

Recent Nuclear Analysis of the IFMIF-DONES Phase 2 Commissioning Accelerator and MEBT

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The International Fusion Materials Irradiation Facility Demo-Oriented Neutron Source (IFMIF-DONES) facility will test materials for use in future fusion power plants using a high-intensity fusion-like deuterium-lithium neutron source. Losses from the deuteron ion beams at IFMIF-DONES will lead to reactions and material activation.

In the present work, highly detailed neutronics models have been created and a detailed approach to radiation sources has been adopted. Accounting for losses in the beamline, beam dump and on collimating scraper blades, shutdown dose rates (SDDRs) and activation levels around the accelerator for Phase 2 commissioning and full operations have been calculated. It is found that SDDRs exceed 100 $\mu\text{Sv/h}$ in the vicinity of the MEBT and diagnostics plate in the hours following Phase 2 operations. The high SDDR is predominantly due to deuteron activation of the beam dump copper cone, and this is therefore highlighted as a priority for shielding.

The IFMIF-DONES beamline

In IFMIF-DONES, deuterium ions will be accelerated up to 40 MeV onto a flowing lithium target.

This will produce **fusion-like d-Li neutrons** with the specific aim of

studying materials in irradiation conditions relevant to EU-DEMO and other future fusion devices.

It will be important to **characterise the radiation fields** around the accelerator, for the purposes of protecting people and systems.

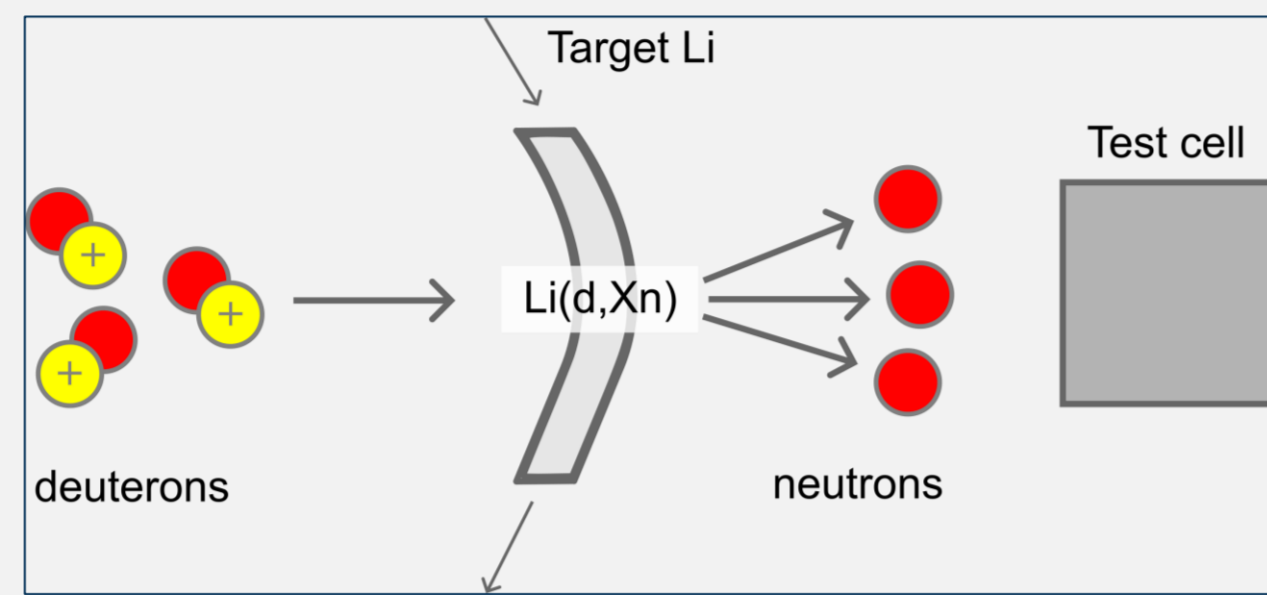


Fig. 1: Reaction of deuterons on DONES flowing lithium target to produce high-intensity fusion neutrons.

