STAFF DOSE CALCULATION DURING A COBALT-60 SOURCE STUCK

by

Eman MASSOUD and Hanan M. DIAB

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One of the most postulated accidents in ^{60}Co radiotherapy units is the source getting stuck, where one or more of the staff should enter the treatment room to deal with the problem. For such an accident, an emergency plan is important. A three-dimensional model of a ^{60}Co therapy room has been done using the Monte Carlo code MCNP4B. The radiation safety measures taken and the drawings of the device are given together with suggestions for future use of the source for irradiation purposes. Moreover, the calculated results were compared with those of an experimental study dealing with this problem and were found to be in very good agreement.

Key words: source stuck, radiation exposure in radiotherapy, dose calculation

INTRODUCTION

A radiological accident is an unintended or unexpected event involving the source of the radiation or an incident with ionizing radiation, which may result in significant human exposure and/or material damage. It includes accidents with reactors, industrial sources and medical facilities. Over the past few years, not only workers, but members of the public as well, have suffered radiation injuries related to radiological accidents. The causes and consequences of radiological accidents have been a recurrent theme in the activities and programs of the International Atomic Energy Agency and World Health Organization dealing with radiation safety and prevention of radiation health hazards. These include occupational radiation protection, assessment and treatment of radiation health effects, emergency planning and preparedness and the safety of radiation sources [1].

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Authors' address:
National Center for Nuclear Safety and Radiation Control, Radiation Protection Dept.
3, Ahmed Alzomer st.
Nasr City, Cairo, Egypt

E-mail address of corresponding author:
hnndiab@yahoo.co.uk (H. M. Diab)

Radiotherapy is well established as an indispensable means of treatment in national cancer control programmes in developing and developed countries. In radiotherapy, radiation is used directly to destroy malignant tissue. With respect to radiation protection, radiotherapy is unique in a number of ways. It is the only application in which high radiation doses are delivered intentionally to a particular part of a human body without any barriers; thus, any mistake made or accident involving the source of the radiation or the beam itself, may have severe consequences not only for the patient, but in some cases for the worker who must deal with the situation. Constant reviewing of radiological accidents and their causes and the dissemination of the lessons learned and conclusions reached have proved to be a valuable tool in the prevention of such accidents [2].

Radiotherapy has evolved considerably in the last 25 years, with the advances in computer hardware image display and plan evaluation tools [3]. Radiation safety in radiotherapy is governed by national legislations, largely deriving from Publication 26 of the International Commission on Radiological Protection [4]. It is important to understand the internationally accepted framework for radiation protection and safety in medical applications in order to pinpoint where a breakdown in an accident has occurred. The safe use of a radiation source implies that radiation hazards associated with any of its particular applications are justified, that radiation protection is optimized and that individual dose limits are in compliance with official recommendations [5]. As for radiotherapy treatment planning, Monte Carlo techniques represent a powerful tool for studying difficulties in transporting radiation, such as those involving the tissue and the separation of primary and scatter dose components.

All over the world, high activity ^{60}Co sources are commonly used in radiotherapy. Intense beams of penetrating gamma radiation are needed to treat cancers, hence high energy and high activity sources are used in specially designed machines to deliver the required amount of radiation doses in a controlled manner [6].

This study has dealt with the assessment of doses required in a ^{60}Co radiotherapy unit, using the Monte Carlo technique to estimate the exposure doses of workers at various distances from the source, in the case when the dose received is a result of a stuck source accident.

MONTE CARLO TECHNIQUE

The Monte Carlo simulation of radiation transport in an absorbing medium is currently the most accurate technique of dose calculation in radiotherapy. The Monte Carlo N-Particle (MCNP) code follows a large number of particle histories, from their birth at the source, until each particle is terminated, either through absorption, its energy falling below a pre-set energy cut-off, or by escaping the geometric volume of interest. Interactions are simulated throughout each particle history, using probability density function determined from atomic and nuclear data. Each particle history is unique and typically only a very small number of the particles contribute to the tally.

