OAK RIDGE National Laboratory

SATIF-16
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Shielding aspects of Accelerators, Targets and Irradiation Facilities

Experience during Ring Injection Dump Parts Exchange at the Spallation Neutron Source

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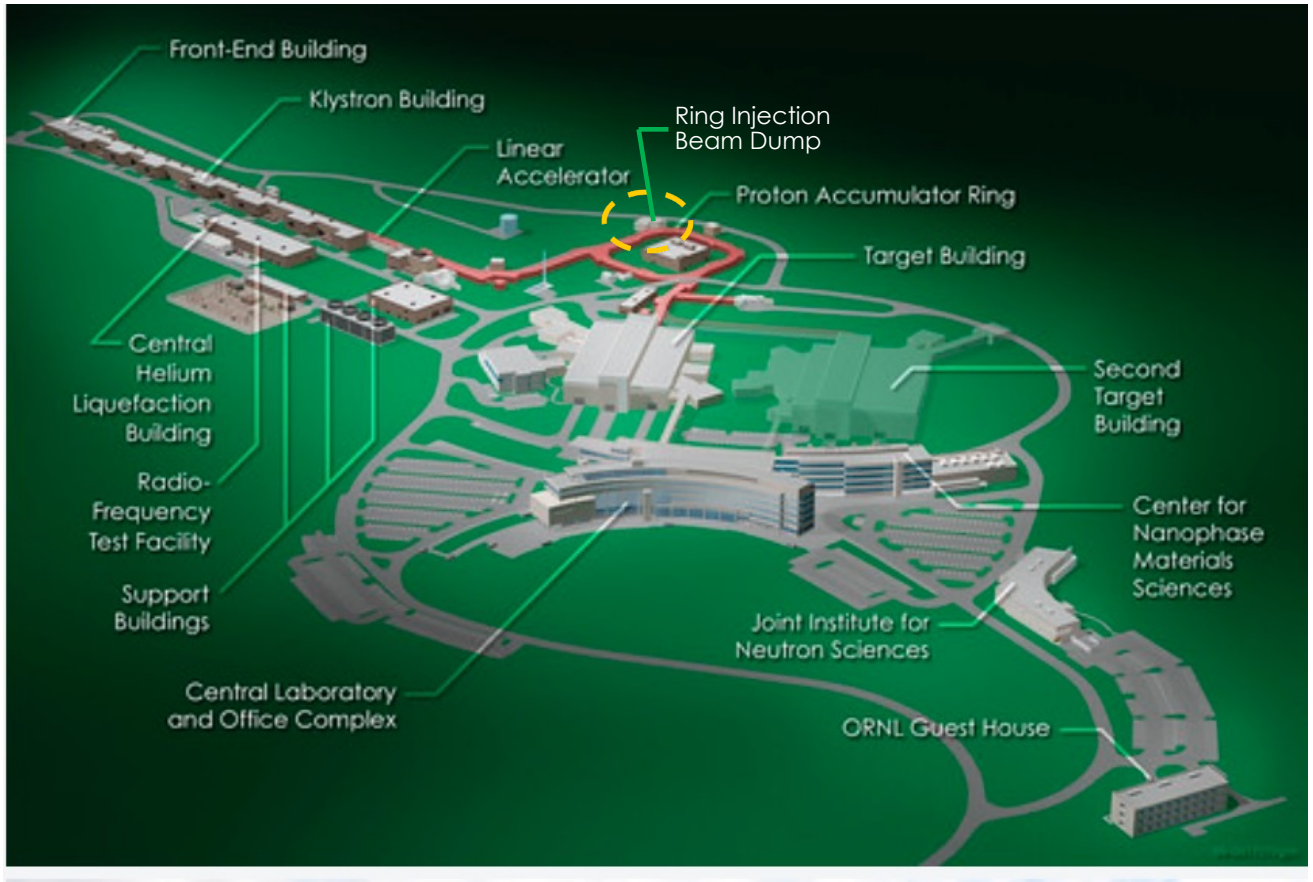
Outline

- Facility Layout
- Analyses Methods and Istruments
- Removal/Replacement Process
- Assumptions
- Results and Comparisons
- Conclusion

Introduction

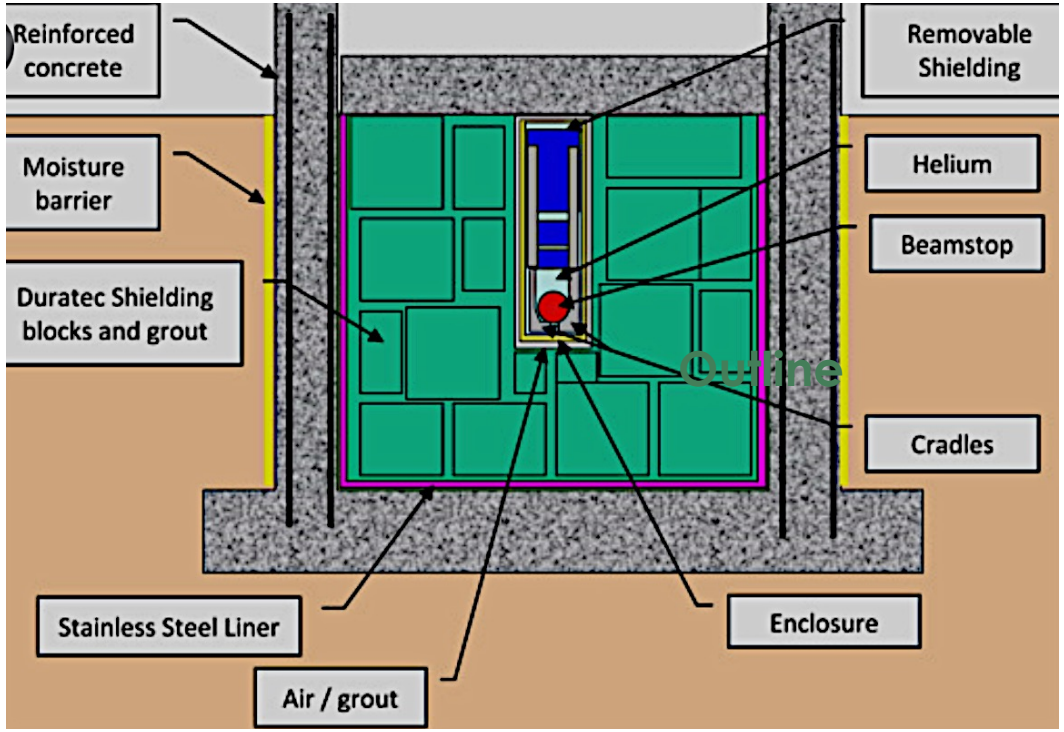
- The Spallation Neutron Source (SNS), is presently the most powerful accelerator-driven neutron source in the world.
- Sub-microsecond 60 Hz proton pulses from the accelerator complex impinge on a liquid-mercury target, generating pulses of neutrons that feed 19 operating instruments, and one more is coming this summer.
- According to the accelerator operation plan, the beam stop and the proton beam window assemblies of the existing RID will be removed, when they have reached their end-of-life



Introduction

- Ring Injection Dump was designed to accept 10% of the main (1.0-GeV, 2-milliamp) deflected proton beam from High-Energy Beam Transfer accelerator section
- Replacement was planned for April 2022 but performed in March-April 2023
- Ring Injection Dump has the most irradiated facility components
- Ring Injection Dump serves facility since the start-up – April 2006
- Due to expected high residual radiation, some components are place directly into temporary storage container while being extracted
- All steps had good work planning to minimize radiation exposure to personal
- Residual dose rate analyses and later on radiological survey are performed for each replacement step

