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Residual Dose Rates Measured vs Calculated during the Replacement of SNS Inner Reflector Plug 2

Irina Popova

F.X. Gallmeier, C. Elam



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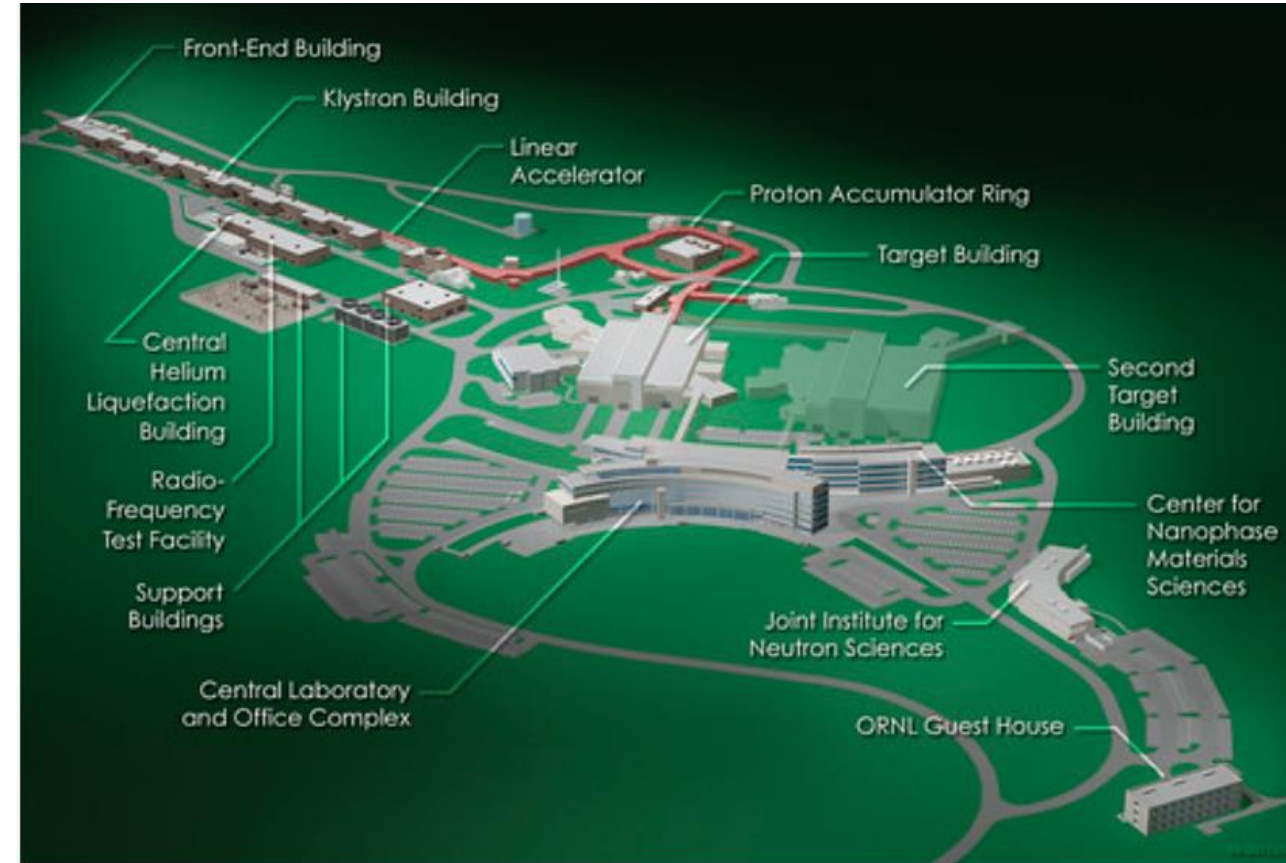


Outline

1. **Introduction** — SNS facility and IRP role in the target monolith
2. **Replacement Operation** — IRP2 removal stages, segmentation, timeline
3. **Instruments** - measurements
4. **Methods and assumptions** — Three-step workflow: transport, transmutation, dose rate estimation
8. **Comparisons** — Example dose rate maps and comparison to measured values
9. **Conclusions**

