A temporary storage for activated UCx targets at SPES

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Abstract

SPES (Selective Production of Exotic Species) is a project of the INFN (Istituto Nazionale di Fisica Nucleare) for the production of radioactive ion beams, through direct irradiation of a fissile target with high-intensity proton beams. The irradiation of the uranium carbide target with protons at 40 MeV energy and 200 μA current during an irradiation cycle of two weeks causes an activity of approximately 10^{14} Bq. Less than 5% of the total activity is due to species of half-lives longer than one month. The replacement of the target takes place at each irradiation shift, ideally once per month, taking into account two weeks of irradiation and two weeks for the facility set-up. For the first years of operation, a temporary storage will host the exhausted targets. This work presents the evaluation of the residual dose rate due to the presence of several irradiated targets in order to design the needed shielding for the storage area and to allow the access nearby. The simulations have been performed with the FLUKA Monte Carlo code.

Introduction

SPES (Selective Production of Exotic Species) is an INFN project to develop a Radioactive Ion Beam (RIB) facility as an intermediate step towards EURISOL (European Isotope Separation On Line). The capability to obtain a RIB of interest for nuclear physics is supported by the presence at LNL (Laboratori Nazionali di Legnaro) of a superconducting linac, able to re-accelerate exotic ions at 8-13 MeV/u.

The RIB is a neutron-rich beam of fission fragments with a fission rate in the target of 10^{13} fissions per second, achieved through the interaction of a proton beam of 40 MeV energy and 0.2 mA current with a target of uranium carbide (production target) [1]. A 70 MeV-0.75 mA cyclotron, actually under construction by Best Cyclotron Systems, Inc. delivers the proton beam.

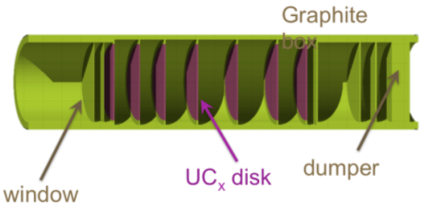
The production target is irradiated for 12 days and then replaced by a new one. A small area close to the irradiation bunker is being equipped to host up to 44 irradiated targets, conveniently located in lead boxes. Once this temporary storage is full, targets will be moved to their final destination as waste. The temporary storage area is not directly accessible but borders on a passageway classified as a controlled zone. This work presents the evaluation of the shielding thickness required in order to keep the ambient equivalent dose rate below 0.5 μSv/h in the accessible corridor. The evaluation has been performed with Monte Carlo simulations, using the FLUKA code [2,3].

Production target

The production target consists of multiple thin disks housed in a cylindrical graphite box. This geometry increases the body surface in order to optimise the target cooling. In fact, the target in a low-pressure environment, the heat due to electromagnetic and nuclear interaction will be dissipated by radiative thermal transfer, directly proportional to the body surface. The disks have 40 mm diameter and 1 mm thickness.

Figure 1 shows the multifoil target as implemented in the Monte Carlo geometry in order to simulate the proton-induced fission process, including the graphite container and the dumping disks.

Figure 1. The SPES production target as implemented in the Monte Carlo geometry



The irradiation of the target lasts 12 days with a total of 10^{21} protons on target per shift and 10^{19} fissions induced. At the end of the irradiation cycle, the radioactivity in the target amounts to around 1 kCi, whose distribution according to the half-life of the products can be seen in Figure 2.

Less than 3% of the total activity is due to species with half-life longer than 1 month and 2% longer than 10 years.

Simulation set-up

In order to simulate the storage of a target after an irradiation cycle, and to evaluate the gamma ambient equivalent dose rate only due to radioactive decay, the capability of FLUKA has been exploited to assign a material to a certain region during irradiation and to change material during decay.

In the present case the target has been placed in the lead box, as it will be performed after an irradiation for storing it, and located in the dedicated area of the storage (the green area in Figure 3, not the yellow one where the irradiation should take place). The volume between the target and the lead box is set to “blackhole” and the irradiation of the target with the proton beam is started. In this simulation phase, all the nuclear and electromagnetic interactions take place but secondary particles do not escape the system because as soon as they leave the target they meet the blackhole.

In this situation the target is activated but the surrounding materials are not, the irradiation is over and the volume between the target and the lead box is switched to air, so that the particles released during the decay can be transported outside and the dose rate in the area of interest can be evaluated.

