IRPA Regional Symposium
Radiation Protection in Neighbouring Countries of Central Europe, Prague, 8-12 September 1997

REMANENT RADIATION FIELDS AROUND MEDICAL LINEAR ACCELERATORS DUE TO THE INDUCED RADIONUCLIDES

CZ9928512

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1. Introduction

The paper describes and interprets some results of the experimental evaluation of radiation fields around two medical linear accelerators, namely Saturn 43 and Saturn 2 Plus, used for the radiotherapeutic treatment of cancer patients. The Saturn 43 accelerator is installed in the Radiotherapy and Oncology Clinic (ROC1) in Praha-Vinohrady while the other linac is used in the Radiation Oncology Clinic (ROC2) in Praha-Bulovka. The measurements included the determination of the dose equivalent rate resulting from photons emitted by induced radionuclides produced in reactions of high-energy photons with certain elements present in the air and accelerator components as well as in shielding and building materials in the treatment rooms, which are irradiated by high-energy X-rays, and due to radionuclides formed by capture of photoneutrons, which can also contribute to induced radioactivity. While scattered photons and photoneutrons are present only during accelerator operation, the residual radioactivity creates a remanent radiation field lasting for some time following the machine shutdown. The activity induced in the accessories with which the staff come into direct contact is also a important source of unwanted exposures.

2. Medical linear accelerators

Medical linear electron accelerators [1,2] are widely used in radiotherapy, where both electrons and X-rays are applied to deliver a sufficient dose to the cancerous tissues or organs. The electron spectrum is essentially monoenergetic, with energies usually ranging from about 6 to 40 MeV. In an X-ray mode, electrons are slowing down in a suitable target where, a large fraction of the electron beam power is converted into bremsstrahlung photons characterised by monolithically decreasing energies extending up to the initial electron kinetic energy. The photons produced are emitted predominantly in the forward direction of the electron beam.

As far as shielding and radiation protection aspects are concerned, electrons generated by linear accelerators do not themselves pose any special difficulties. Actually, the electrons travel only a finite distance through matter; e.g., the range of 20 MeV electrons in water or tissue is only about 10 cm. However, a completely different situation obtains with electron accelerators used for production of high-energy X-rays and its acceleration potential exceeds about 10 MV. Photonuclear interactions in the machine parts, shielding components and other materials in the treatment room as well as in the air lead to generation of photoneutrons, which give rise to creation of induced radioactivity formed as a result of both neutron production and neutron capture processes [3-5].

3. Induced activity

Interactions of high-energy photons of bremsstrahlung radiation with some elements existing in the air and in machine parts such as the target, the collimator and beam flattener as well in other structures, including the beam dumps and shielding materials, which are intercepted by a primary beam result in production of radionuclides having various half-lives. Many of induced radionuclides are pure β^+ (positron) emitters where for each positron emitted, two 0.51 MeV photons be produced in the annihilation process. It is therefore impossible to separate these radionuclides by gamma spectrometry. The dose equivalent rate curves have to be followed to identify the radionuclides by their half-lives.

Most of induced radioactivity comes from photoneutron reactions, namely (γ, n), but to certain extent also from the reactions (γ, 2n) and (γ, in). In these photonuclear processes, which can be observed for a wide range of target elements, X-rays are the incident radiation. The product nucleus is often radioactive and resulting photoneutrons may be absorbed, forming a second radioactive nucleus. Photonuclear reactions are characterized by a threshold energy and a probability of their occurrence represented by the relevant cross section. Giant resonances occur in the reaction cross-section, with photons of energies about 20 MeV.

Photoneutrons which originate in the target, primary collimator, and flattening filter contaminate the useful beam. Others are filtered through the treatment head, while some are generated in the patient, patient support components (including the stretcher), and beam dump (also the counterweight), and most are multiply scattered by the barriers comprising the room, where elemental composition of building materials used is an important factor.

The photoneutrons, leakage and scattered X-rays, together with radiation emitted by induced radionuclides affect - each in its specific way contributes to the exposure of both the patient and the operators as well as maintenance technicians.

As to materials contained in machine parts, especially the target, collimators, field flattener and inside surfaces of the head shielding, their correct composition is usually not known and is generally different in various accelerators. Some typical elements, however, may be anticipated and resulted radionuclides assessed.

In some cases, the induced activity in the treatment aids, such as plastic trays, lead, shielding blocks, aluminium plates, lucite trays, and wax and brass devices (including wedges), may also cause significant dose rates at their surfaces or at close contact.