There are a number of systems along the beamline, with specific functions for creating, controlling and monitoring the beam. These are **commissioned in stages** [1].

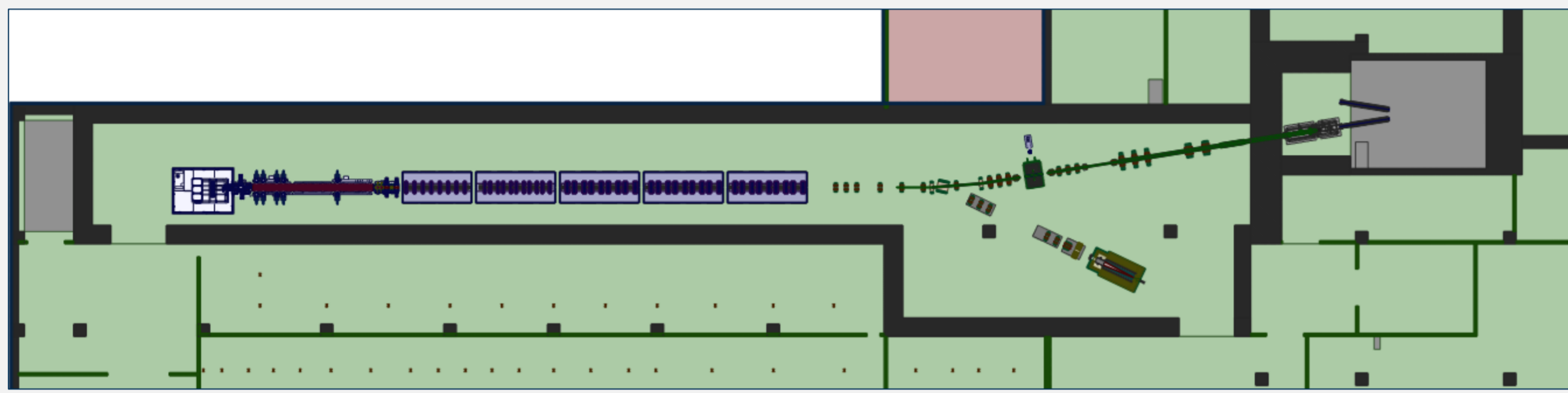


Fig. 2: CAD of DONES building level 2, accelerator hall and target systems (horizontal cross-section).

Beamline components

In the final beamline, deuterons from the **Injector** will be accelerated from 0.1 MeV up to 5 MeV in the Radio-Frequency Quadrupole (**RFQ**) accelerator. They will then be guided down the Medium-Energy Beam Transport (**MEBT**) line, then accelerated up to 40 MeV in the Super-Conducting Radio-Frequency (**SRF**) Linac modules.

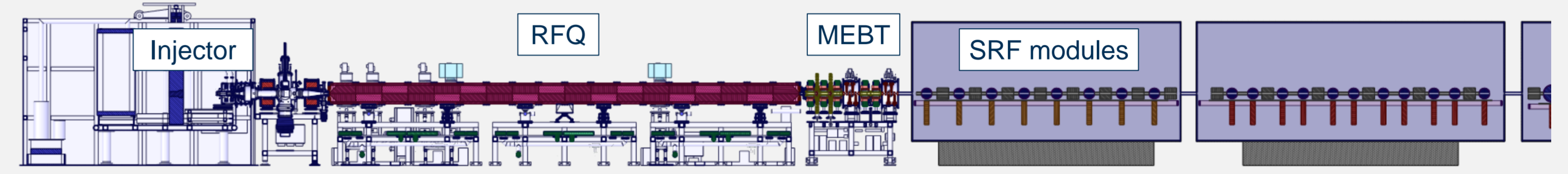


Fig. 3: DONES beamline up to superconducting RF Linac modules, leading to high-energy beam transport line.

