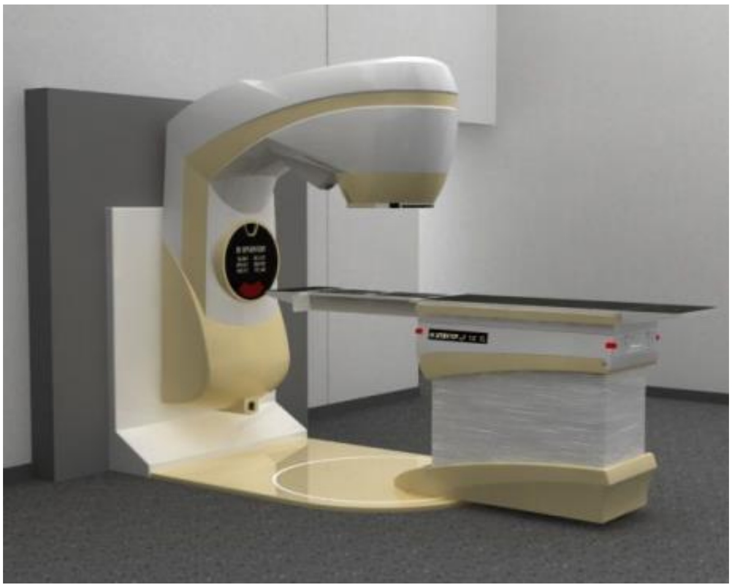

Figure 3. The radiotherapy Co-60 unit Terabalt ACS 100, which replaced an old Cs-137 irradiator at the Regional Hospital at Kladno.

3. Radiation fields in treatment rooms

In accordance with the relevant requirements introduced in the Czech Republic by the national nuclear regulatory authority (State Office for Nuclear Safety) as well as keeping in line with the IEC-60601-2-

11[4] standards for teletherapy unit heads, the leakage radiation from a Co-60 head in the source OFF position is not supposed to exceed the level of the dose rate of 20 µGy/h and 200 µGy/h at a distance from the head surface of 1 m and 5 cm, respectively. The exposure of personnel operating radiotherapy equipment due to the mixture of leakage and scatter radiation (stray radiation) in the treatment room can be assessed based on the distribution of this radiation in terms of the ambient dose equivalent and the position/movement of operators in the treatment room. The stray radiation field can be mapped using an appropriate monitor calibrated in units of the ambient dose equivalent rate. This operational quantity can reasonably approximate the effective dose as the main dose limit quantity.

The measurement of radiation fields around the head of the radiotherapy machine in the treatment room was carried out at 1 m above the floor following a grid of 30 cm x 30 cm. The monitor FH 40 G 10 [6,7] calibrated in SI units of the ambient dose equivalent rate, $H^*(10)$, in the energy range 30 keV – 1.3 MeV where its measuring range is essentially from about 80 nSv/h to 100 mSv/h. The results were processed by MatLab [8] software which was used to draw iso-levels corresponding to selected constant ambient dose equivalent rate values. This mapping was used to assess the exposure of personnel moving around the units taking into account their position in the treatment room and the time spent at that position.

Obviously, since every individual treatment room has a unique configuration, size, thickness and composition of the walls and ceiling of the treatment room as well as the distribution of other materials around including some materials and accessories in the room, the spatial distribution of the ambient dose equivalent rate is at each installation is rather unique resulting in characteristic spatial shape of relevant iso-levels at the level at 1 m above the floor.

The ambient dose equivalent rate is as expected much higher in the area close to the unit head than at the entrance door where its level is only slightly about the radiation background in the room. The actual distribution of the radiation field shows some specific pattern and is not symmetrical near the head at the patient couch where the operator spends most of his time while in the treatment room before the irradiation begins.

For the purpose of this work, the measurement has been carried out manually point by point and then the results were processed using the MatLab software. At present, the work is continuing in order to make such measurements as much automatic as possible. The aim is to use a robot equipped with the arm carrying the monitor and scanning the room continuously with the on/line transfer to the computer.