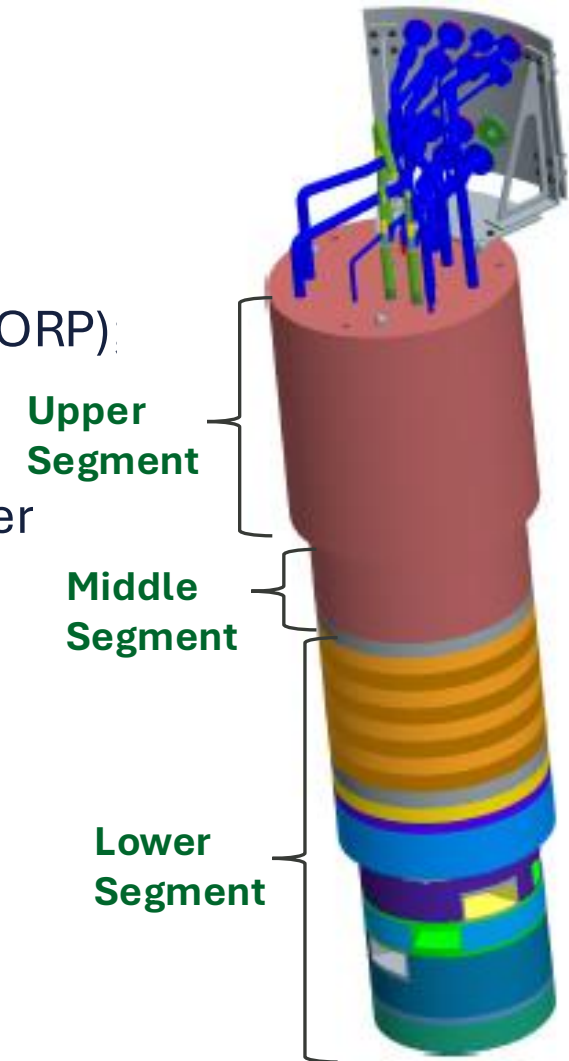
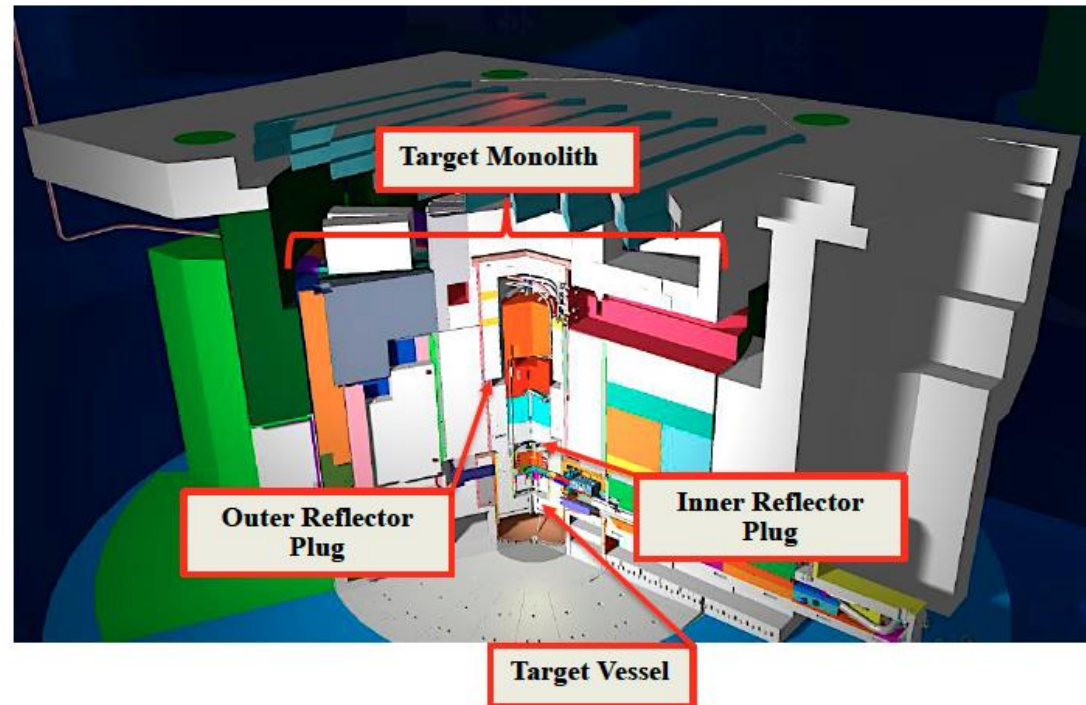
Introduction: The Spallation Neutron Source