In Phase 2 Commissioning, deuterons will leave the MEBT via a Diagnostics Plate (**DP**) before being deposited in a re-positioned High-Power Beam Dump (**HPBD**). During Phase 2, DONES will operate at a reduced duty cycle, peaking at 20% of its full power.

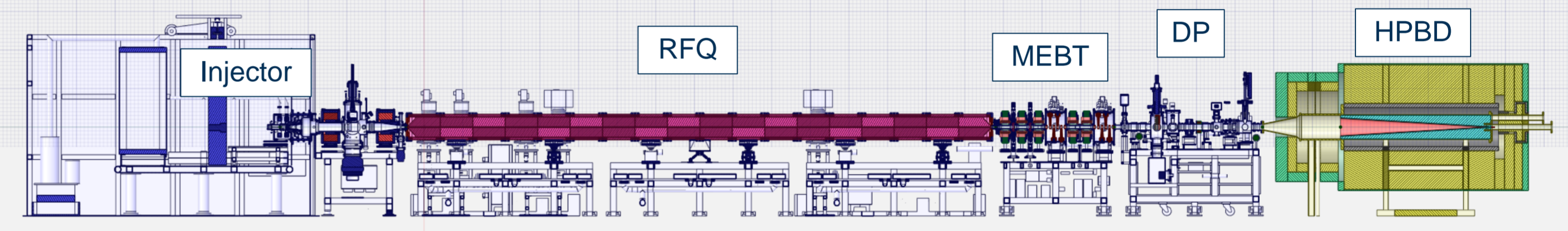


Fig. 4: Shortened DONES beamline during Phase 2 Commissioning, ending at high-power beam dump.

Results

For accurate deuteron, neutron and photon transport, this work made use of tools developed by UNED (the MCUNED and srcUNED-Ac MCNP patches) and by CCFE (FISPACT-II, MCR2S).