The MCNP tallies are normalized per starting particle and given in the output file accompanied by the estimated statistical uncertainty. These quantities are computed after each complete Monte Carlo history, which accounts for the fact that the various contributions to the tally from the same history are correlated.

For a well-behaved tally, the estimated statistical uncertainty will be proportional to $(1/n)^{1/2}$, where n is the number of histories. Thus, to halve the estimated statistical uncertainty, the total number of histories must be increased by fourfold in order for the sample population to adequately represent the true estimation of the problem.

A Monte Carlo code is very precise in specifying complex geometry. Thus, it requires longer items to obtain an acceptable estimation of the tallies [7], if no variance reduction techniques were used. A drawback of the method is the long computing time, especially in the case of photon beams needed to get dose results of reasonable statistical accuracy. However, faster computers and adapted Monte Carlo methods [8-10], will turn Monte Carlo dose planning into a routine in the near future.

MATERIALS AND METHODS

The MCNP4B code [11] was used in this study to simulate the dose in the ^{60}Co room which has dimensions of about 6 10 m. Figure 1 illustrates the physical layout of the treatment room consisting of a radiation cell and a source manipulation room. The source rests 20 feet underground when not in use. Figure 2 illustrates the head of the ^{60}Co model theratron which was used in this study, with diaphragm was supposed to be 20 20 cm field area at 80 cm SSD (Source Surface Distance) and 15 15 cm at 60 cm for SSD. The source is mechanically pushed along a long tube surrounded by a thick block of lead towards the ON position, at which point no one except the patient is allowed to enter the treatment room. After the exposure, the source must go back to its OFF position where it may get stuck; one or more of the staff must