- The Spallation Neutron Source (SNS) is presently the most intense accelerator-based neutron source.
- Sub-microsecond 60 Hz proton pulses at 1.3GeV from the accelerator complex impinge on a liquid-mercury target, generating pulses of neutrons that feed 20 operating instruments.
- Inner Reflector Plug (IRP): beryllium reflector + moderator vessels surround the target
- IRP accumulates high activation dose over operational lifetime → periodic replacement required



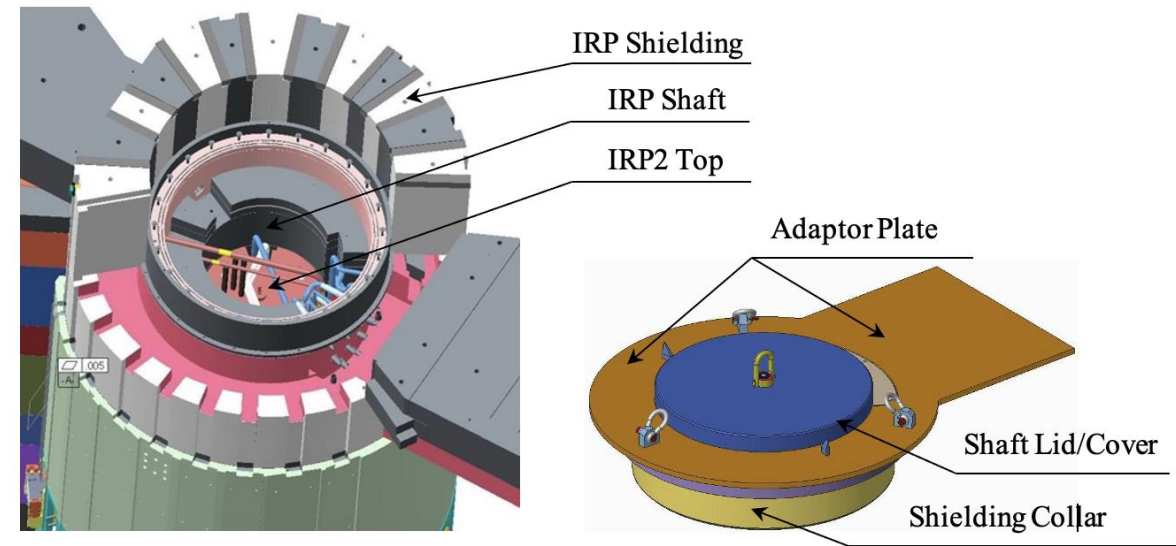
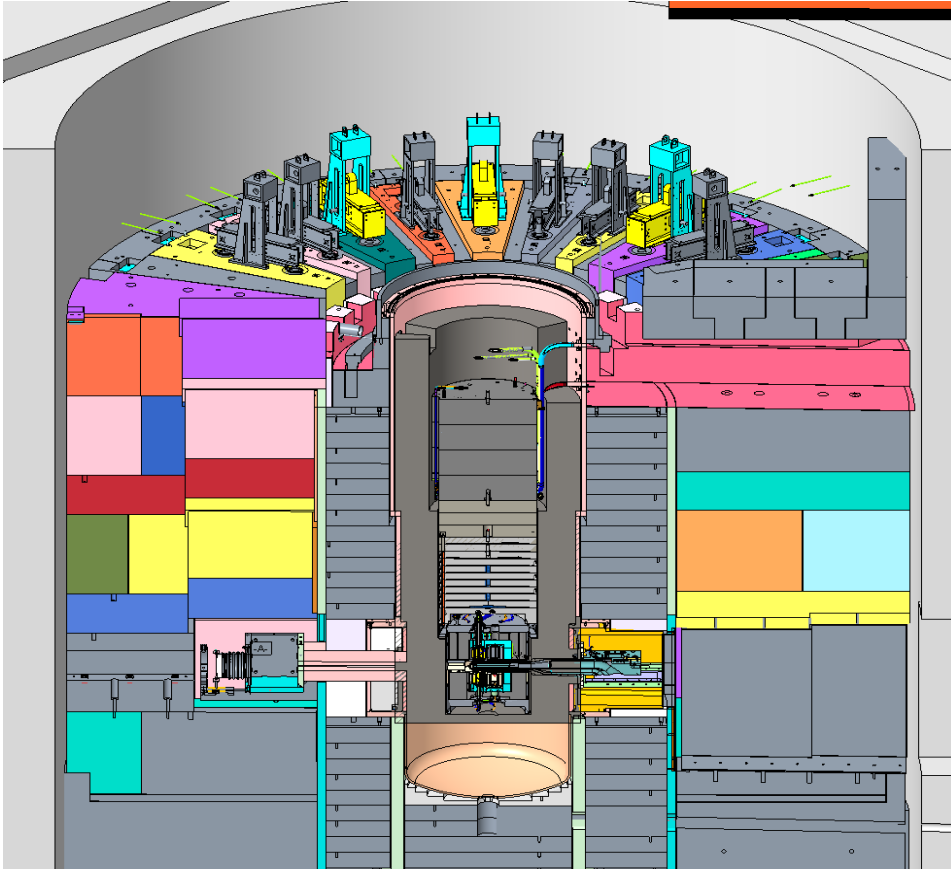
Replacement Operation