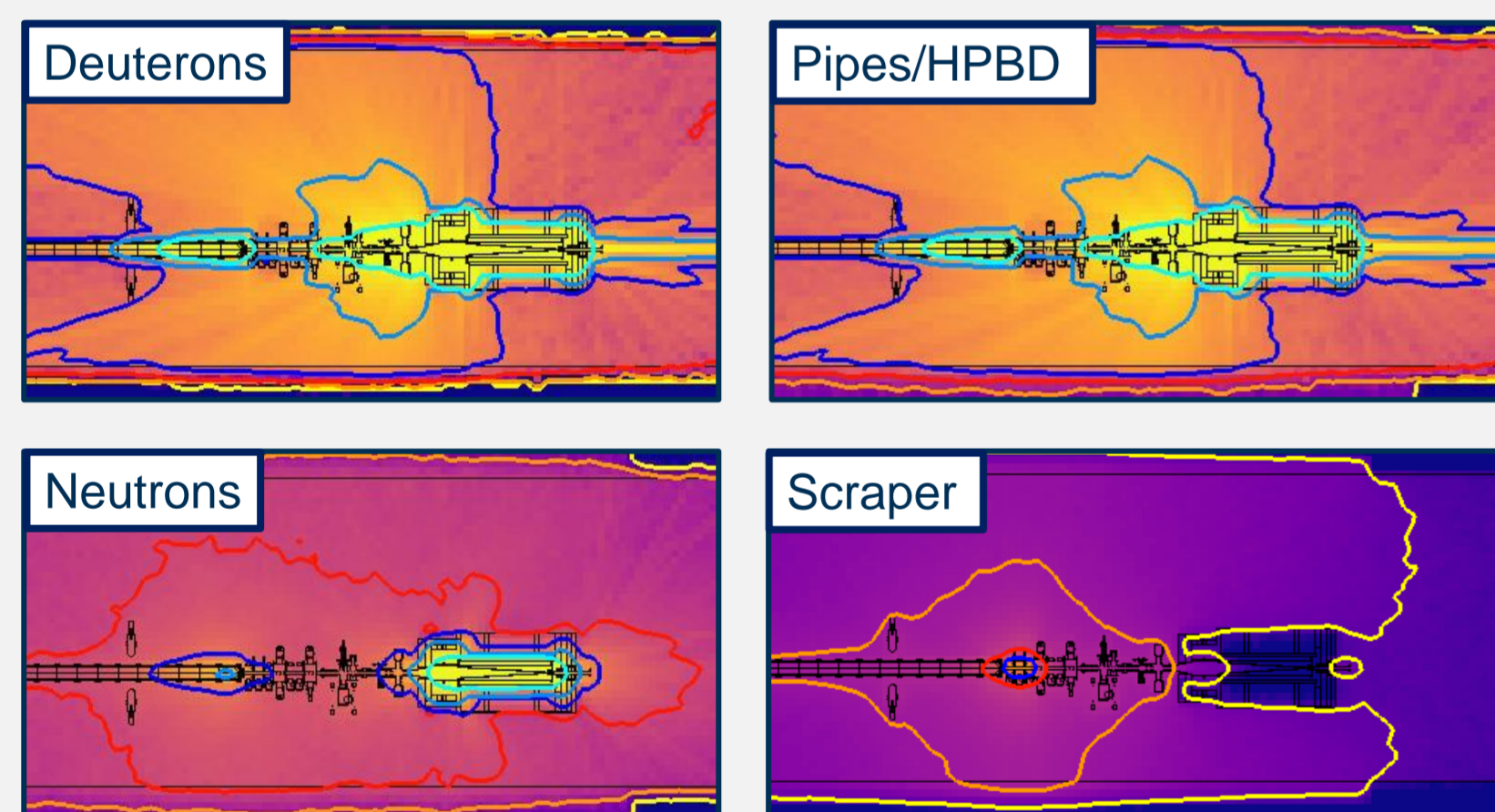


Fig. 5: 1-hour SDDRs ($\mu\text{Sv/h}$, scale below) separated by activating particle (left) and source (right).

Results (Fig. 5) suggest that **deuteron activation in the HPBD** dominates, so must be prioritised.

SDDR results are shown in Fig. 6 for the Commissioning Phase 2 accelerator (2 months @ 20% power).