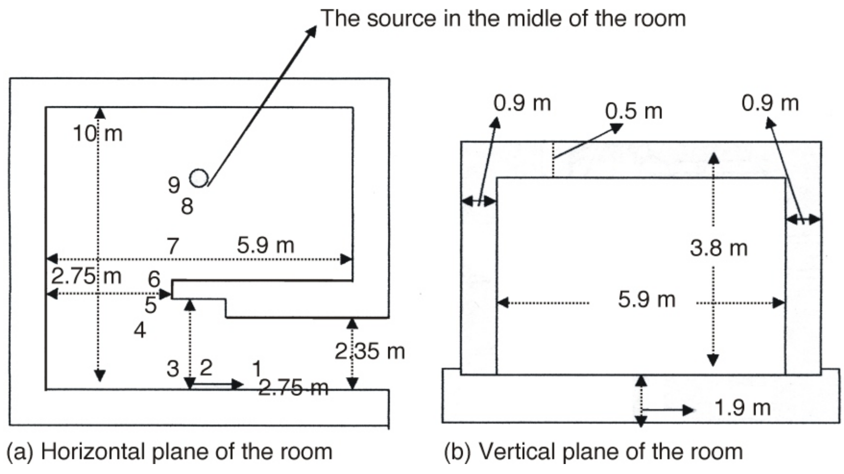

Figure 1. Cobalt-60 source layout. Numbers 1-9 denote points in the worker path

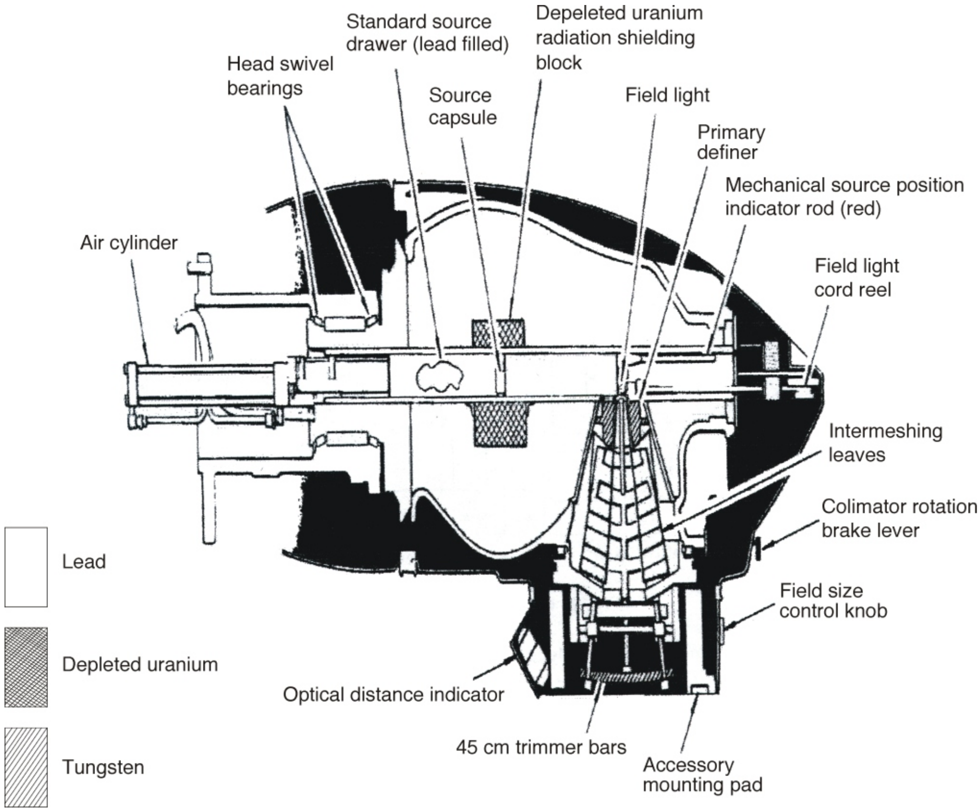

Figure 2. Head of the Co machine

then enter to deal with the problem, pushing the capsule manually, with a rod 100 cm long, prepared for this purpose. The radiation beam is defined by a manually adjustable slope-sided collimator assembly. This collimator uses a fixed rectangular field to be obtained.

Point detector techniques and F5 tally are used to calculate the gamma rays flux at different points in the path and the ANSI /ANS photon flux-to-dose conversion factor are used to determine the dose rate. Ten million photon histories are used to accumulate the tallies which are normalized to the cobalt source. The statistical uncertainties of the results range between 1-3% for all tally values. The simulation time for each calculation point is approximately 1-2 hours, at computer platform PC-1700 MHz. (The point detector technique usually consumes a lot of computer time, but also achieves a better precision). A default cross section library is used for photon tally and the code reads the cross section automatically from the photon cross section library MCPLIB22. The ^{60}Co source emits two photons per disintegration, with energies of 1.333 and 1.17 MeV.

Figure 3 gives a two dimensional plane of the described model, as given by MCNP4B in an irradiation position, where the source appears inside the tungsten shield, surrounded by a thick shield of lead.

The scenario of the accident was drawn up according to an experimental study which illustrated an experimental model of radiation dose measurements for occupational personnel during a source stuck. A PDM portable dosimeter and Kodak radiation monitoring films were fixed on a Rando phantom [12]. The time required to deal with the problem, including that required to enter the room, go to the treatment couch, shift a stretcher into position, carry the phantom onto the stretcher and remove it from the room, was found to be 40 s as:

(1) entering and leaving the room in a certain rout away from the patient required 16 s, and

(2) transferring the phantom from the table to the stretcher, 24 s.

To verify this model, the average dose in these two steps was calculated at a height corresponding to the middle point of the worker's trunk.

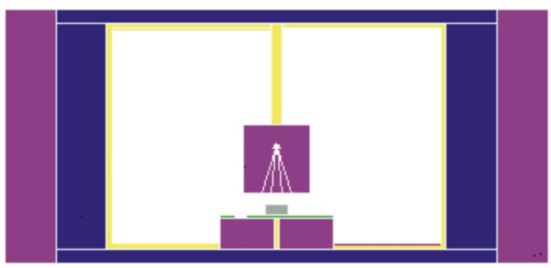

Figure 3. Vertical cross section view of the room

RESULTS AND DISCUSSIONS

The dose rate at different positions inside the room was calculated according to the scenario described previously. The calculated dose rate in the first stage was 18 Sv per 16 s, the experimental one 19 Sv per 16 s. The dose received in the case when the patient is transferred from the table to the stretcher was also calculated. The calculated dose rate turned out to be 247.5 Sv per 24 s, the experimental one 249.6 Sv per 24 s. So, the total dose received during the process was 265.5 Sv, while the experimental value was 268.6 Sv in a period of 40 s.