- ❖ IRP2 replacement with IRP3: December 2025 maintenance outage
- ❖ Critical operation demanding significant planning for a variety of activities
- ❖ Target monolith is located inside the target building
- ❖ Monolith outer radius ~5.10 m, houses steel shielding and Outer Reflector Plug (ORP)
- ❖ IRP2 is inserted into shaft has radius ~1.30 m, height ~3.40m
- ❖ IRP is split into three axial segments during the replacement: lower, middle, upper



Replacement Operation

- ❖ Shielding removed from the shaft to open IRP2
- ❖ Adaptor plate installed on the top of the shaft



Dose Evaluation to support radiological planning

Dose rate analyses required at each stage: worker dose compliance (10 CFR 835), remote handling equipment qualification, cask shielding verification.

Instruments

- **Survey instruments:** RadEye B20-ER and Ludlum Model 3000 both multipurpose survey meter
- **Calibration:** Calibrated at ORNL by the Instrumentation and Control Services Group
- **Detector standoff:** Detection element positioned approximately 0.5 cm from the surface
- **Measurement technique:** Readings were obtained by manual positioning of the instrument
- **Positioning limitation:** Exact detector location could not be reproduced more precisely than within 10 cm
- **Orientation sensitivity:** Measured response depended on detector orientation relative to the surface
- **Estimated uncertainty:** Positioning and orientation effects introduced an overall measurement uncertainty of approximately **30%–40%**