Some other radionuclides are induced in accelerator components, and room walls, ceiling and floor. The actual composition of these materials is usually not known and they may differ one machine or installation to another.

4. Dose equivalent rate resulting from induced radionuclides

The measurement was carried out by a sophisticated gamma monitor GammaTRACER [6] which was continuously monitoring the dose equivalent rate every 1 or 10 minutes and automatically stored the results in the internal memory. Using a modem, the information was transferred via infrared radiation to a computer, where dose equivalent time profile could be displayed and further processed.

The accelerators were run in the X-ray mode and set to 21 MV (ROC1) and 18 MV (ROC2) with the field size 10 cm x 10 cm. The standard water phantom was used to simulate the patient body. The monitoring instrument was placed at different points in the treatment room and at the control desk. The spectra of photons and photoneutrons during the machine operation were also measured (to be reported later). The main aim of conducting the measurements was to assess the levels of external photons following the accelerator runs under the typical clinical conditions.

As to the effect of induced radionuclides on the radiation level at the control desk, no contribution was detected even due to the activated air inside the treatment room. However, in the case of the higher photon energy and unfavourable shielding-geometry factors, at the RO1 facilities, clear contributions from the scattered X-rays were noticed (Fig. 1).

The situation in the treatment room is illustrated in Fig. 2, showing the time profiles of the dose equivalent. Its values close to the treatment head immediately after machine operation were in the range of 5 to 30 μSv/h, the maximum 80 μSv/h at the collimating jaws. The levels dropped to their halves in about 10 minutes.

Fig. 1. Dose equivalent rate as a function of time measured for several days at the control desk of the Saturn 43 accelerator working in various modes. The radiation level increases during morning and afternoon sessions while during the night returns to steady background. The actual dose rate depends also on the gantry angles; the maximum dose equivalent rates may reach as high as 0.5 - 0.6 μSv/h

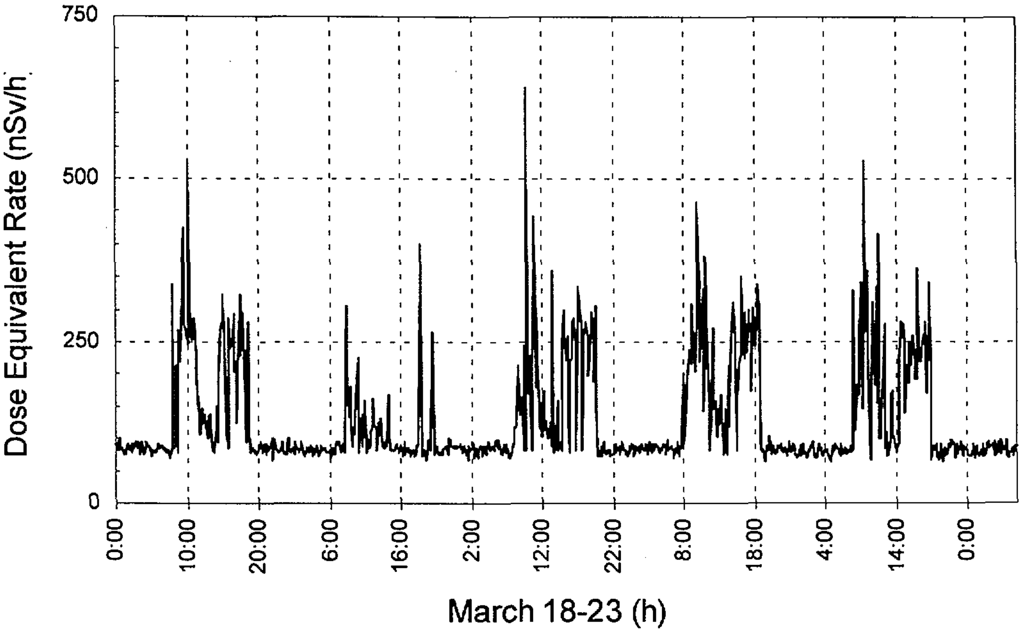
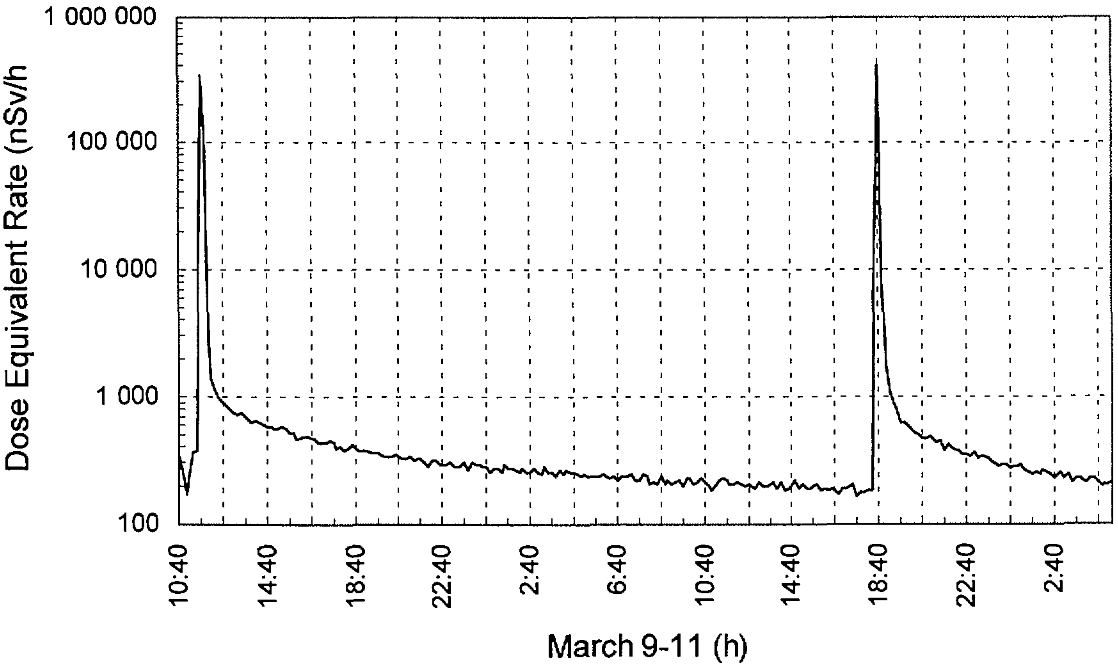