Faculty Hospital Královské Vinohrady in Prague

The spatial distribution of $H^*(10)$ around the Co-60 head in the treatment room in this hospital is presented in Figure 4. It can be seen that the radiation fields in nSv/h is unevenly distributed with the highest values of the ambient dose equivalent rate reaching nearly 8 µSv/h while its lowest value was below 0.5 nSv/h. At each measurement point the reading was taken at least three times and a final value represent an average from all measurements.

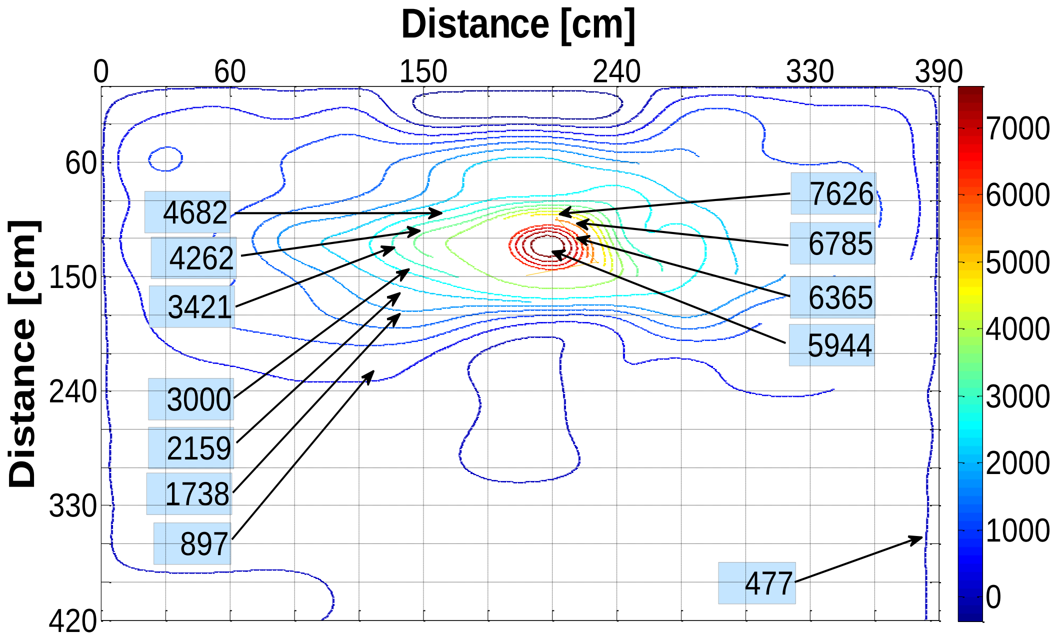

Figure 5. The spatial distribution of the ambient dose equivalent rate (nSv/h) in the in the Teragam K-2 treatment room at 1 m above the floor, only some iso-levels are presented. In this case as well as in other two distributions presented below, the head of the unit was in the initial position.

General Faculty Hospital in Prague

The Oncology Clinic uses the Theratron 1000 Co-60 manufactured by Theratronics in Canada [4]. The iso-levels of the ambient dose equivalent rate in the treatment room are in Figure 5.