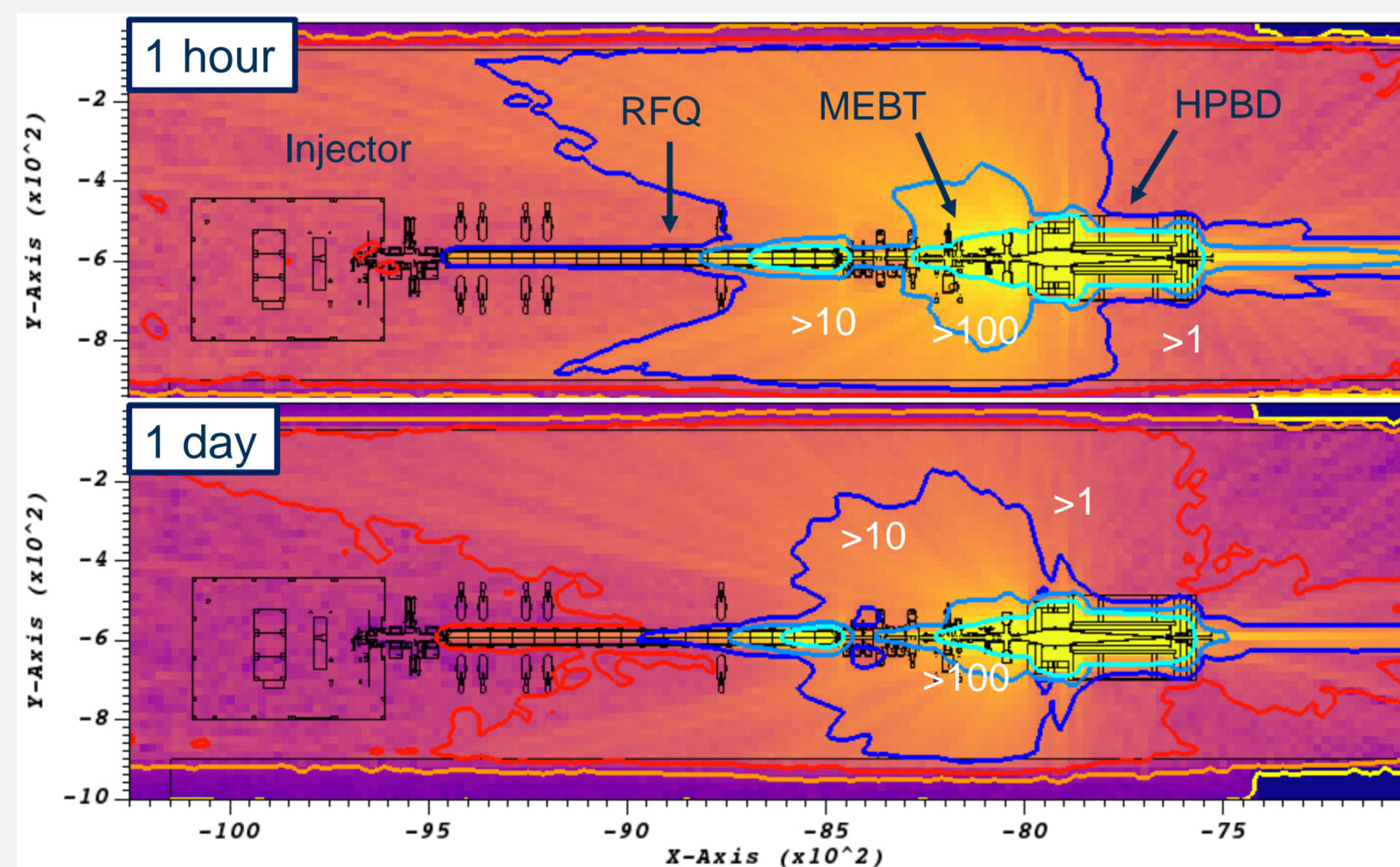


Fig. 6: Shutdown dose rates ($\mu\text{Sv/h}$) around the Phase 2 accelerator (horizontal slice) at 1 hour, 1 day decay times.

These indicate **high (>100 $\mu\text{Sv/h}$) dose rates** close to the accelerator, and particularly the HPBD, at short decay times.

Similarly, 1-hour SDDR results around the MEBT following 2 years of full-power operation are shown in Fig. 7.

