design of shielding for active irradiation.

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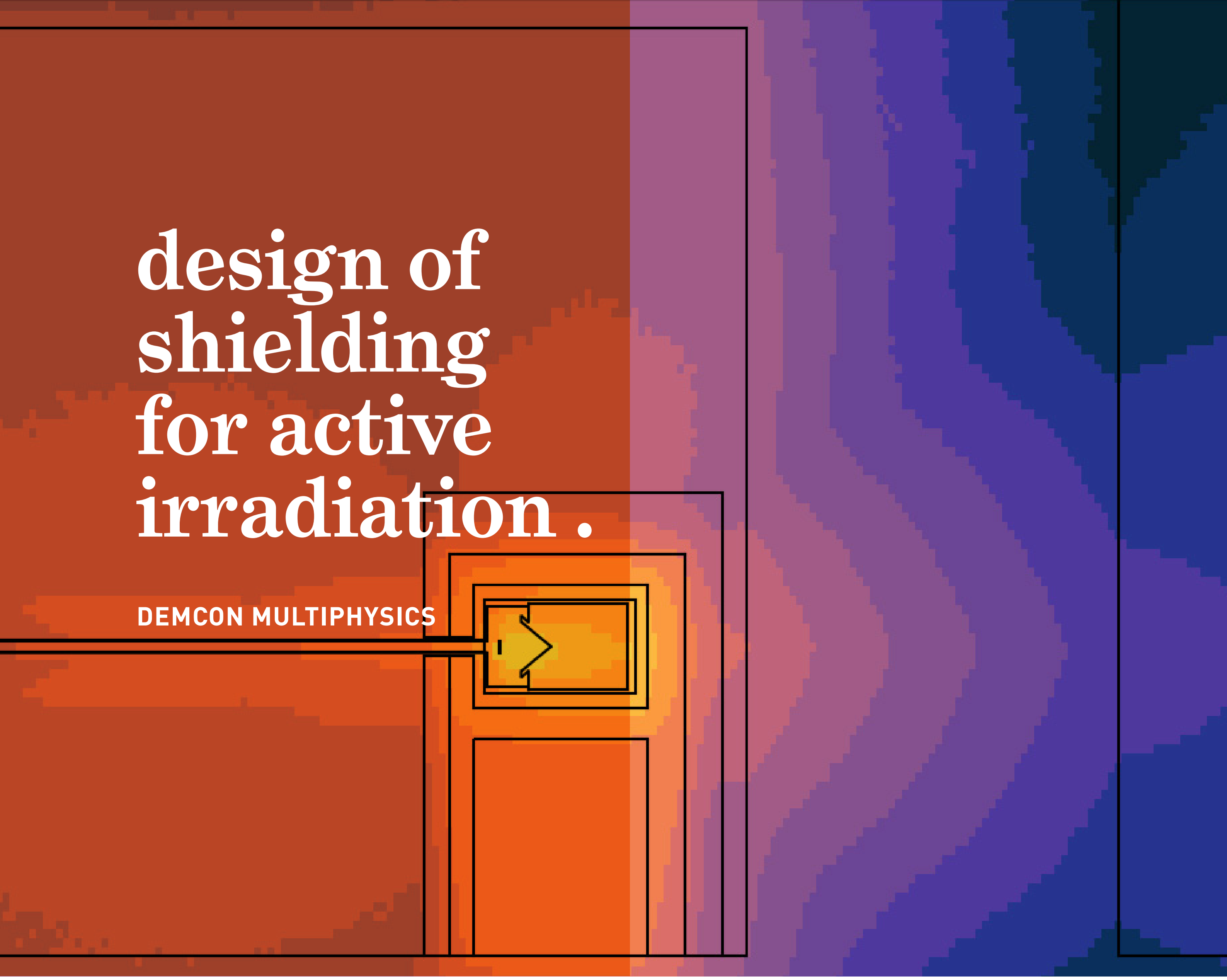

Goal

The production of medical isotopes Mo-99 and Tc-99m is conventionally achieved in nuclear reactors, where a nuclear reaction with highly enriched uranium takes place. Alternatively, high energy electrons impinging on a Mo-100 target can be used to produce Mo-99 through a (γ,n) reaction. This method of production is currently of great interest, and experiments on this have been performed. See e.g. [1] and [2].

In such a process, radiation is released that endangers the safety of people and could potentially cause failure of equipment. To guarantee safety, a shielding design is thus required. Below we present a comparable scenario, and show how through Monte-Carlo analysis, we can show that shielding ensures human safety, both during the experiment, and after.

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Approach

To simulate the radiation environment, the profile of the electron beam is first modeled in detail. Next, the geometry of the setup is modeled in sufficient detail to account for potential shielding weaknesses, while also ensuring that the proper materials are selected. Figure 1 shows a shielded vacuum chamber, with inside it the target and a beam dump. The beam is incident from the left.

