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PHYSICAL INSTRUMENTS FOR ECOLOGY, MEDICINE, AND BIOLOGY

A Protective Subsurface Container for Holding and Temporary Storage of Activated Targets

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Abstract—An accelerator-driven source of epithermal neutrons has been developed by the Budker Institute of Nuclear Physics for carrying out investigations into neutron capture therapy of malignant tumors. Safe handling of targets with ^{7}Be radionuclide accumulated in them is one of the problems encountered in generation of neutrons in the ^{7}Li(p, n)^{7}Be reaction. It is proposed that targets will be decontaminated in a natural course, being placed in a subsurface container located in the room of the accelerating facility. The maximum activity of the targets enclosed in the container after scheduled generation of neutrons at the facility is estimated. Analytical estimates and Monte Carlo calculation of γ-ray transport are performed to determine the optimum container size, such that the γ-ray flux from its contents is reduced to the acceptable level. The preliminary design of the container and its embodiment are presented.

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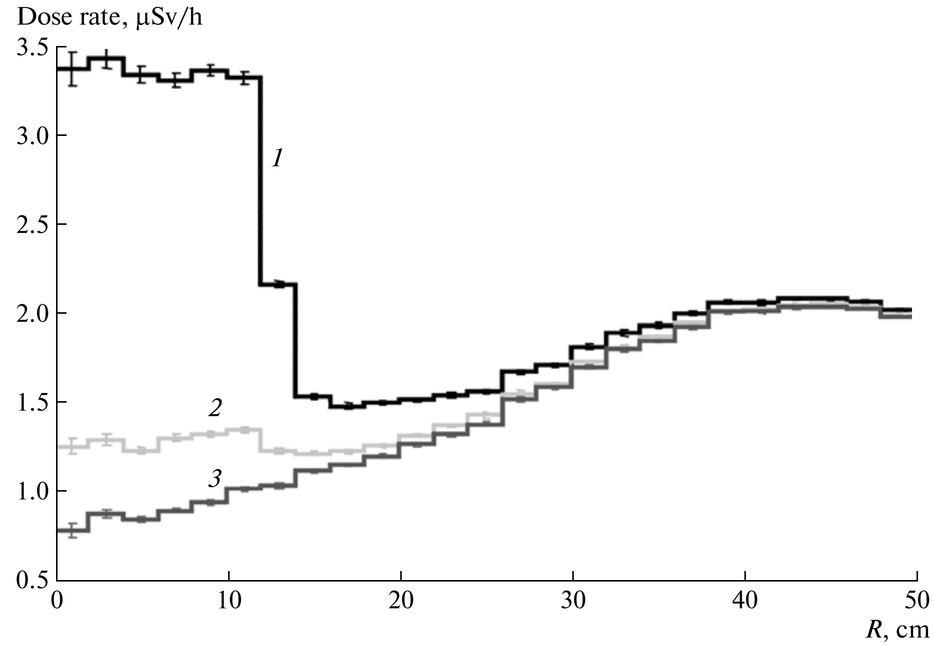
A source of epithermal neutrons based on the use of a tandem accelerator with vacuum isolation and threshold reaction ^{7}Li(p, n)^{7}Be was proposed for neutron capture therapy of malignant tumors in 1998 [1]. A study aimed at maintaining long-term generation of neutrons and forming an epithermal neutron beam is currently being conducted on a pilot model of the source at the Budker Institute of Nuclear Physics (BINP). One of the problems to be solved is concerned with target activation as a result of the ^{7}Li(p, n)^{7}Be reaction. Generation of neutrons in this reaction is accompanied by accumulation of radioactive isotope ^{7}Be inside the lithium layer. The high-efficiency heat pickup in [2] helps to hold the lithium layer in a solid state (below the melting point of lithium, which is 180°C) when it is heated by a proton beam with a power as high as 25 kW, providing thereby confinement of the radionuclide inside the lithium layer and its nonpropagation over the whole facility. After the activity reaches a certain value hampering the carrying out of experiments or therapy, or when the service life of the target comes to the end under irradiation with the proton beam, the target should be removed and a part of the target (the beam absorber with a lithium layer; see [3, Fig. 1]) be placed in a protected subsurface container for holding and temporary storage. This procedure seems to be optimal, since, on the one hand, the half-life of ^{7}Be (53.3 days) is not so long to simply wait until the target is naturally decontaminated, and, on the other hand, it is long enough to execute preventive operations of target dismounting from the facility and placing into the container.

To prepare the preliminary design of the protective subsurface container and its subsequent manufacture, the maximum activity of activated targets was determined. To optimize the size of the container providing its safe use, the analytical estimates were made and the Monte Carlo calculations of γ-ray transport were performed using the PRIZMA code [4].