Facility Layout

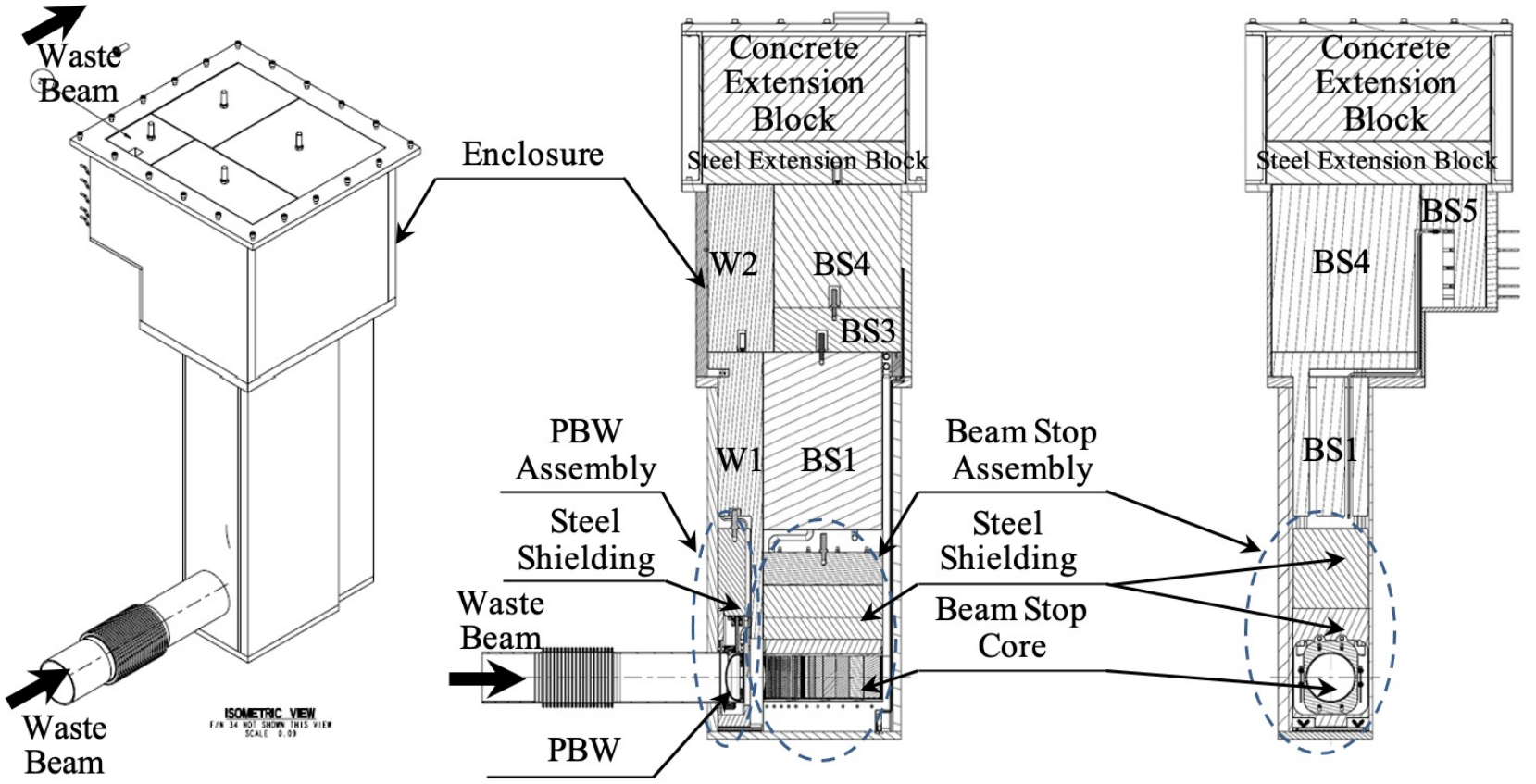


- Facility is located underground straight down stream from HEBT
- Beam stop is located inside the cradle with removable steel shielding on the top of the beam stop in the enclosure.
- The enclosure is inserted to SEG steel shielding blocks inside the reinforced concrete vault.

Facility Layout

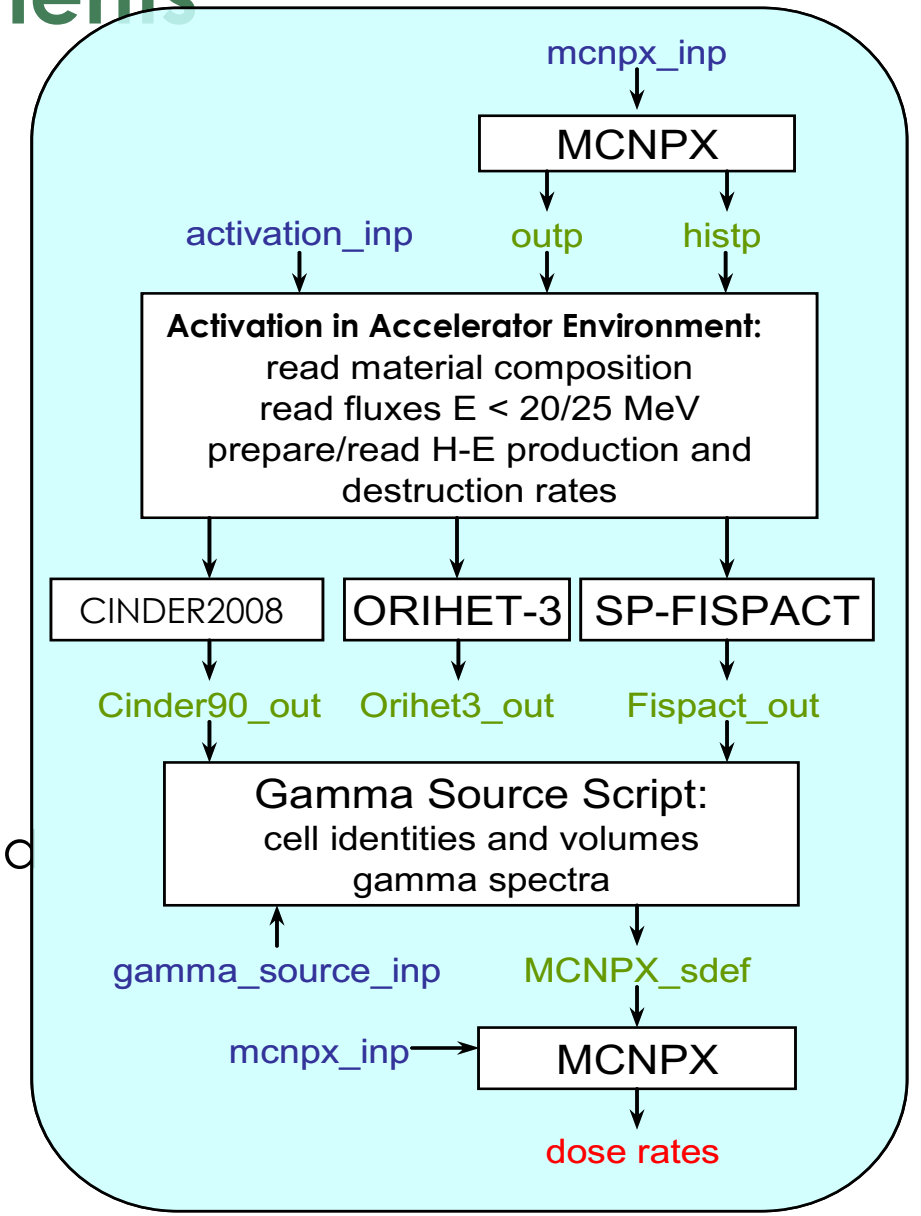
Beam Stop Enclosure containing:

- PBW and Beam Stop Assemblies
- Shielding Blocks



Analyses Methods and Instruments

- To obtain reaction rates in the beam stop full three-dimensional radiation transport calculations for rigorously modeled RID are performed with MCNPX
- The decay gamma sources in the activated material are calculated using AARE script
- The beam operation history was taken from SNS archives
- Cool down assumed 20 days
- Then decay gammas spectra in the multi-group structure and gamma power are extracted for each cell and are fed back to MCNPX input file



Analyses Methods and Instruments

Measurements are performed during each removal exchange stage

- to assure radiation safety for radiation protection personnel who were performing hands-on manipulations;
- to identify the highest dose rate locations

Used instruments for dose reading

- RadEye B20ER multi-Purpose Survey Meter
- Ludlum Model 79 Stretch Scope Survey Meter