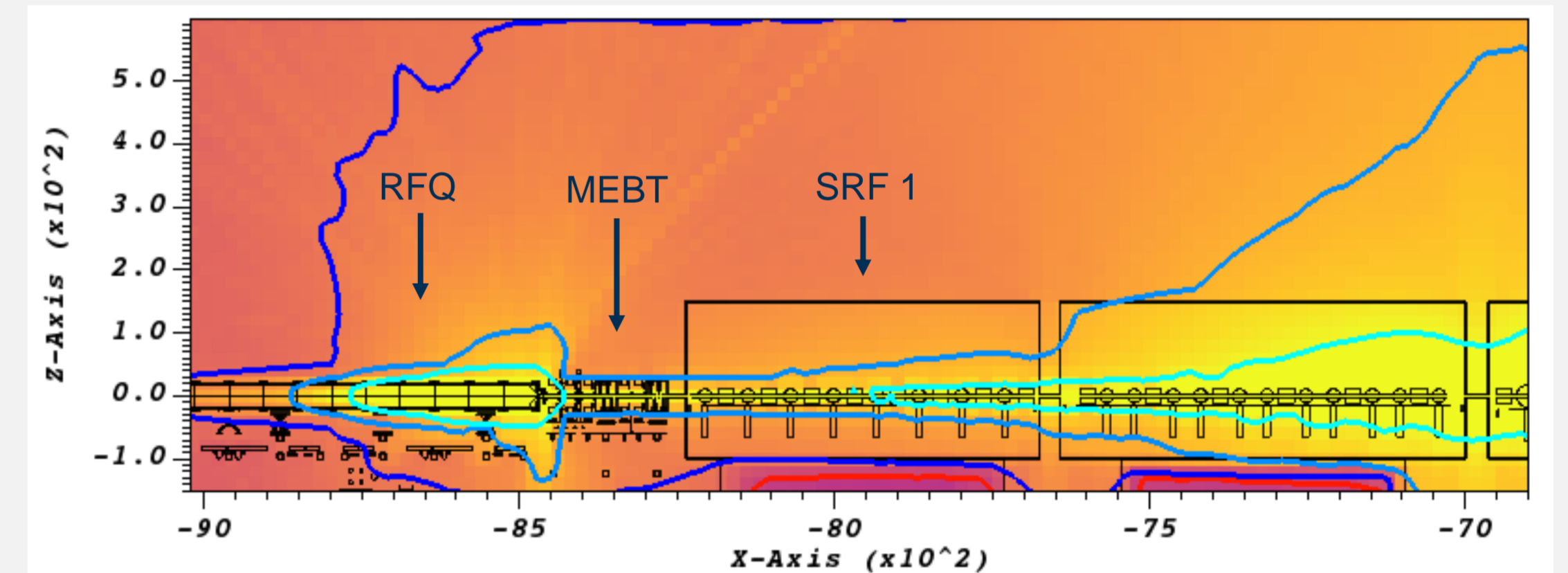
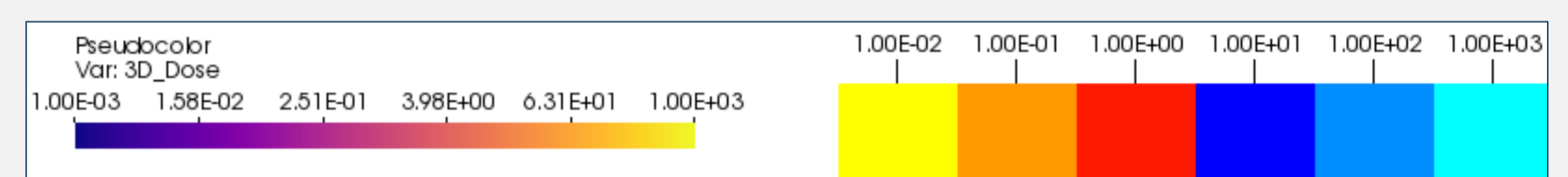


Fig. 7: Shutdown dose rates ($\mu\text{Sv/h}$) around the accelerator (vertical slice) at 1 hour decay time following 2 years of operation.

The results imply a similar SDDR field around the MEBT as for commissioning, despite the increased irradiation. This is attributed to the high losses in the commissioning HPBD. The dominant source here is the **high RFQ losses**.