Two modes—standard (at a proton beam energy of 2.5 MeV) and near-threshold (at 1.915 MeV)—are used in the facility to generate neutrons. In the first case, the neutron yield is 8.9×10^{12} s^{-1} at a proton current of 10 mA; in the second case, the yield is almost a factor of 30 less [5]. The neutron generation mode at an energy of 2.5 MeV is the worst for target activation. Let us now consider this mode.

Each neutron is associated with the formation of a ^{7}Be nucleus, which is transformed with a half-life period of 53.3 days into a stable ^{7}Li nucleus. The decay is accompanied by emission of a 0.4776-MeV photon with a probability of 10.3% [6].

When estimating the target activity, we assume that the source generates neutrons not 24 hours a day, but only over one-tenth of this time. This seems to be realistic and even attainable. For the sake of simplicity, we consider in the subsequent calculations that generation of neutrons is continuous, but the proton beam current is 1 mA. Beryllium is produced with a characteristic time of 77 days, and, approximately in a year, the ^{7}Be activity reaches its steady-state value of 8.9 ×



Distribution of the dose rate above the container along radius R from the tube axis at a height of 0.5 m for a lead disk (*1*) 40, (*2*) 50, and (*3*) 60 mm thick.

10^{11} Bq, which is numerically equal to the neutron generation rate at a current of 1 mA. At an activity such as this, 9.2×10^{10} photons with an energy of 0.4776 MeV will be emitted from the target per second.

It should be taken into account that the assumed service life of the target is substantially shorter than the ^{7}Be half-life; therefore, the saturation state will not be attained for each individual target. The above-mentioned saturation values can be referred to as the total activity of all targets sequentially used at the facility.

When estimating the protection requirements for the container, we assume that the total amount of ^{7}Be in targets housed in the container corresponds to the saturation state, i.e., the total activity is 8.9×10^{11} Bq.

The calculation of the kerma constant of ^{7}Be (by the kerma of air) in accordance with the handbook [7] yields the value of 1.86×10^{-18} Gy m^2/(s Bq). The saturation value of the kerma equivalent for ^{7}Be, which is attained in a year, will be 6×10^3 μGy m^2/h. At a distance of 2 m from a point source that has an activity such as this and is not surrounded by any materials, the kerma rate will be 1.5×10^3 μGy/h. In rooms of temporary residence of personnel, the projected equivalent dose rate is 12 μSv/h for standard conditions in accordance with [8]. Ignoring the distinction between the corresponding numerical values of the equivalent dose rate and the air kerma rate, which is small in our case, we can see that the kerma should be attenuated by a factor of ~125. According to the data of the universal tables ([7, Tables 5.41 and 5.43]), such an attenuation of radiation from a point isotropic source can be attained for an infinite geometry of the medium by protection with a 3-cm-thick lead or 40-cm-thick concrete layer.

It was proposed that the container for holding and temporary storage of activated targets will be designed as a long steel tube with an outer diameter of 219 mm and a height of 2 m. The cylinder will be plunged into the soil, and activated targets will be placed in its 10-mm-thick bottom. On the top, the cylinder is covered with a lid, which is a sandwich of a steel disk 10 mm in thickness and 280 mm in diameter (60 mm larger than the outer diameter of the tube) and a thicker lead disk mounted on it. The final thickness of this disk will be selected after additional calculations. The design of the lid must allow its hermetic sealing in order to prevent the ingress of moisture and, if necessary, to provide filling of the tube with a heavy noble gas.

The fact that, apart from the direct flux of 0.4776-MeV photons from the target, a considerable amount of radiation scattered by the steel wall of the container tube and the adjacent soil is incident on the protective lid from below is a distinctive feature of the proposed container configuration. In addition, the flux of radiation multiply scattered by the soil, which emerges from the floor surface in close vicinity of the protective lid perimeter, may also have a significant effect on the radiation field formed over the container. In this case, the results of the above simple estimations of the protection requirements, obtained using the universal tables in [7], seem to be insufficient. In order to more adequately take into account the geometrical features of the proposed container design, the Monte

Carlo simulation of the γ-ray transport from ^{7}Be has been performed.

In these calculations, the set of activated targets was simulated by a point isotropic γ-ray source with an energy of 0.4776-MeV and an intensity of 9.4×10^{10} s^{-1}, which was located at the bottom of the tube. The aim of the calculations was to determine the optimum thickness of the lead disk and the sufficiency of the selected lap of the lid over the tube. With this aim in mind, we calculated the radial distribution of the dose rate over the container at a height of 0.5 m over the floor for four values of the disk thickness: 30, 40, 50, and 60 mm. The partition along the radius was uniform, and the pitch was 2 cm. The results of the calculations for the disk thicknesses of 40, 50, and 60 mm, as well as their statistical accuracy, are presented in the figure.