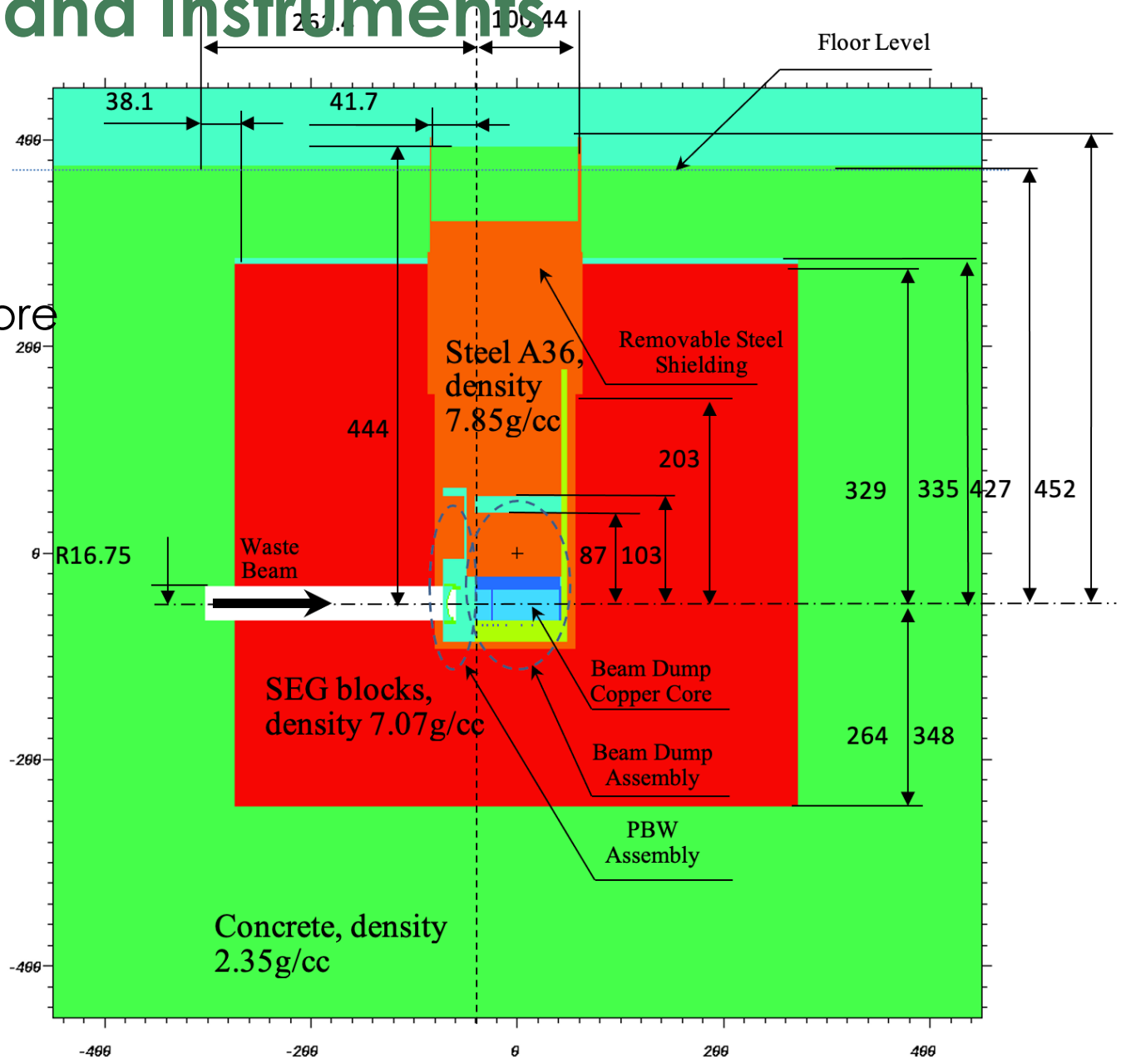
Instruments are calibrated at ORNL

Analyses Methods and Instruments

RID detailed model includes:

- Beam stop assembly with copper core
- PBW assembly with Inconel window
- Shielding blocks in the enclosure
- SEG permanent shielding blocks
- Concrete envelope

- The RID geometry is modified accordingly to each stage of exchange reflecting :
  - Extracted parts
  - Container placement
  - Parts lifted into the container on the top of the enclosure

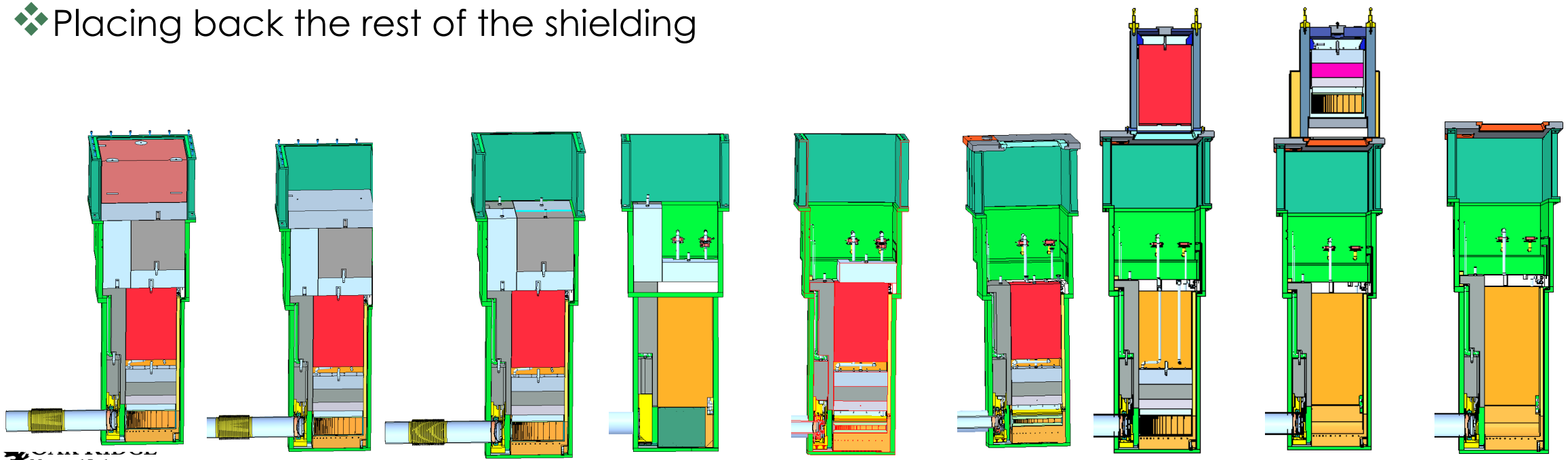


Removal/Exchange Process

- Extraction/replacement of the beam stop assembly is performed in stages
- Block-by-block beam dump shielding removal
- Beam stop assembly exchange

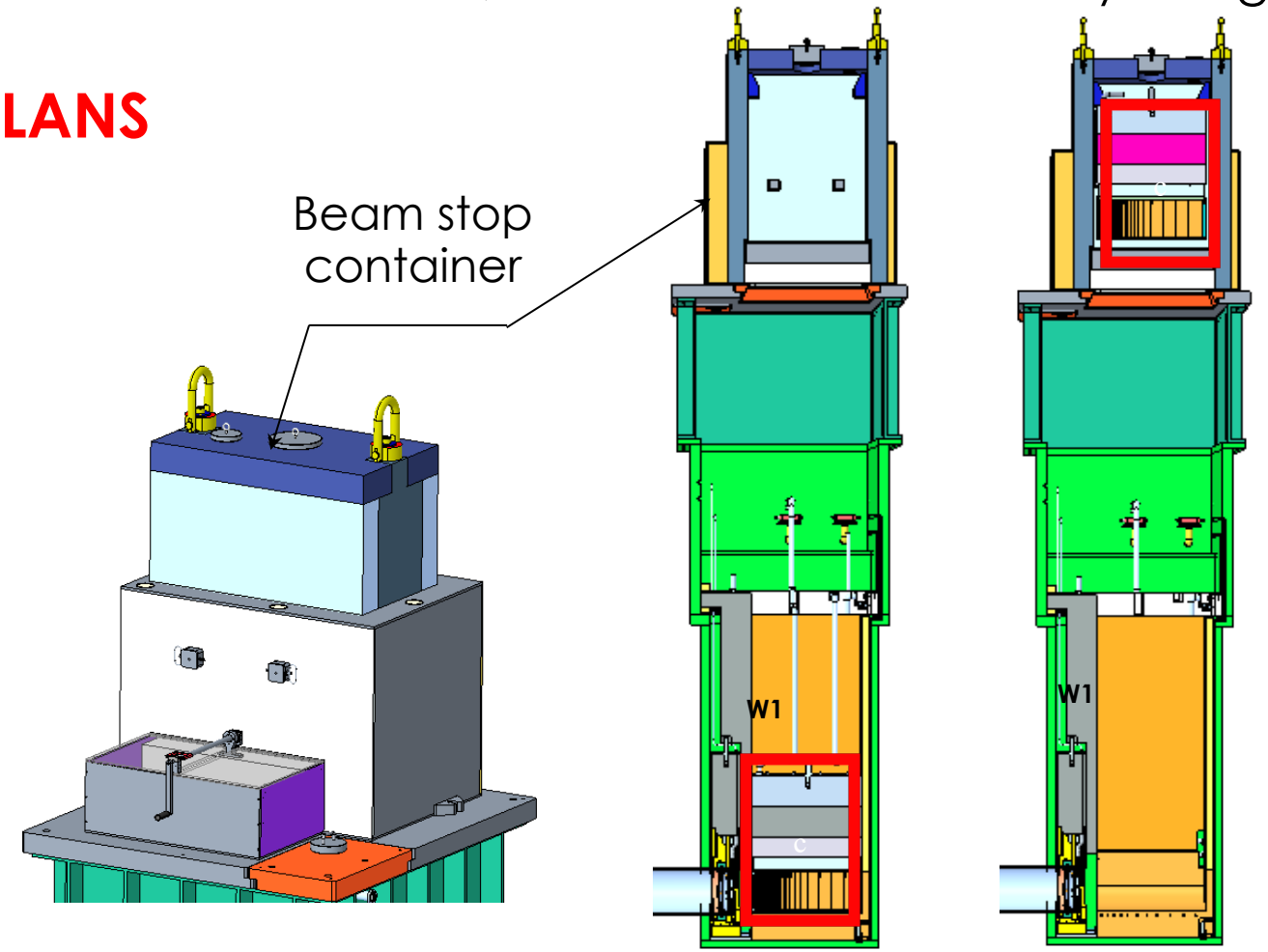
Beam stop get stacked, change in scenario – PBW W1 is removed