Methods and Assumptions

Step 1

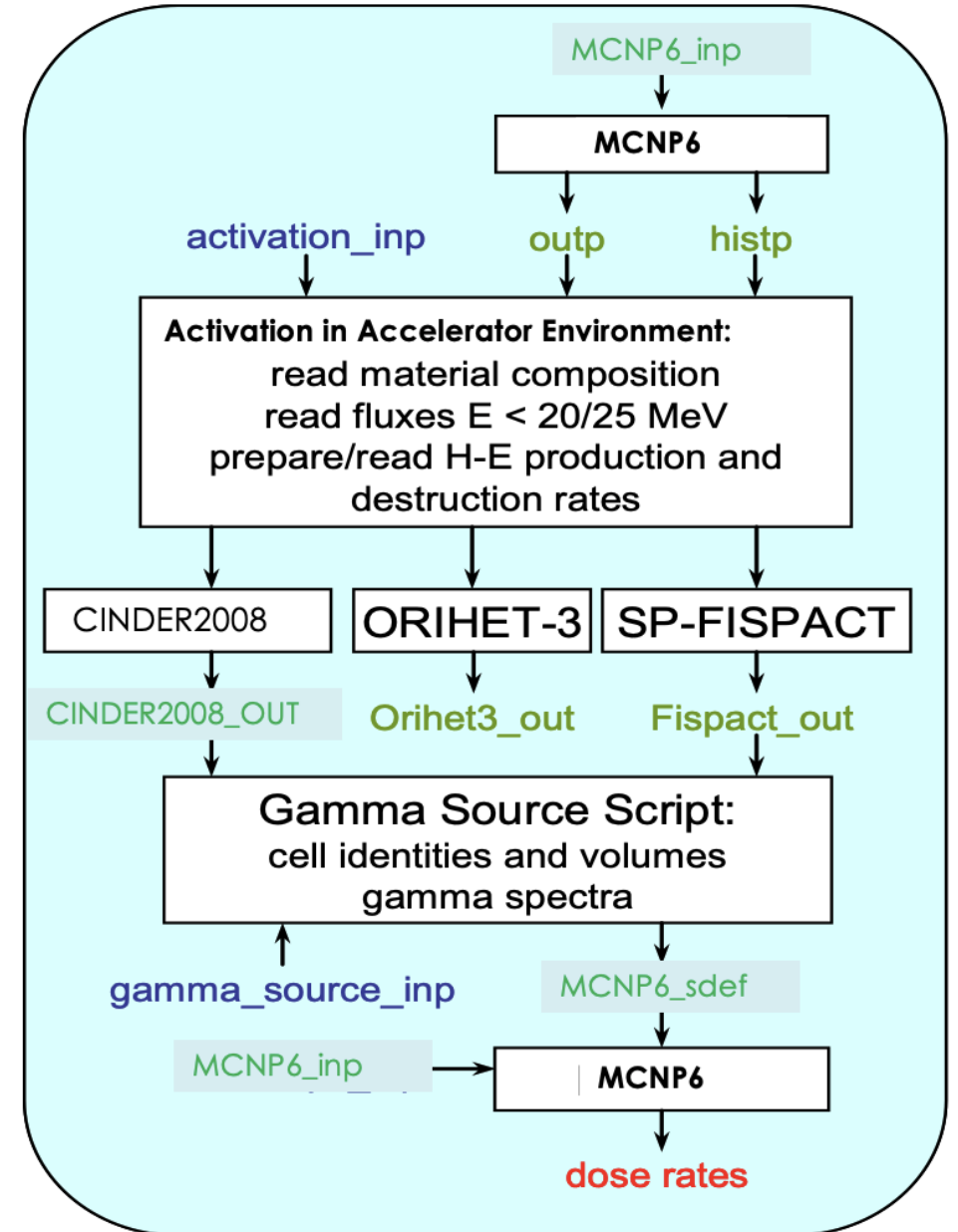
Full three-dimensional radiation Monte Carlo transport calculations analyses performed with MCNP6 obtain neutron fluxes below 20MeV and reaction rates above 20 MeV

Step 2

The decay gamma sources in the activated material are calculated using AARE (Activation in Accelerator Radiation Environments) script

Step 3

Then decay gammas spectra in the multi-group structure and gamma power are extracted for each cell and are fed back to MCNP6 input file