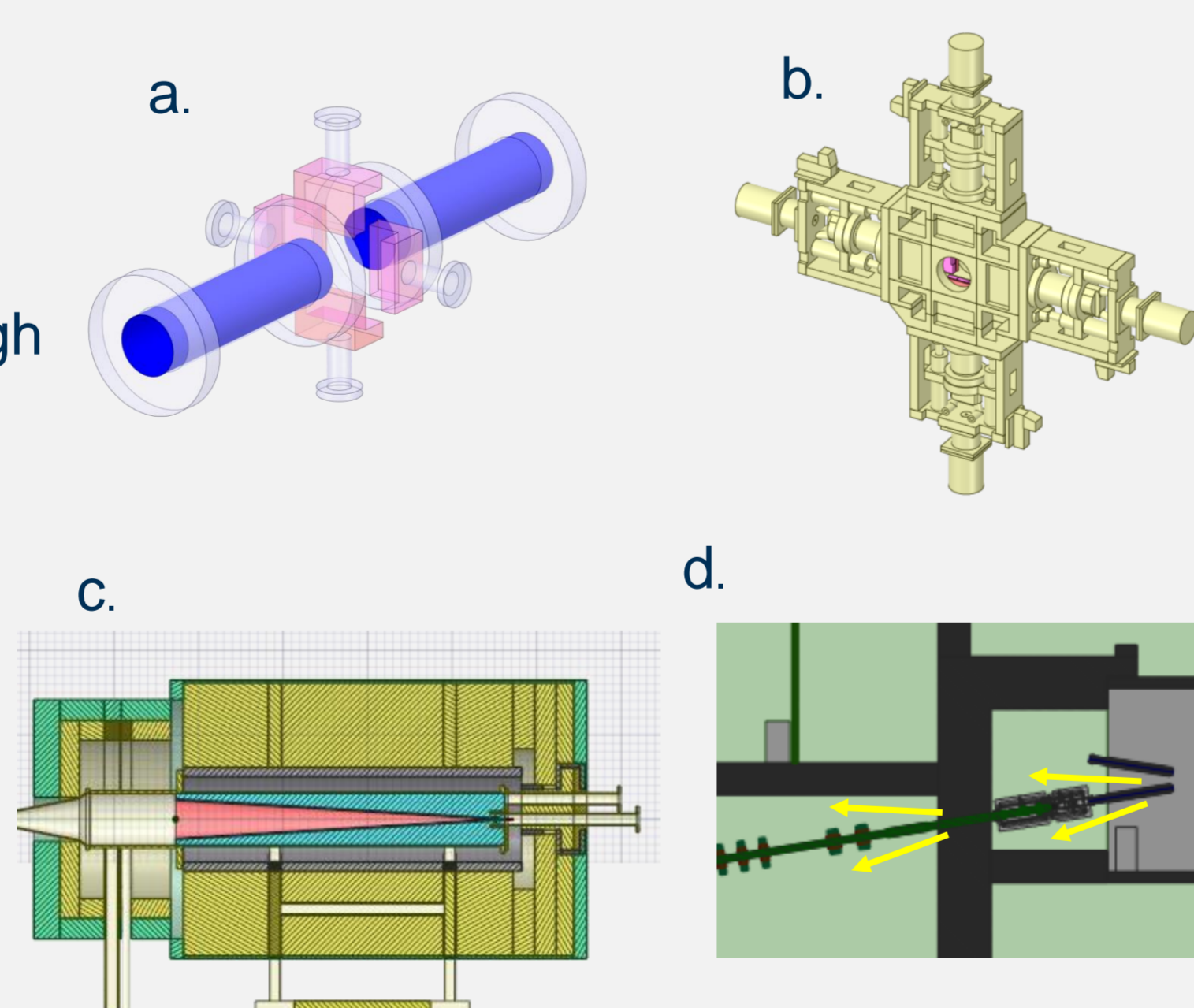


Radiation sources

There are a number of radiation sources in the DONES hall, including from:

- Losses along the **beamline**, with particularly high losses anticipated in the RFQ
- Deposition on collimating **scraper blades** at several locations (1.2 kW in the MEBT)
- Deposition in the **HPBD** copper cone at even higher flux (125 kW)
- Target system leakage (ignored here)

The accelerated deuterons may directly react with the beam-facing materials. They may also **produce neutrons** in nuclear reactions, and can undergo **D-D reactions** with previously implanted deuterons to produce 2.45 MeV neutrons [REF].



These deuterons and neutrons may produce prompt radiation, or activate materials resulting in decay radiation.

Conclusions

- Dose rates and activation for the low-energy DONES accelerator have been calculated in detail
- Shielding **HPBD entrance** should be prioritised in terms of SDDR during commissioning
- Shielding **high-energy RFQ** is priority for lower SDDR during MEBT maintenance
- Accuracy on d-Cu reaction rates essential to results

It will be important to update results as more accurate, less conservative, operating schedules become known.