- ~~Placing partially back some of the beam dump shielding~~
- Replacing beam stop assembly
- Replacing the PBW assembly
- Placing back the rest of the shielding



Removal/Exchange Process

- The temporary storage container is placed on the top of the adapter plate
- The beam stop assembly started to be is lifted
- The lifting process was not successful; the beam stop assembly caught the PBW shield block W1
- **CHANGE OF PLANS**

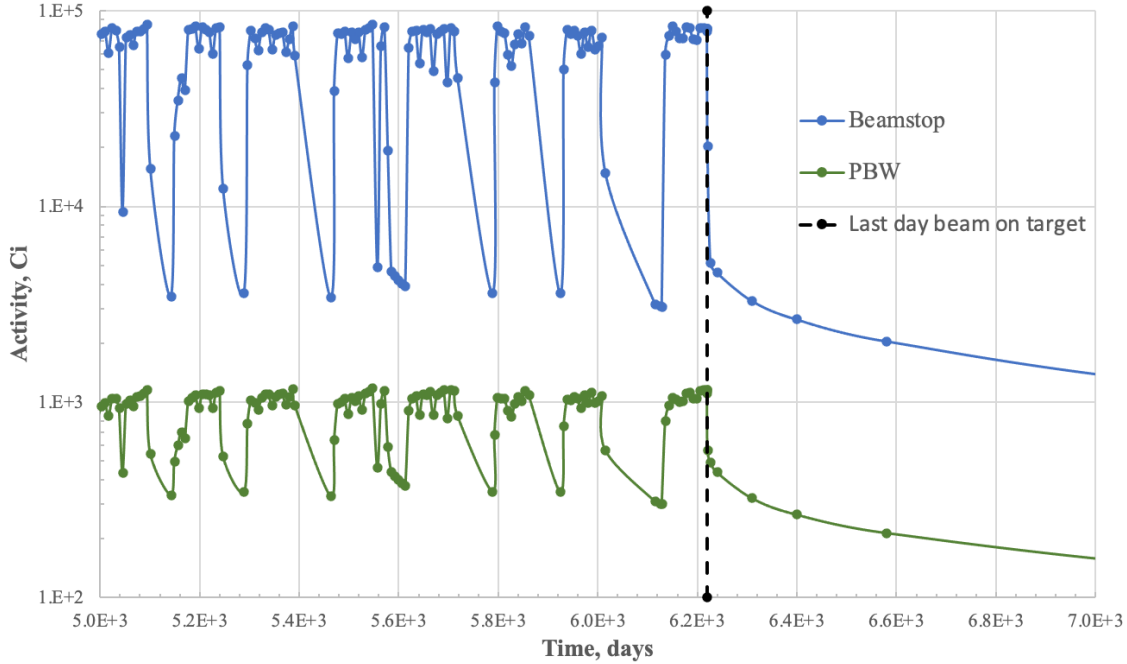


Assumptions

- For prompt dose rate 5% from beam at 1GeV at 1.4 MW is going to the beam stop, multiplication factor is 4.375e14 proton/s
- Initial analyses were performed for the last beam on target on March 20, 2023
- Actual last day beam on target February 28, 2023
- Total beam energy deposited to the beam dump of 3.412 GWh
- Beam stop removal started March 2023

Assumptions
Gamma Sources

Activity built up after 13.5 years of facility operation (about 5,000 days) and decay for beam stop and PBW structures