Fig. 2. The time profile of the photon dose equivalent in the treatment room during two typical runs at 21 MV X-rays (the monitor was 2 m from the isocentre at 1 m above the floor). Although due to the dead-time losses, the maximum levels during the machine operation were not recorded adequately (the actual dose rate during the machine operation is much higher), the tail following the runs illustrates the presence of induced radionuclides with shorter and longer half-lives. The interval between the monitor readings was 10 minutes



The equivalent dose rate in the treatment room of the accelerator from the accelerator operating at 18 MV are shown in Fig. 3 and 4. The sampling time interval was 1 min in this case. From Fig. 3 it can be seen that it takes several hours (actually about 16) for the radiation level in the treatment room to reach the background dose rate following the intensive operation of the machine. Some more details concerning the time variations of the equivalent dose rate during a normal treatment session are given in Fig. 4.

Fig. 3. Time variations of the contribution from the induced radionuclides to the equivalent dose rate in the treatment room of the Radiation Oncology Clinic in Prague (2 m from the isocentre)

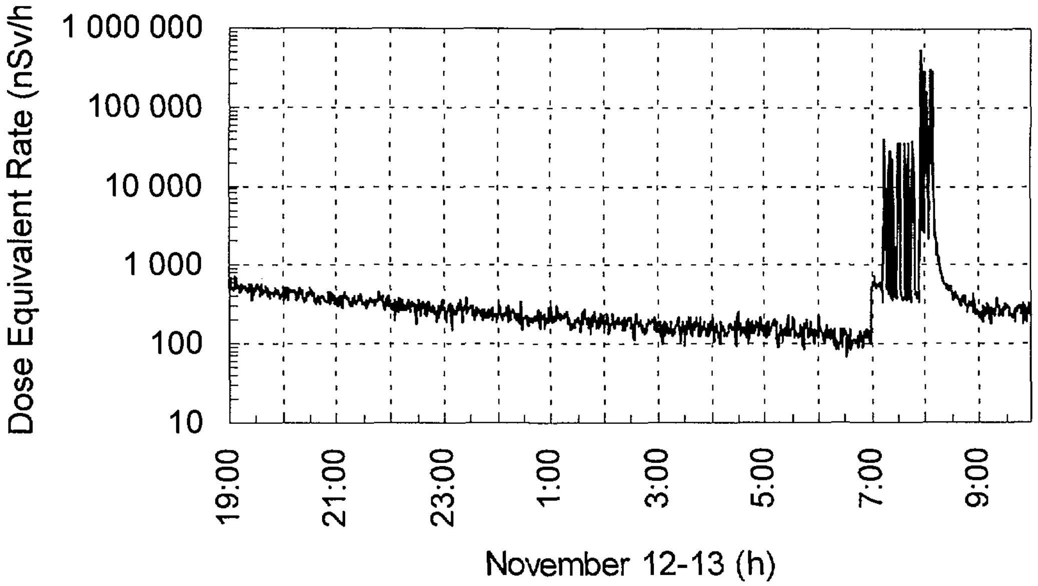
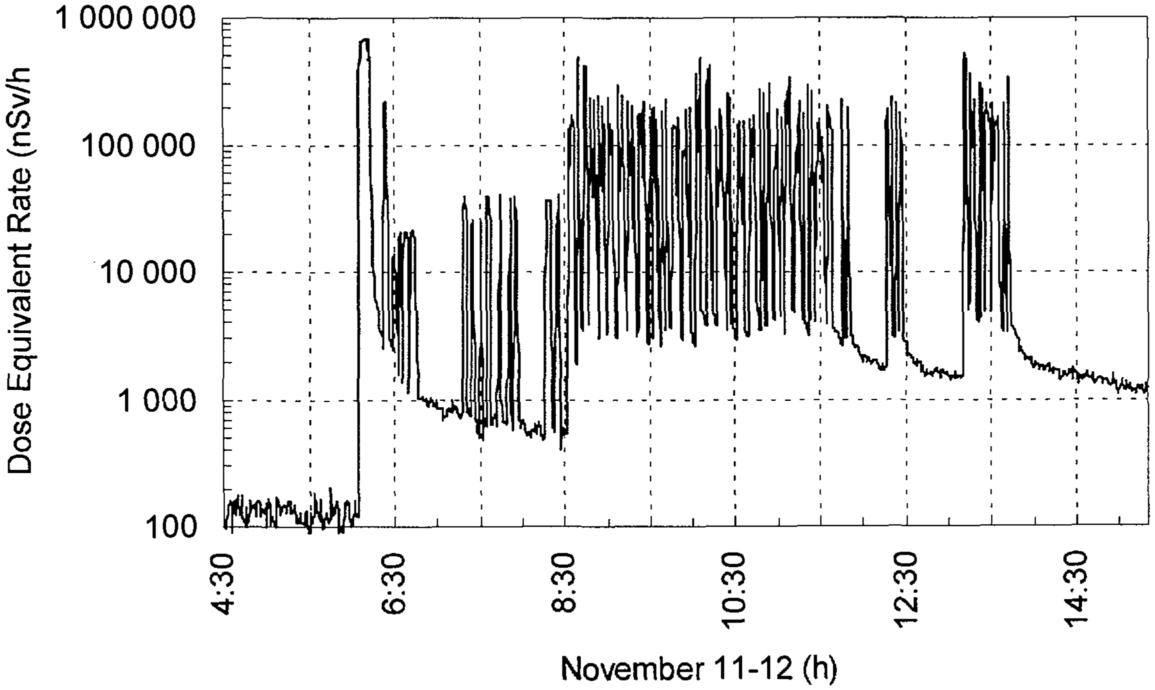


Fig. 4. Dose equivalent rate from its background level (after the machine was not operated during 2 days) following the typical regime of operation starting with the morning quality assurance tests



5. Discussion and conclusions

The exposure due to induced radionuclides in the treatment room of linac facilities may constitute an important contribution to the occupational doses of the operating personnel and especially maintenance engineers. Although, under normal circumstances, the total exposures are not expected to exceed the current dose limits, applying the ALARA principle, however, even these unwanted exposures should be reduced to a very minimum consistent with the operation and maintenance of the machine, where special care should be taken particularly in cases when X-ray beams above 15 MV are used for long treatments, such as total-body exposure. This is particularly important for the maintenance immediately after the last irradiation.

It may be desirable to pay more attention in analysing the composition of materials in the construction components of the accelerator head and other accessories which come in contact with the beam in order to identify the most prominent induced radionuclides so that the proper choice of materials in these parts of the accelerator could result in reducing unwanted remanent radiation fields.

6. Acknowledgement

This work has been supported in part by the Ministry of Education, Youth and Sport of the Czech Republic (the grant PG No. 9760-2304 1070) and the internal grant of the Czech Technical University No. 3049 7498. The photon monitor was kindly provided by Genitron Instruments GmbH.

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