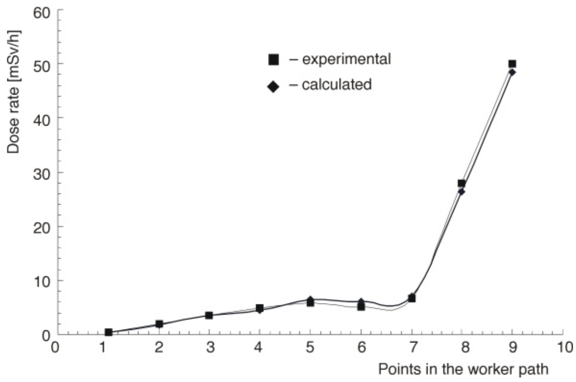

Figure 4. Comparison between experimental and calculated dose rate

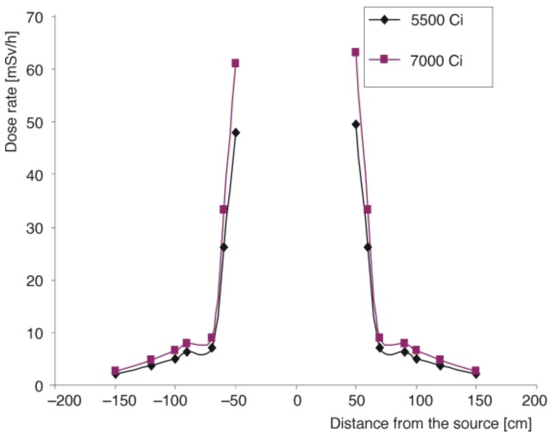

Figure 5. Dose rate distribution in Cobalt-60 treatment room for different source activities

The comparison between calculated and experimental dose rates at the same field size (20 20 cm) and the same source activity of 5500 Ci (1 Ci = = 3.7 10^{10} Bq) were illustrated. The standard deviation in the results was determined to be 20%. Figure 4 shows both experimental and calculated dose rate distributions in the postulate path of the worker dealing with the problem of a source being stuck. All these points were measured and calculated at a height of 125 cm from the floor, corresponding to the middle point of a worker's trunk. Results indicate that the dose rate increases as the worker moves closer to the source. The effect of scattered radiation appears at points 5 and 6, as shown in fig. 5, where the effect appears at 30 cm from the shield.

The dose was also measured at the activity of 7000 Ci, which corresponds to the real activity in the time being. The calculated dose rate was found to be 23.32 Sv per 16 s and 314.5 Sv per 24 s.

CONCLUSION

Some emergency procedures need to be in place at any treatment unit in case of an accident. In general, the first steps are to use the source driving mechanism to return the source to its position. If this is not immediately successful and there is a patient present, the patient must be removed from the source area and the area secured from further entry until the situation has been put under control. The worker should be well trained to deal with the problem and the dose that he has received must be recorded.

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Еман МАСУД, Ханан М. ДИАБ

ПРОРАЧУН ОЗРАЧЕНОСТИ ОСОБЉА У ТОКУ ОТКЛАЊАЊА ЗАСТОЈА КОБАЛТНОГ ИЗВОРА

Застој извора је један од најочекиванијих акцидената у радиотерапији кобалтом, када један или више техничара морају да уђу у терапијску просторију ради отклањања квара. За овакав акцидент нужан је план о деловању у ванредним околностима. Коришћењем Монте Карло програма MCNP4B, начињен је тродимензионални модел просторије за терапије кобалтом. Приказане су предузете мере радијационе сигурности и нацрт уређаја, заједно са предлозима за даље коришћење извора у сврхе озрачивања. Најзад, резултати прорачуна упоређени су са експерименталним подацима за овај случај и потврђена је њихова веома добра сагласност.

Кључне речи: застој извора, радијационо излагање у радиотерапији, прорачун дозе