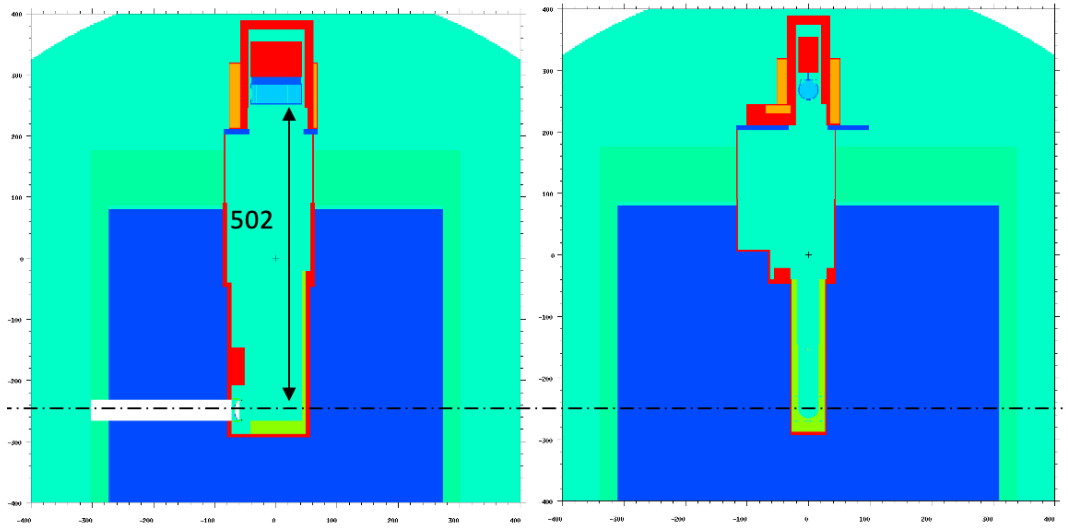


Activation build-up and decay for beam stop and PBW structures

- Equilibrium reached
- 50 times reduction in activation in one day of cooldown

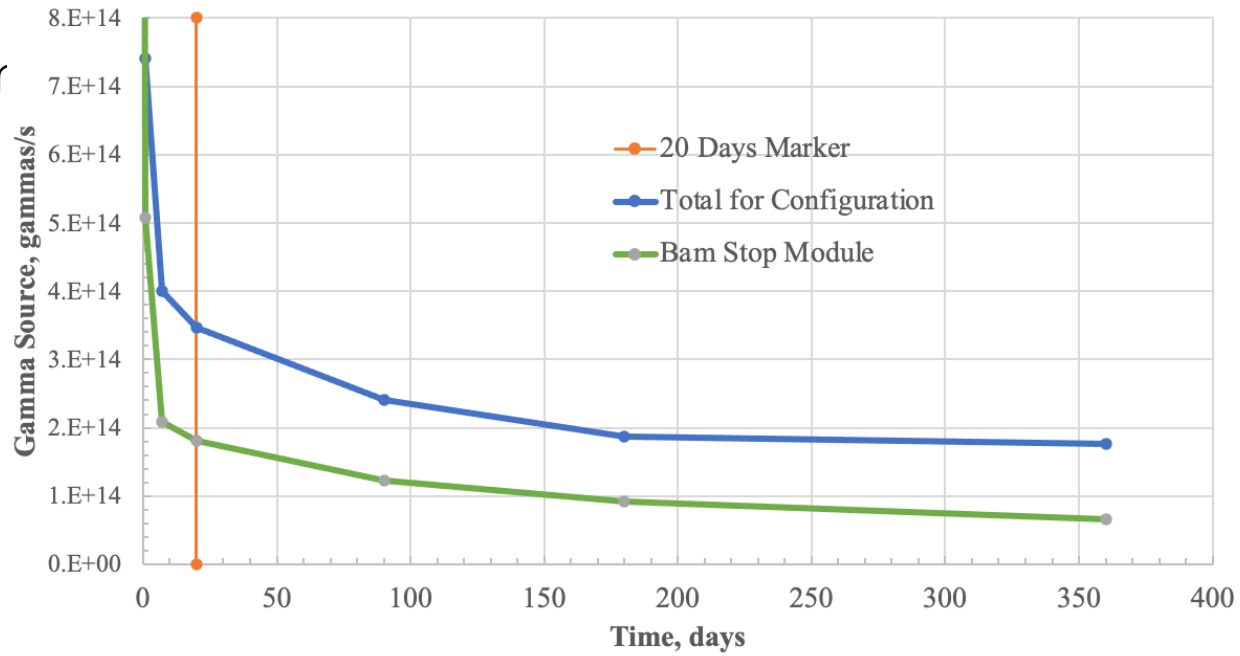
Assumptions
Gamma Sources

- ✓ Exchange process took place between 7 and 35 days after the facility shutdown.
- ✓ Dose rate calculations were performed on source terms extracted for 20 days after the shutdown



Gamma source power over cool down time

- ❖ Huge reduction of source strength from beam termination time to one day
- ❖ From one day to 20 days the gamma source strength drops only about a factor of 2

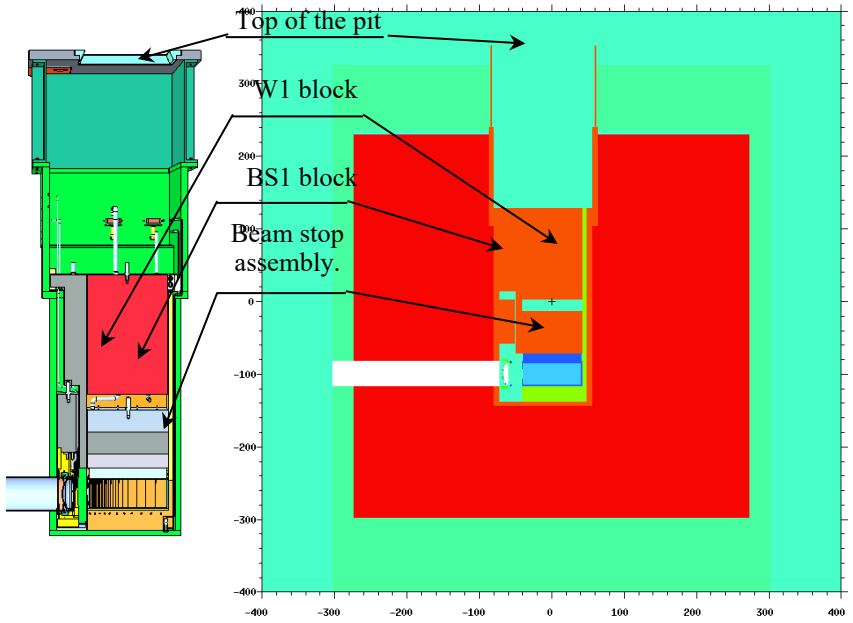


Results

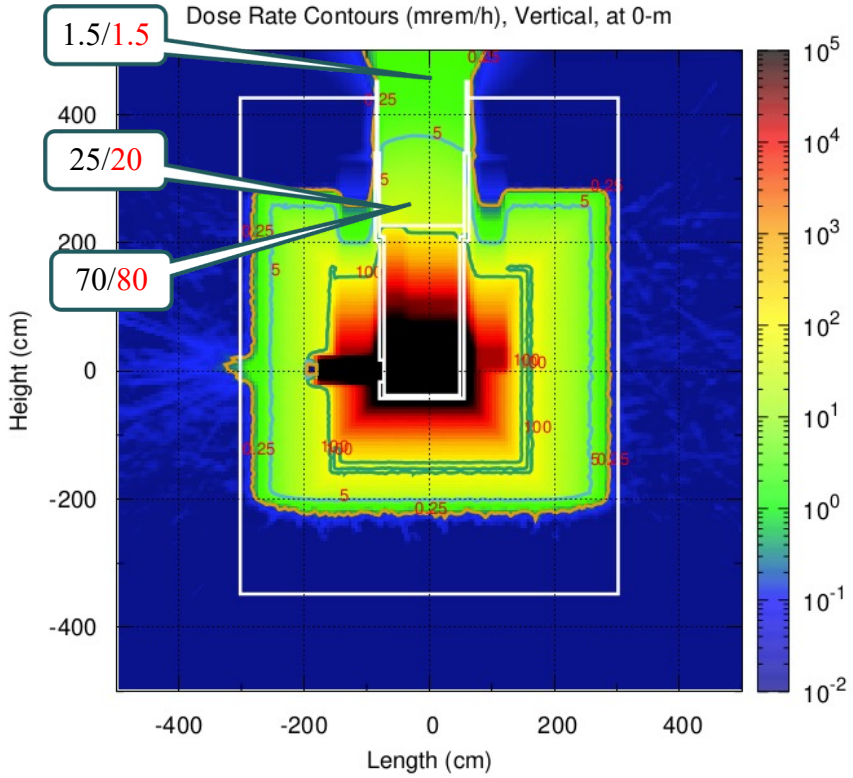
- Dose rates are calculated for each stage of removal/replacement
- Results are given as dose rates maps with indication of calculated/measured dose rates in callouts
- For comparison calculation with measurements dose rates are taken from mesh plots
- Uncertainties in detector positioning for dose rates measurements are with in 10-cm (factor of about 2)
- Uncertainties in the analyses are driven by:
  - Material description
  - Part of the proton beam going to the beam stop
  - Standard deviation
  - Time for which analyses are performed

Results
Dose rates

Concrete and steel extension block, steel shielding blocks B1-3 and W1 are removed and W1 PBW shielding block



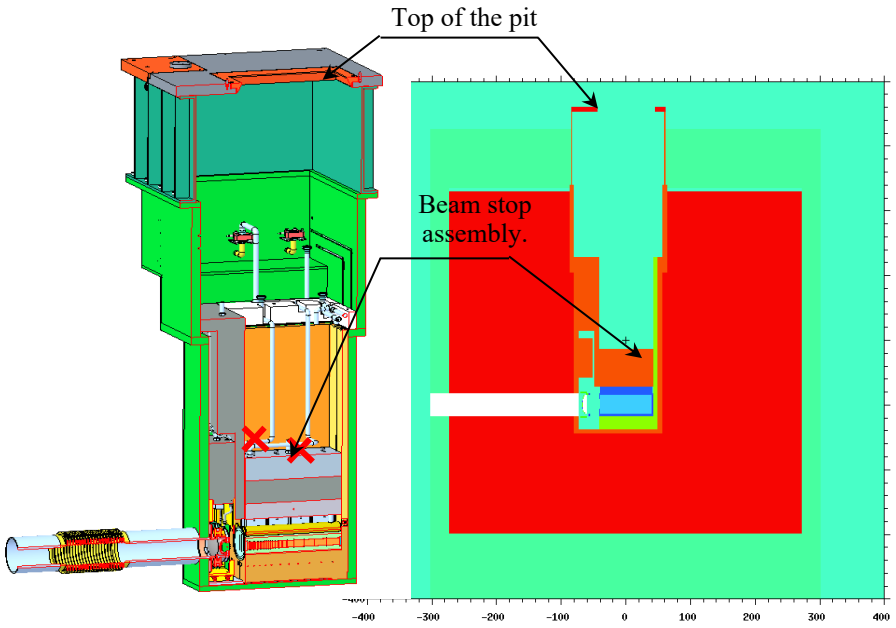
Survey data is taken on 03/20/2023



Comparison of measured vs. calculated dose rate shows good consistency: results are within 17%. Calculated dose rates are lower than the measured dose rates