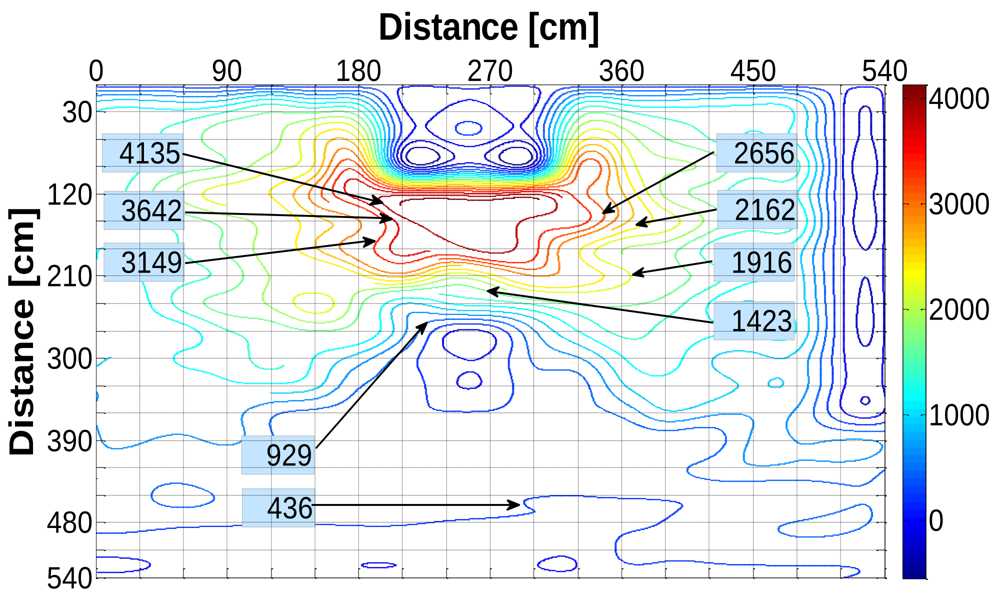

Figure 5. The spatial distribution of the ambient dose equivalent rate (nSv/h) in the in the Theratron 1000 treatment room at 1 m above the floor.

Regional Hospital at Kladno

The results of the measurement of the ambient dose equivalent rate distribution in the treatment room are shown in Figure 6.

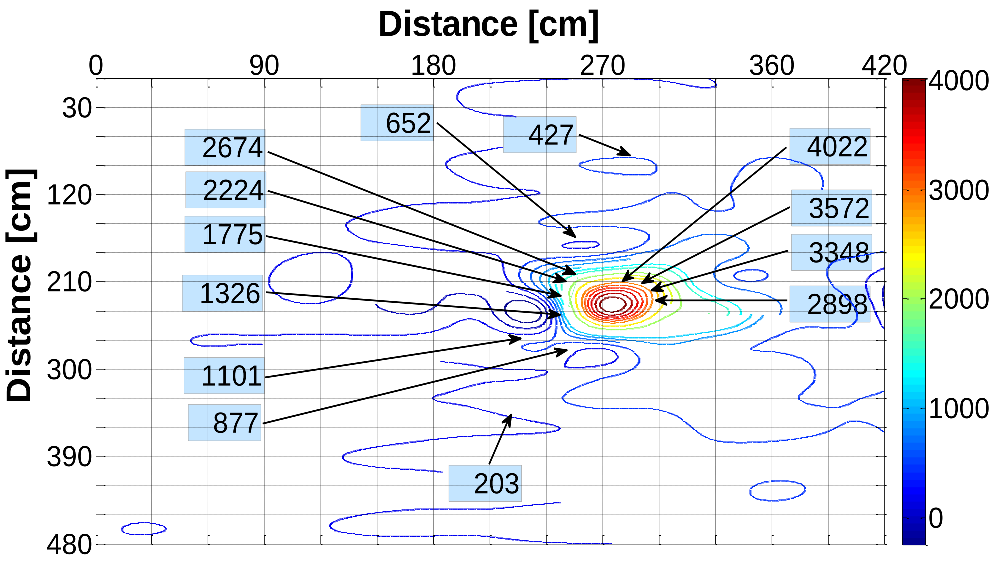

Figure 6. The spatial distribution of the ambient dose equivalent rate (nSv/h) in the Terabalt ASC 100 treatment room at 1 m above the floor.

4. Interpretation of monitoring results

The obtained results can be interpreted in many different ways. For the purpose of the assessing the possible reduction in exposure, the data from three representative situations are used to illustrate the potential for reducing the radiation burden on personnel. Table 1 gives the yearly exposure (based on the measured levels of the ambient dose equivalent from the position the operator is working in or moving around in) corresponding to a typical, the worst and the best scenarios.