Methods and Assumptions

① Challenges

- ❖ Overall activation includes life-time monolith activation and IRP2 activation
- ❖ Cooling media for IRP1 - regular water
- ❖ Cooling media for IRP2 - regular water
- ❖ During IRP2 operation an upgrade of SNS facility took place – Proton Power Upgrade – 1GeV to 1.3 GeV
- ❖ Complex geometry

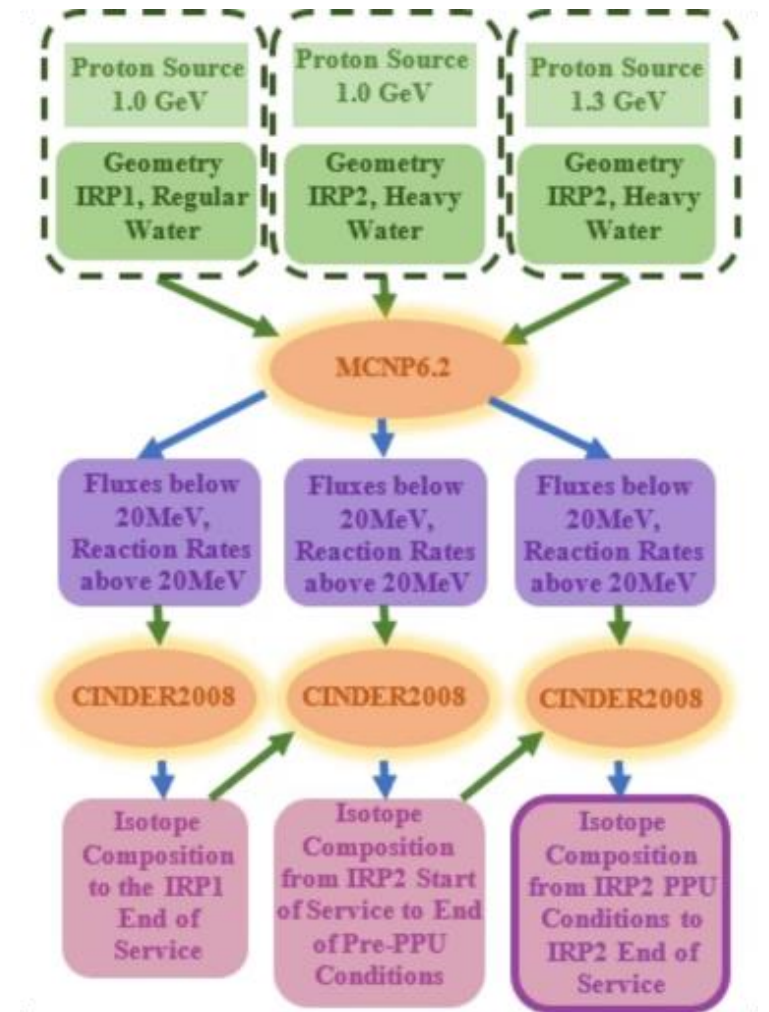
② Assumptions

- ❖ Same target model is used in all analyses
- ❖ Operation scenario is taken from SNS log-books
- ❖ Analyses for the target monolith cells assume operation time since facility start-up in April 2006
- ❖ The last day of beam on target of November 25, 2025