Results
Dose rates

Concrete and steel extension blocks are removed including all beam-stop and W2-3 shielding block, adaptor plate installed



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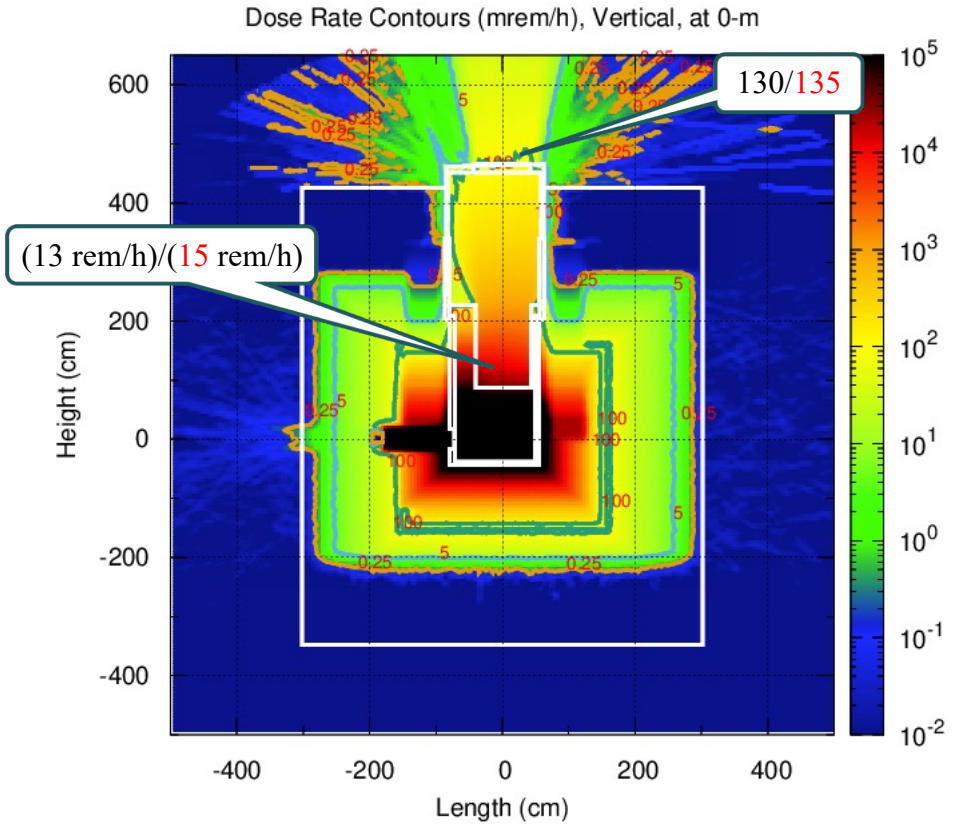
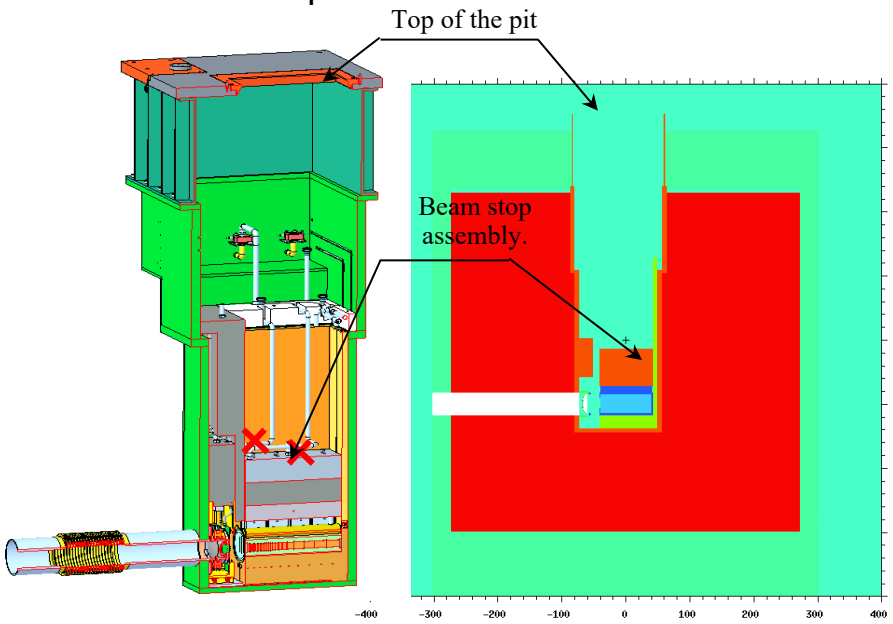


Comparison of measured vs. calculated dose rate shows good consistency; results are within 13%. Calculated dose rates are lower than the measured dose rates

Results
Dose rates

Concrete and steel extension blocks are removed including all beam-stop and all PBW shielding block, adaptor plate installed



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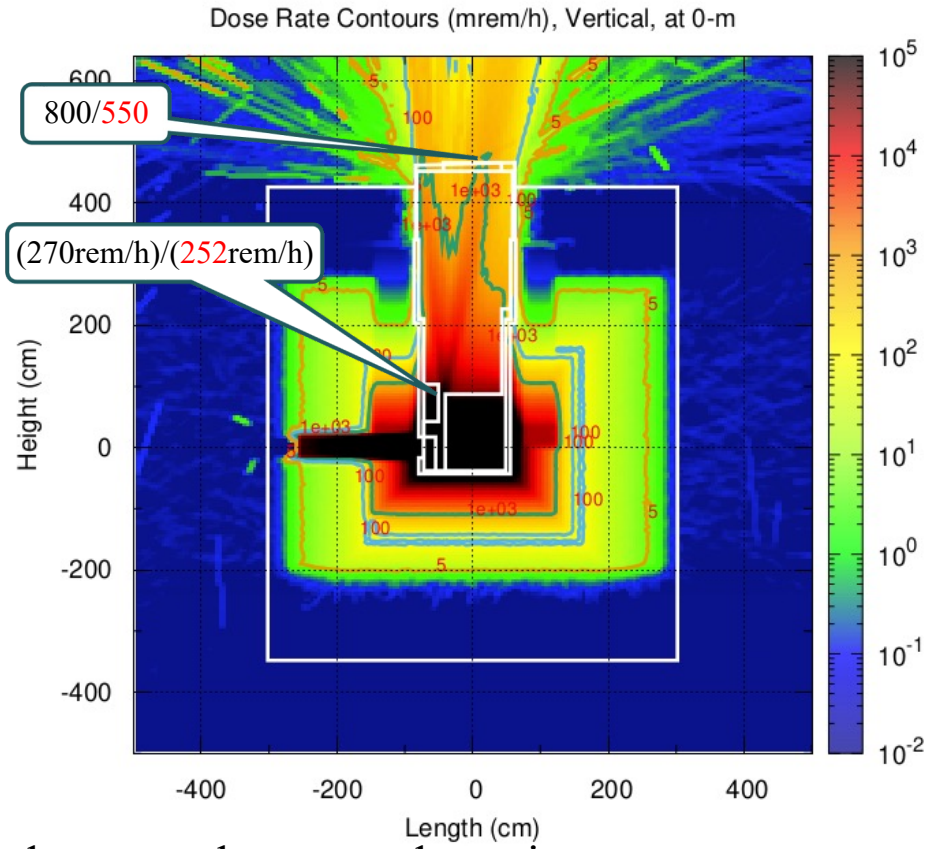


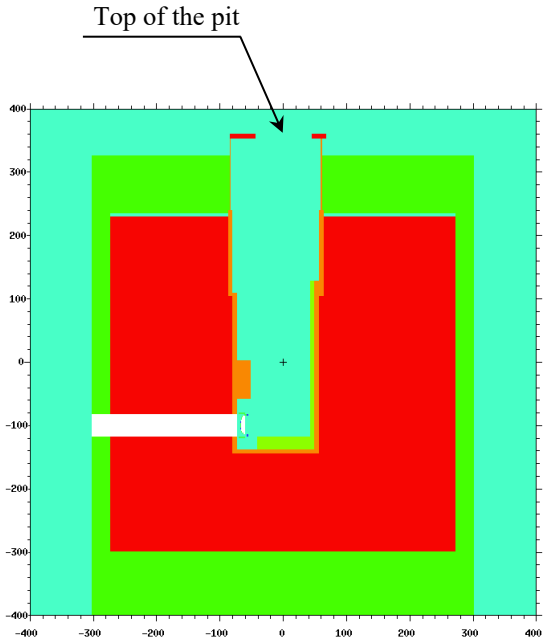
Comparison of measured vs. calculated dose rate shows good consistency, results are within 45%. Calculated dose rates are higher than the measured dose rates