It is evident that the operator may reduce his/her exposure if s/he takes into account the distribution of the radiation field in which s/he has to move. Usually, when this is not considered, the exposure is likely be higher than the exposure corresponding to the situation in which s/he pays attention to the surrounding field. This is illustrated in Table 1 where there the exposure associated with three specific scenarios for all three facilities is recorded.

The behaviour of operators was analyzed paying special attention how much time was spent at specific locations during the preparation of a patient for treatment. The total time per year an operator typically spends in the room is estimated taking into account three scenarios corresponding to (i) the worst case resulting in the highest exposure, (ii) the best possible practice resulting in the lowest exposure, and

(iii) the outcome when the operator takes no account of the variation in the radiation field in which s/he is working.

Based on this methodology, the annual exposure in terms of mSv/y has been assessed. The results, summarized in Table 1, show that there is considerable difference in the exposure received under the individual cases and the ALARA principle can be applied without practically any other specific requirements with respect to the need to change anything in handling the patient and the machine. One has only to keep in mind that due to the uneven distribution of the radiation field the movement of the operator should be modified accordingly.

Table 1. The exposure received by an operator of Co-60 machines during his/her presence in the treatment room. All data are normalized to the same annual workload. The exposure is expressed in terms of the total effective dose in mSv/y. The best scenario reflects the optimum procedures adopted in order to minimize the exposure taking into account the actual distribution of the radiation field.

Scenario	**Facility equipped with the following Co-60 unit**		
	Teragam K-2	**Theratron 1000**	**Terabalt ASC 100**
Worst	**3.81**	**7.32**	**1.60**
Optimized	**0.76**	**2.56**	**0.87**
Routine	**1.49**	**3.42**	**1.26**

The measurements show that in all installations scrutinized the exposure was far below the relevant annual dose limit (20 mSv/y) but at the same time the careful mapping of the radiation field inside the treatment room demonstrated that the exposure can further be reduced by more than 30% of the average or routinely received dose in each of these facilities. The differences in the exposure in individual radiotherapy departments are mainly due to diverse type of the unit, different design of the treatment room and last but not least because of different activity of the Co-60 source.

5. Conclusion

The monitoring of radiation levels in terms of the ambient dose equivalent rate around the Co-60 units in the treatment rooms at three different radiotherapy departments has shown that the iso-levels always follow some specific distributions unique for each installation. Taking into account the spatial radiation field distribution one can considerably reduce the exposure received by operating personnel during their work in the treatment room, where they spend some time setting up the machine and preparing patients for treatment. The reduction in exposure may be as much as about 40% of normal exposure where the operator does not take into account the surrounding radiation field which is not usually known. The proposed approach is aimed at minimizing exposure to personnel applying the ALARA principle. In principle, such procedure does not affect the normal operation of the source or machine and can be used in any similar situations around powerful sealed radioactive sources or radiation generators.

Acknowledgement

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References

[1] International Commission on Radiological Protection. *1990 Recommendations of the International Commission on Radiological Protection.* Publication 60. Ann. ICRP 1 (3) (1991).

[2]International Commission on Radiological Protection. *2007 Recommendations of the International Commission on Radiological Protection.* Publication 103. Ann. ICRP 1 (3) (2009).

[3] Teragam K-2, UJP Praha, a.s., Nad Kamínkou 1345, Prague, Czech Republic; http://www.ujp.cz/?lang=en.

[4] Theratron 1000, MDS Nordion, 447 March Road, Otawa, Canada; http://www.theratronics.ca/.

[5] Internation Electrotechnical Commission, Part 2: Particular requirements for the safety of gamma beam therapy equipment, 1997, IEC-60601-2-11.

[6] FH 40 G Multi-Purpose Digital Survey Meter; https://fscimage. fishersci.com/images/F73071~wl.jpg.

[7] Hupe, O., Ankerhold, U. *Determination of ambient and personal dose equivalent for personnel and cargo security screening.* Rad. Prot. Dosimetry, Dec. 2006, 121 (4), pp. 429-437.

[8] Version 7 (R14) MATLAB Software; **Error! Hyperlink reference not valid.**.