Figure 2. Distribution of the target activation products as a function of the half-life

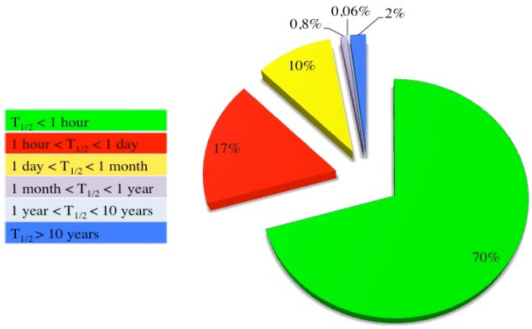
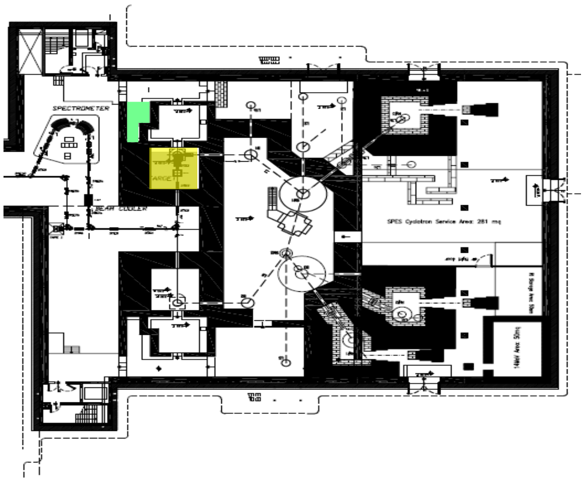


Figure 3. Layout of the SPES Facility (re-acceleration line not included)



The irradiation bunker is highlighted in yellow and the storage area in green.

Results

The gamma dose rate in correspondence with the passageway is about 300 uSv/h (as indicated by the position of the man in Figure 4), and the photons contributing to this dose rate have an energy in the range of 0.3-3 MeV. In order to fulfill the radiation protection constraints for controlled areas (0.5 uSv/h), a standard concrete wall 70 cm thick must be provided. This allows a dose rate reduction of a factor 10^3 [4].

Furthermore, the configuration of the whole storage filled with targets was studied. To do this, 44 separate simulations were run, one for each target stored. Some preliminary considerations have to be clarified: before being placed in the storage, the irradiated target remains in its position for 14 days.

The targets will be automatically moved from the irradiation cave to the storage area. Once there, a lift will be able to place each target in a dedicated location in a rack.

After a few targets have been stored, their positions will be exchanged so that the furthest position from the passageway will always be free for the most active target in order to take advantage of the shielding effect by the other target boxes.

The results of this study are shown in Figures 5 and 6. All the available positions have been filled with targets, and the most active is in the furthest position. The dose rate in the passageway in this configuration is below 50 uSv/h, and a reduction of a factor 100 must be achieved. A standard concrete wall 50 cm thick will be sufficient to prevent a dose rate of 0.5 uSv/h where personnel can access.

After the first one or two irradiation cycles, shielding the exhausted targets with some empty lead boxes might be considered (they do not need to be prepared specially as they will be used for future targets). As shown in Figure 7, the dose rate at the desired position is about 50 uSv/h, similar to the "full rack" configuration and the shielding wall can be kept as thin as 50 cm.

Figure 4. Gamma dose rate (uSv/h) at the end of an irradiation cycle

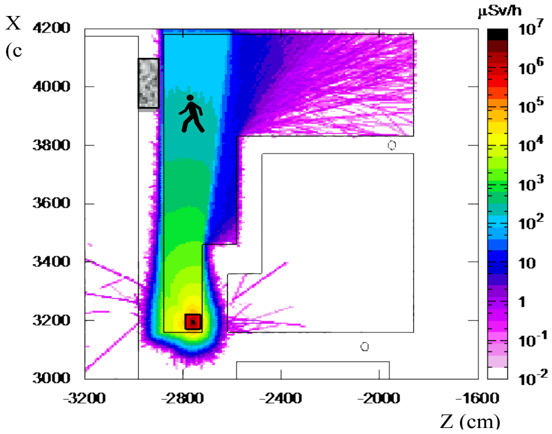


Figure 5. Gamma dose rate (uSv/h) due to 44 stored irradiated targets (aerial view)

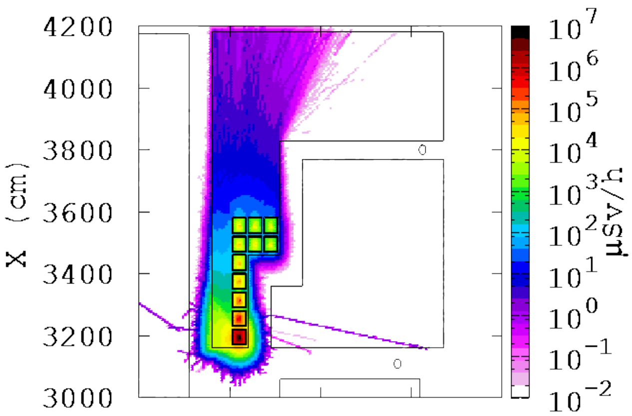


Figure 6. Gamma dose rate (uSv/h) due to 44 stored irradiated targets (side view)