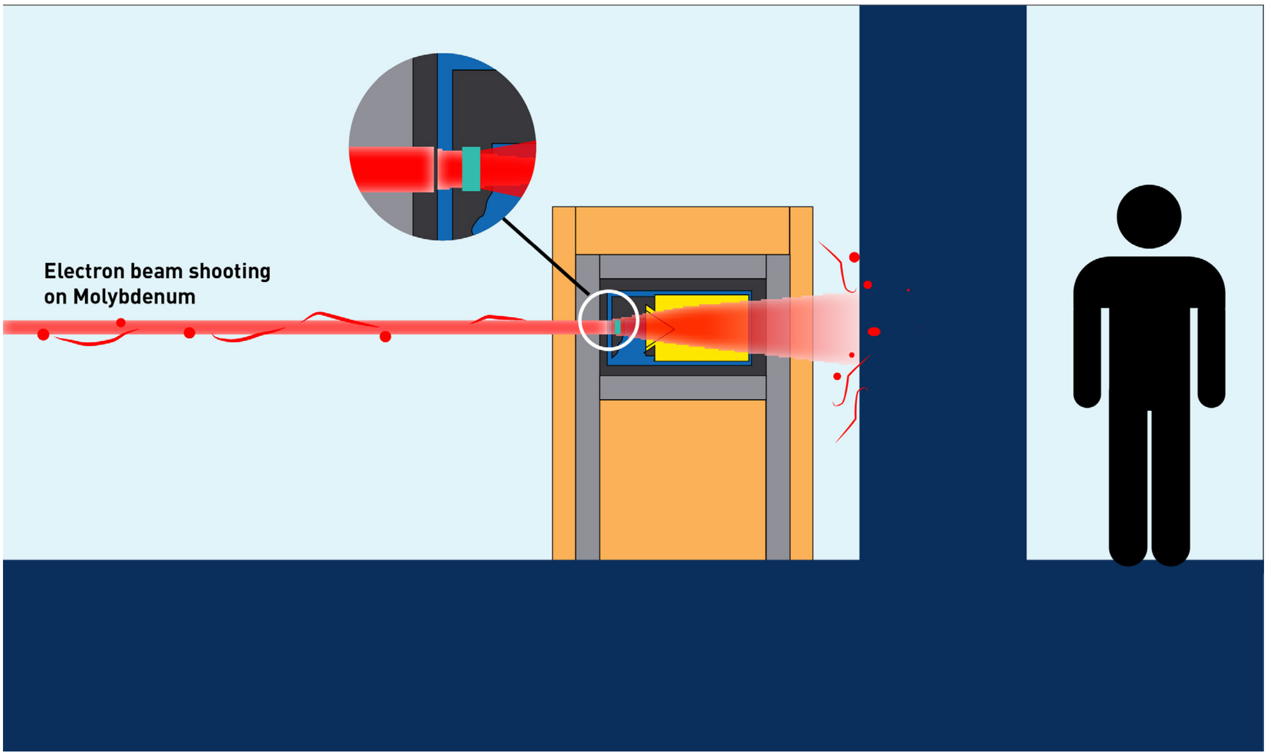

Figure 1: Geometry of the FLUKA model, with the material colors indicated. The beam is incident from the left.

The radiation that leaves the target is made up of high-energy photons and neutrons. Knowing the radiation spectra is of great importance in devising a successful shielding strategy. A shielding strategy was chosen where, to efficiently shield photons, a first shielding layer of lead is placed. As a high-density material, lead is well-suited at these energies due to the generation of electron-positron pairs through a process called pair-production. To then shield and moderate neutrons, an additional layer of borated polyethylene is placed. As a final shielding layer, a thick borated concrete wall with a thickness of 1.5 m is present. The addition of boron increases neutron moderation and absorption.

A general challenge in Monte Carlo simulations is ensuring sufficient statistics in regions of interest. Using advanced biasing techniques, we can achieve good results on the dose rate behind the concrete wall.

Figure 2 shows the dose equivalent rate during operation. The obtained results for the dose equivalent rate are then compared to human safety standards, such as those put forth by regulatory bodies, and commissions such as the ICRP. Using these guides, we can identify regions that are safe, or potentially hazardous.

During primary irradiation, radioactive isotopes are produced in the setup and its structural materials. This information is critical when considering e.g. waste treatment in facilities on the long term, as well as a safety issue.

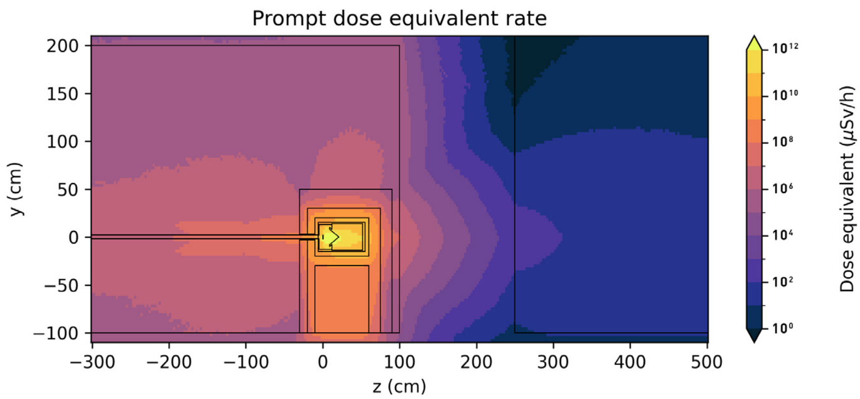

Figure 2: The prompt dose equivalent rate in μSv/h.