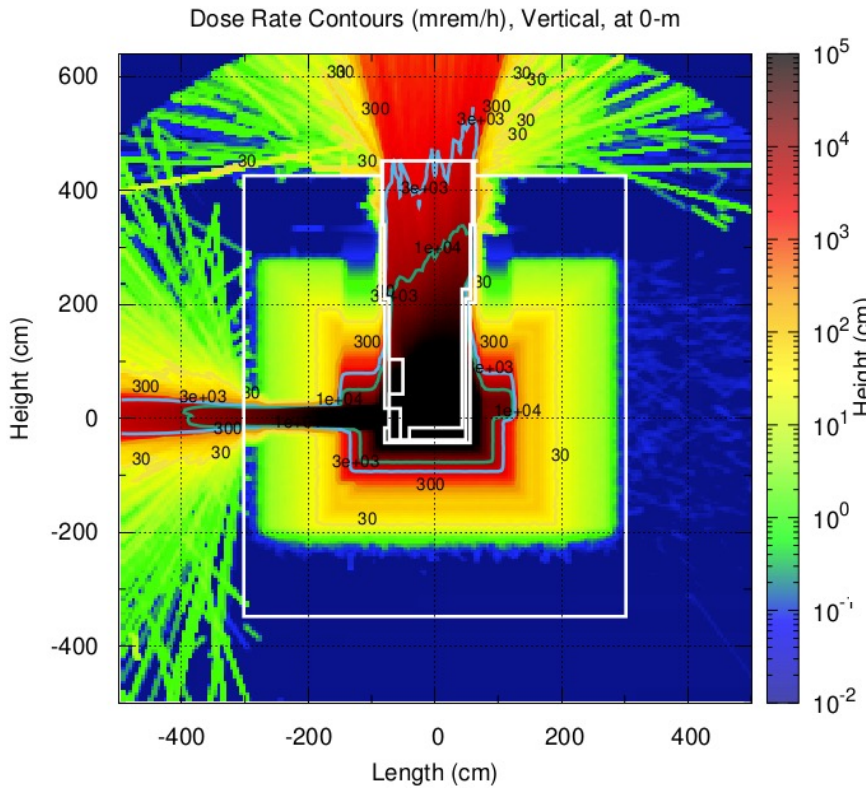
Results

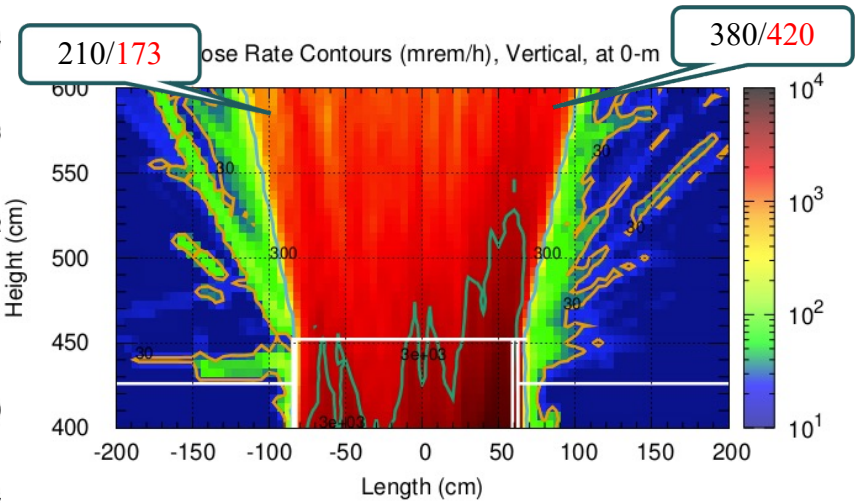
Dose rates

Steel and concrete extension blocks, all beam dump shield blocks, all PBW shield blocks, and the beam stop module were extracted.

Survey data is taken on 03/23/2023

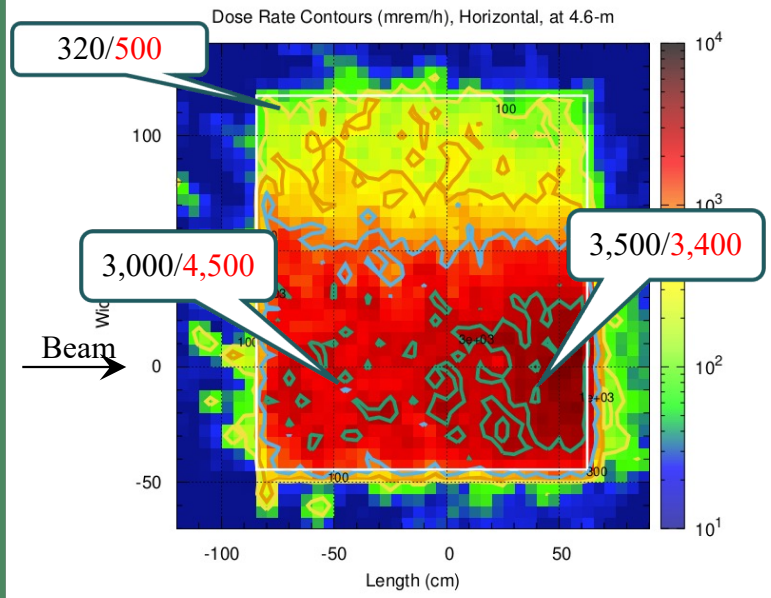


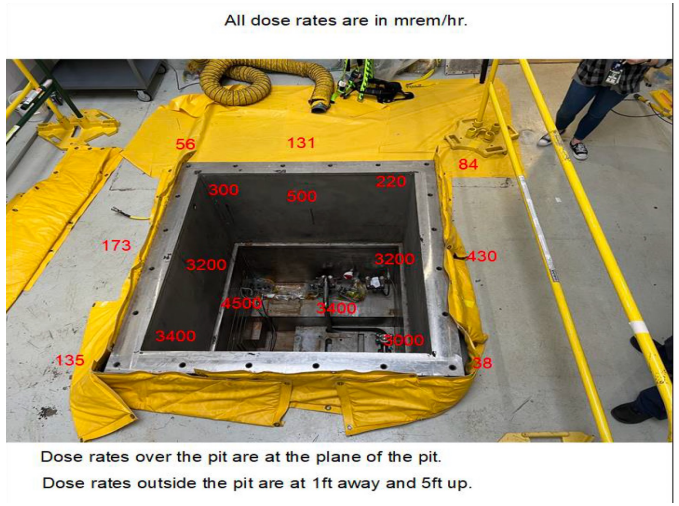




Results
Dose rates

Survey data is taken on 03/23/2023





Dose rates over the pit are at the plane of the pit.
Dose rates outside the pit are at 1ft away and 5ft up.

Location	Calculated	Measured	Ratio calculated/measured
At about 5ft from the floor and 1ft to the outside and upstream of the pit opening	210	173	1.21
At about 5ft from the floor and 1ft to the outside and downstream of the pit opening	380	420	0.9
At the upstream pit plane at 30 cm from the edge, inside the pit, left corner	400	500	0.8
At the upstream pit plane at 50 cm from the edge, inside the pit, above the beam centerline	3100	4500	0.69
At the upstream pit plane at 30 cm from the edge, inside the pit, right corner	2900	3400	0.85
At the downstream pit plane at 30 cm from the edge inside the pit, left corner	260	220	1.18
At the downstream pit plane at 50 cm from the edge inside the pit, above beam center line	4000	3400	1.17
At the downstream pit plane at 30 cm from the edge inside the pit, right corner	3100	3000	1.03

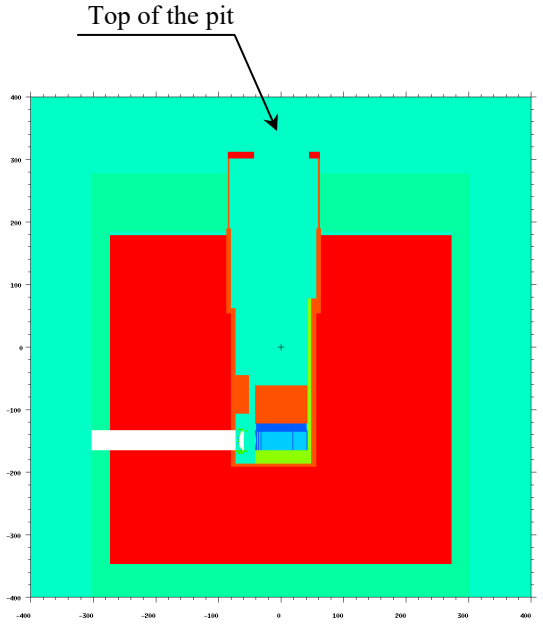
The calculation and measurements at the outside perimeter of the pit compared well enough. Measured dose rates compare to calculated dose rates within 31%.