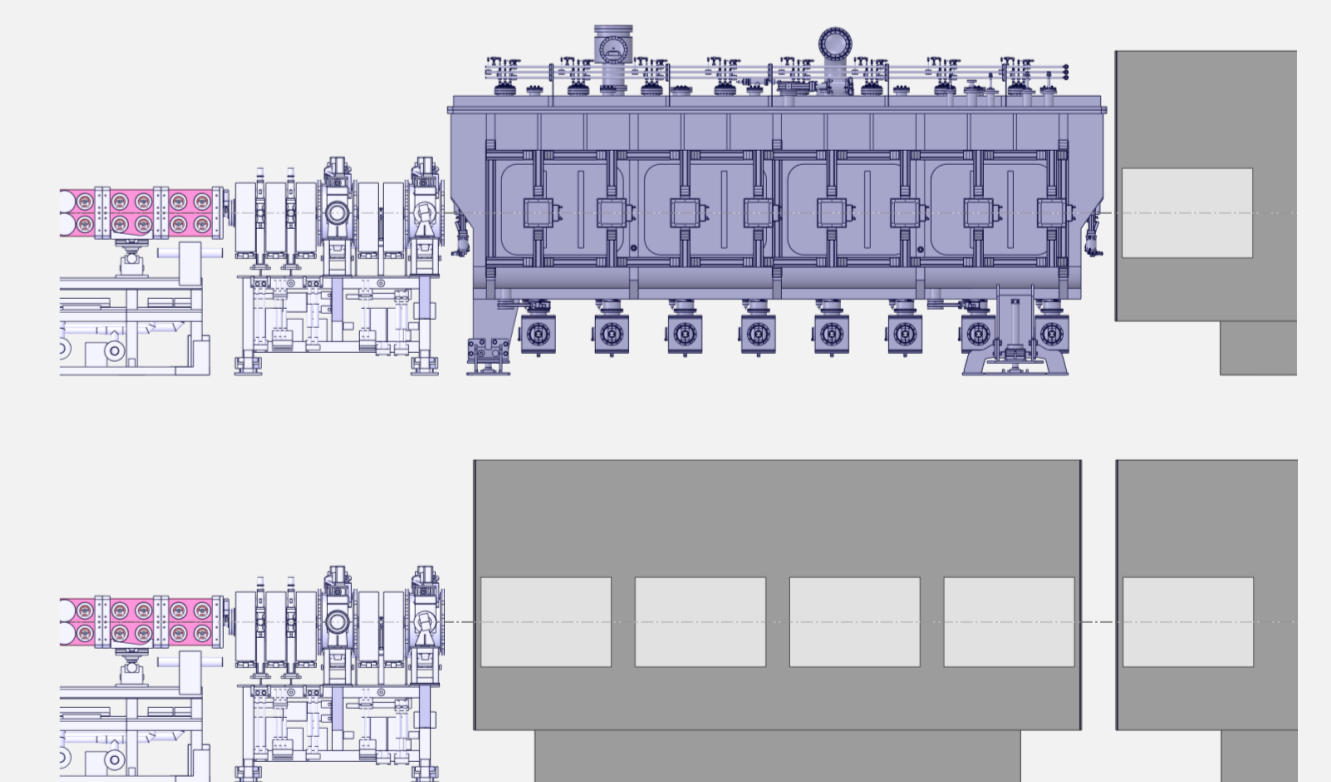


Fig. 8: Neutronics models of the SRF Linac modules will be created for more detailed studies in future.

The results **inform shielding and maintenance assessments**, and also indicate dominant sources and nuclear data priorities.

References:

[1]: I. Podadera *et al.*, Proc. LINAC'22, "Commissioning plan of the IFMIF-DONES accelerator" (2022)