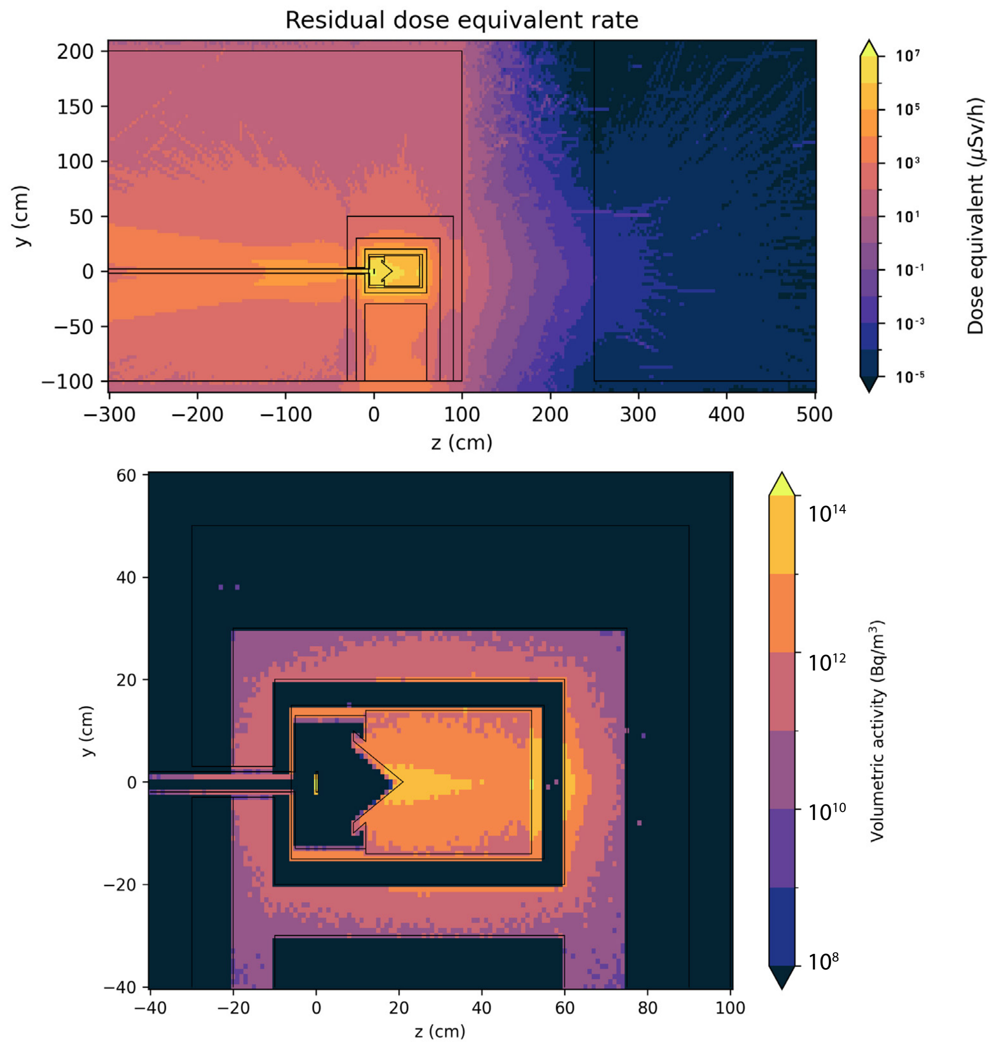

Figure 3: The residual dose equivalent rate in μSv/h (top) and a map of the volumetric activity (bottom).

We mapped the activated materials, and the residual radiation emitted by the activated material. Figure 3 shows the activity density map and the resultant residual radiation after a certain irradiation time and cooldown period.We can see the beamline penetration of the shielding layers results in large residual dose rates along the beamline opening. This is a potentially hazardous area for humans.

With the use of our expertise in Monte Carlo techniques and nuclear physics, we were able to design and verify an effective shielding strategy. Other metrics, such as heat load and activation of the target can also be considered and tested. All these aspects combined contribute to a safe and successful experiment, and are used to prove the feasibility of a nuclear process.

Bibliography

[1] International Atomic Energy Agency, Non-Heu Production Technologies For Molybdenum-99 And Technetium-99M, Bernan Distribution / International Atomic Energy Agency, 2012.

[2] "Four US companies chosen for Mo-99 production funding," [Online]. Available: https://world-nuclear-news.org/Articles/Four-US-companies-chosen-for-Mo-99-production-fund.