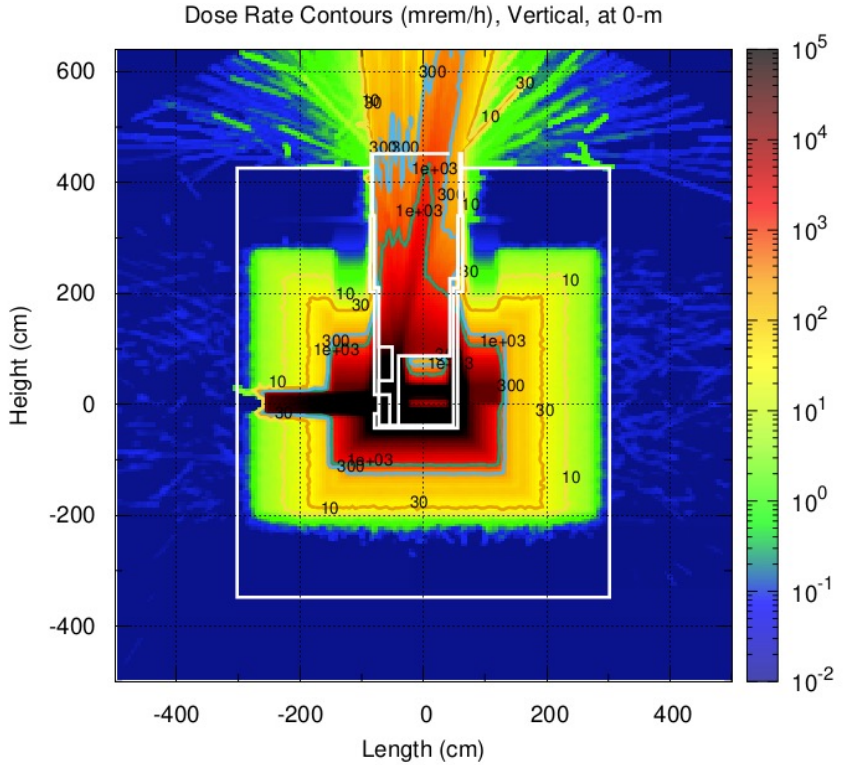
Results

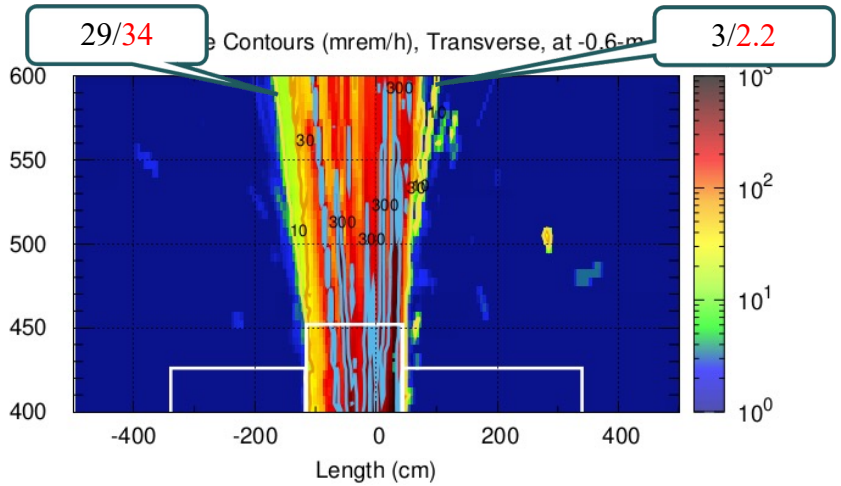
Dose rates

All shield blocks were extracted and new beam stop assembly installed.

Survey data is taken on 03/23/2023

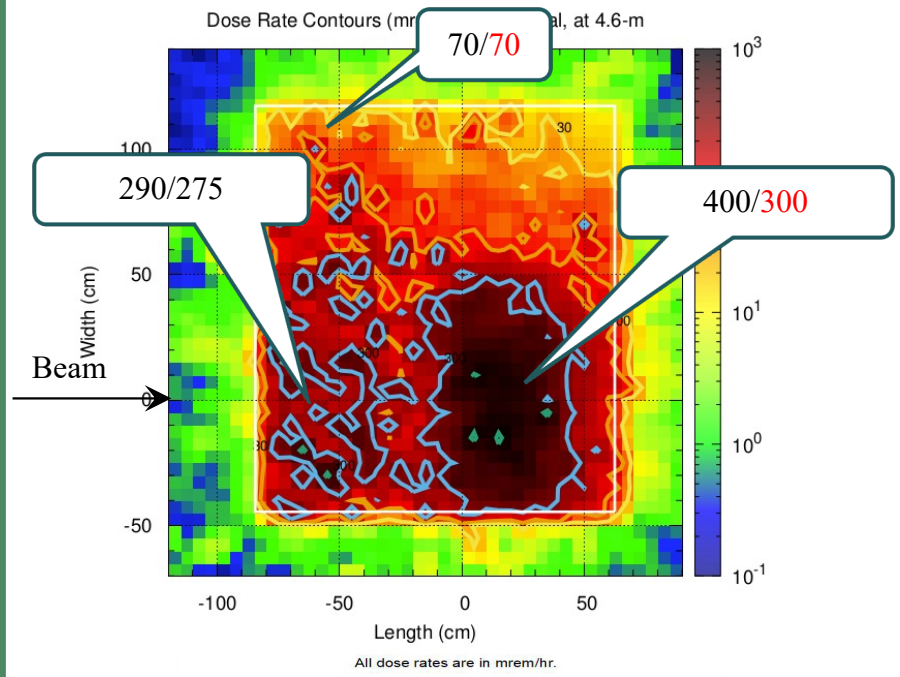


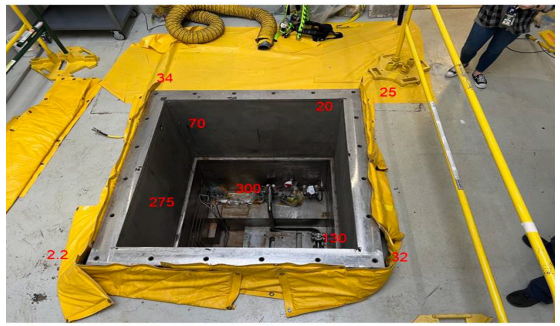




Results

Dose rates





Dose rates over the pit are at the plane of the pit.
Dose rates outside the pit are at 1ft away and 5ft up.

Location	Calculated	Measured	Ratio calculated/measured
At about 5ft from the floor and 1ft to the outside and upstream of the pit opening, left corner	29	34	0.85
At about 5ft from the floor and 1ft to the outside and downstream of the pit opening, right corner	3	2.2	1.36
At the upstream pit plane at 30 cm from the edge, inside the pit, left corner	75	70	1.07
At the upstream pit plane at 30 cm from the edge, inside the pit, above the beam centerline	290	275	1.05
At the downstream pit plane at 30 cm from the edge inside the pit, left corner	25	20	1.25
At the pit middle, above beam center line	400	300	1.33
At the downstream pit plane at 30 cm from the edge inside the pit, right corner	190	130	1.46

Measured dose rates compared to calculated dose rates within 45%.

Conclusions

- Extensive planning was done for beam stop and PBW modules replacement
- Neutronics analyses to evaluate the residual dose rates are performed for each replacement stage
- Work not always go as planned – change of the exchange process
- Both components are successfully replaced
- Comparisons of dose rate measurements vs calculated dose rates show good consistency within factor 1.5