It is apparent that the dose rate strongly depends on the lead disk thickness in the region lying directly above the disk ($R < 14$ cm), and a weaker dependence is observed in the outer region. From these results, it follows that the disk thickness of 30 mm, for which the dose rate at the axis is as high as 16 μSv/h, and, perhaps, a 40-mm thickness are insufficient. The disk thickness of 50 mm seems to be the best, since an increase in the thickness to 60 mm causes the dose rate to decrease by a factor of 1.5 directly above the disk, remaining almost unchanged above the adjacent soil. Therefore, the container lid with a 50-mm-thick lead disk will make it possible to maintain the dose rate at a level of 2 μSv/h or less, which is 6 and 3 times lower than the permissible dose rates for rooms with temporary and permanent residence of personnel, respectively.

A 40-mm thick lead layer attenuates the kerma rate in a wide beam of γ rays from ^{7}Be by a factor of 900 [7]. Nevertheless, the results of the Monte Carlo calculations for the region above the lid display approximately a 300-fold attenuation. This means that, if the lead layer in the lid has a thickness such as this, the contribution to the dose made by photons scattered by the top of the container tube and the adjacent soil becomes comparable to or even exceeds the dose contribution due to the "direct" flux of 0.4776-MeV photons from the source, which hit the lid from below. At a 50-mm lead thickness, the contribution of this "direct" component to the dose above the lid evidently is no longer predominant.

The radiation scattered by the top of the container tube and the adjacent soil almost fully determines the "dose" field in the region above the floor at a certain distance from the container lid. For example, there are 5.4-cm-thick iron layers (with allowance for the "oblique" incidence on the tube wall) and a soil layer equivalent to ~105 cm of concrete along the ray from the source toward the detection point located at a height of 0.5 m from the floor and 40 cm away from the container axis. The contribution made only by the propagation of radiation in this direction to the dose rate at the detection point was estimated according to the simple ray-trace method using the above-mentioned universal tables. This result occurred to be underestimated approximately by a factor of 10^5 as compared to the result of the Monte Carlo calculation! This fact is a vivid illustration of the importance and usefulness of the Monte Carlo method in analyzing the efficiency of the protective container with the proposed geometry.

Based on these calculations, the preliminary design of the container for holding and temporary storage of activated targets has been developed and agreed with the Department of Radiological Investigations and Radiation Safety of the BINP. It was determined that the lower room of the underground shelter that houses the accelerator-driven neutron source is the best place for placing the subsurface protective container. A hole was made in the concrete floor, a recess was drilled in the soil, and a tube with a bottom welded to it was inserted in this recess. The free space around the tube was backfilled with soil and concreted on the top. The tube was installed with a small dais above the floor surface and covered with a lid. A safety system warning about opening of the lid was mounted, and a fence was erected. As a result, building of this subsurface protective container for holding and temporary storage of activated targets will make it possible to effect long-term generation of neutrons needed for investigations in the field of boron-neutron-capture therapy of malignant tumors.

REFERENCES

1. Bayanov, B., Belov, V., Bender, E., et al., *Nucl. Instrum. Methods Phys. Res. A*, 1998, vol. 413, nos. 2–3, p. 397.
2. Bayanov, B., Belov, V., Kindyuk, V., et al., *Appl. Radiation Isotopes*, 2004, vol. 61, no. 5, p. 817.
3. Bayanov, B., Kashaeva, E., Makarov, A., et al., *Appl. Radiation Isotopes*, 2009, vol. 67, nos. 7–8, Suppl. 1, p. S282.
4. Kandiev, Ya.Z. and Serova, E.V., *At. Energ.*, 2005, vol. 98, p. 386.
5. Blue, T. and Yanch, J., *J. of Neuro-oncology*, 2003, vol. 62, p. 19.
6. *ICRP Publication 38: Radionuclide Transformations: Energy and Intensity of Emissions*, International Commission on Radiological Protection, Pergamon, December 01, 1983. Translated under the title *Skhemy raspada radionuklidov. Energiya i intensivnost' izlucheniya*, Moscow: Energoatomizdat, 1987.
7. Mashkovich, V.P. and Kudryavtseva, A.V., *Zashchita ot ioniziruyushchikh izluchenii: Spravochnik* (Protection against Ionizing Radiations: A Handbook), Moscow: Energoatomizdat, 1995.
8. *Osnovnye sanitarnye pravila obespecheniya radiatsionnoi bezopasnosti (OSPORB-99). SP 2.6.1.799-99* (General Sanitary Code on Provision of Radiation Safety OSPORB-99), Moscow, Ministry of Public Health of the Russian Federation, 2000.