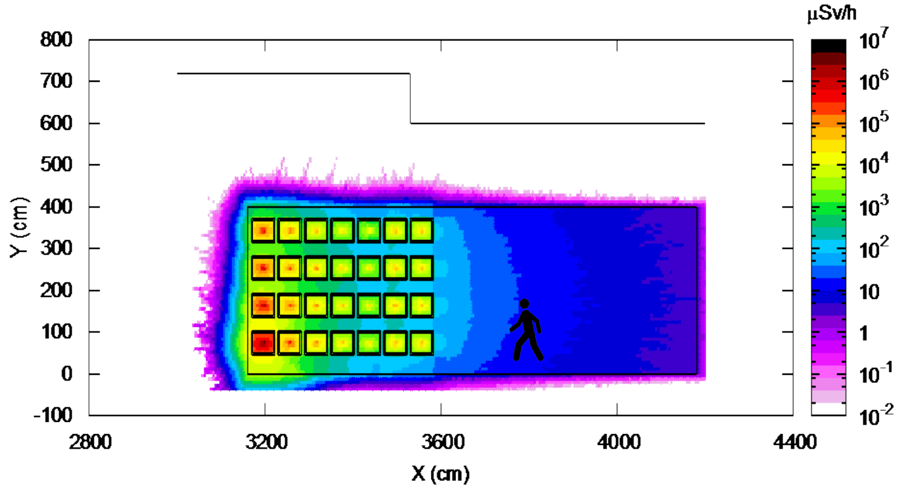
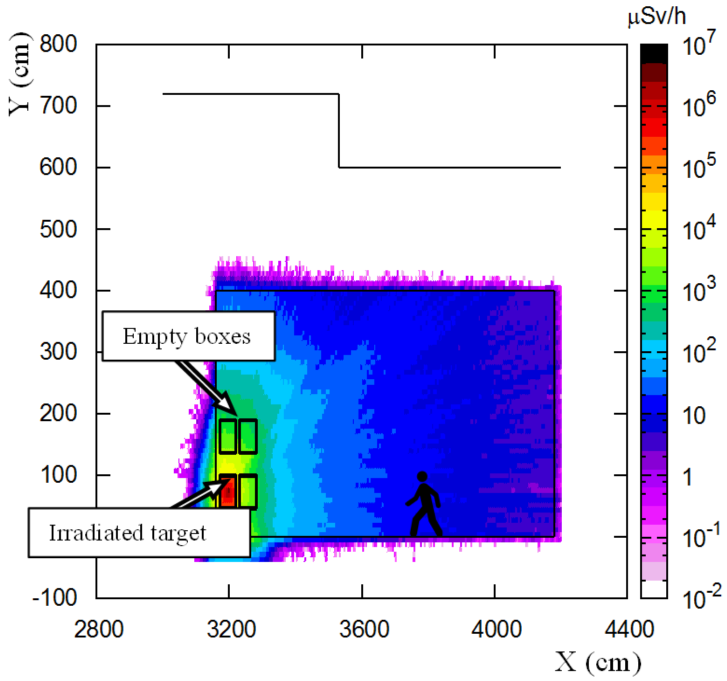


Figure 7. Gamma dose rate (uSv/h) at the end of an irradiation cycle



The irradiated target is shielded by some empty lead boxes (side view).

Conclusions

The schedule of the SPES project foresees the irradiation of an uranium carbide target for 12 days and a cooling time of two weeks before the start of a new irradiation cycle. The irradiated target is then placed in a lead box 2.5 cm thick and temporarily stored in a dedicated area close to the bunker, where a rack hosting up to 44 targets is installed.

Due to space restrictions, an accurate evaluation of the dose rate at a certain distance from the targets was needed in order to design an adequate shielding wall. The temporary storage, in fact, borders on a passageway with controlled access of personnel.

It has been seen that a single target, at the end of an irradiation cycle, causes a dose rate higher than 300 uSv/h at the distance of 6 metres. When the storage is completely filled with targets, the dose rate at 6 metres distance drops to less than 50 uSv/h, due to the fact that the targets shield each other.

Considering the full configuration as source term to design the shielding wall would cause an underestimation of the dose rate in the first operation cycle and this could lead to an overexposure of personnel passing through the corridor nearby. In order to keep both the wall thickness reduced and the dose rate as low as 0.5 uSv/h in controlled areas, it has been decided to shield the first irradiated target deposited in the storage with some empty lead boxes, taking advantage of the lead as shielding. In this scenario a concrete wall 50 cm thick will be sufficient to meet the radiation protection constraints in the corridor.

Acknowledgements

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References

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[2] G. Battistoni et al. (2007), "The FLUKA code: Description and benchmarking" *Proceedings of the Hadronic Shower Simulation Workshop 2006, Fermilab 6-8 September 2006, AIP Conference Proceeding* 896, 31-49.

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