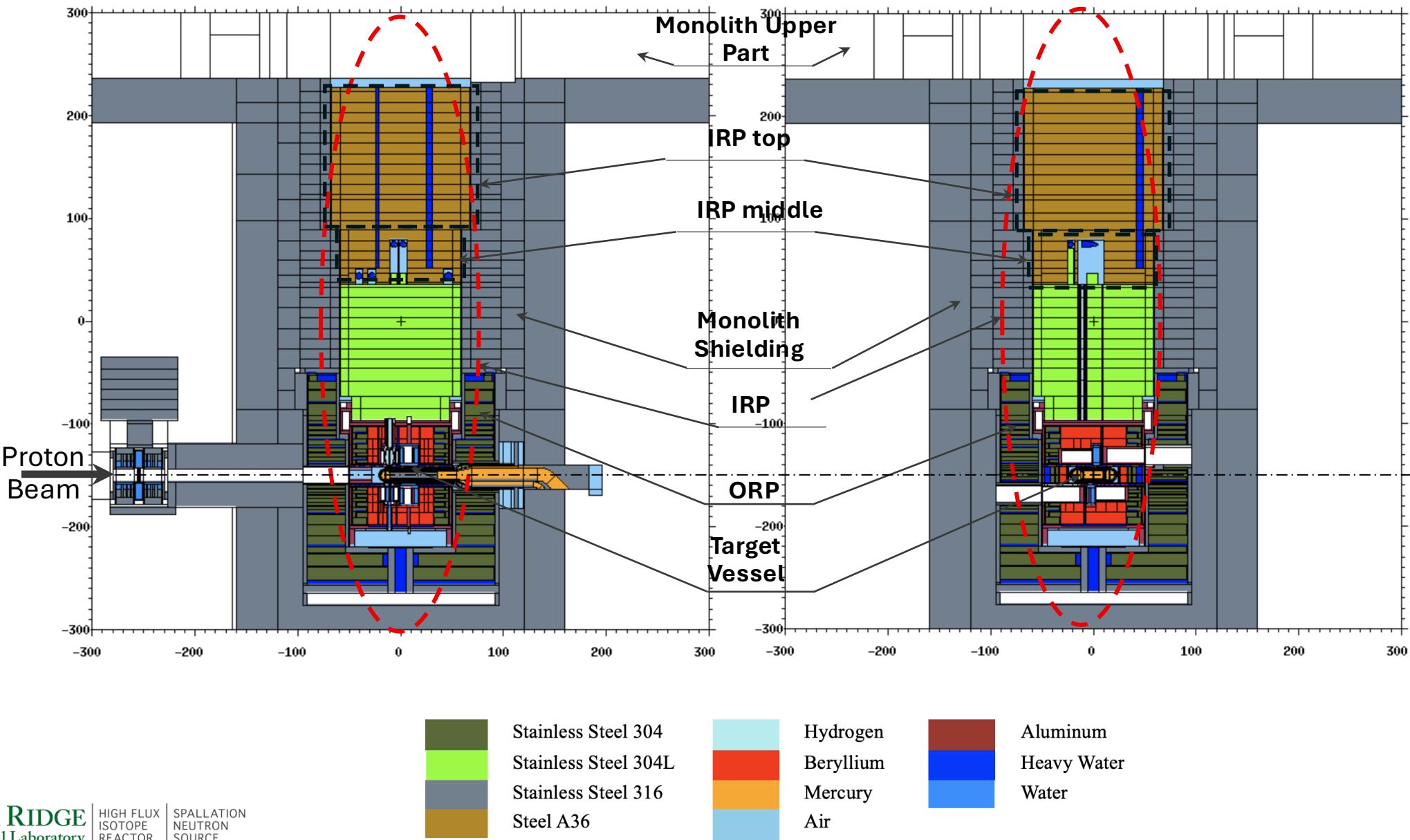
Methods and Assumptions

MCNP6.2 → AARE → CINDER2008 Coupling

- ❖ Transmutation analyses for the target monolith are performed to the end of IRP1 operation cycle
- ❖ Results are stored in a binary file (*alldnz*) containing the atom densities of all nuclides present initially or produced in the time intervals of the calculation for each cell
- ❖ Transmutation analyses are performed using the results from the transport analyses for IRP2 for timeline of operation at 1GeV
- ❖ *alldnz* files for previous analyses for target monolith(IRP1) copied into each of new cell with name *dnz* and input file for each monolith cell changed to used monolith isotope inventory by the beginning of the IRP2 services
- ❖ Auxiliary perl code is written to copy *alldnz* files to *dnz* files and to modify input file for more than >600 activation cells



Geometry

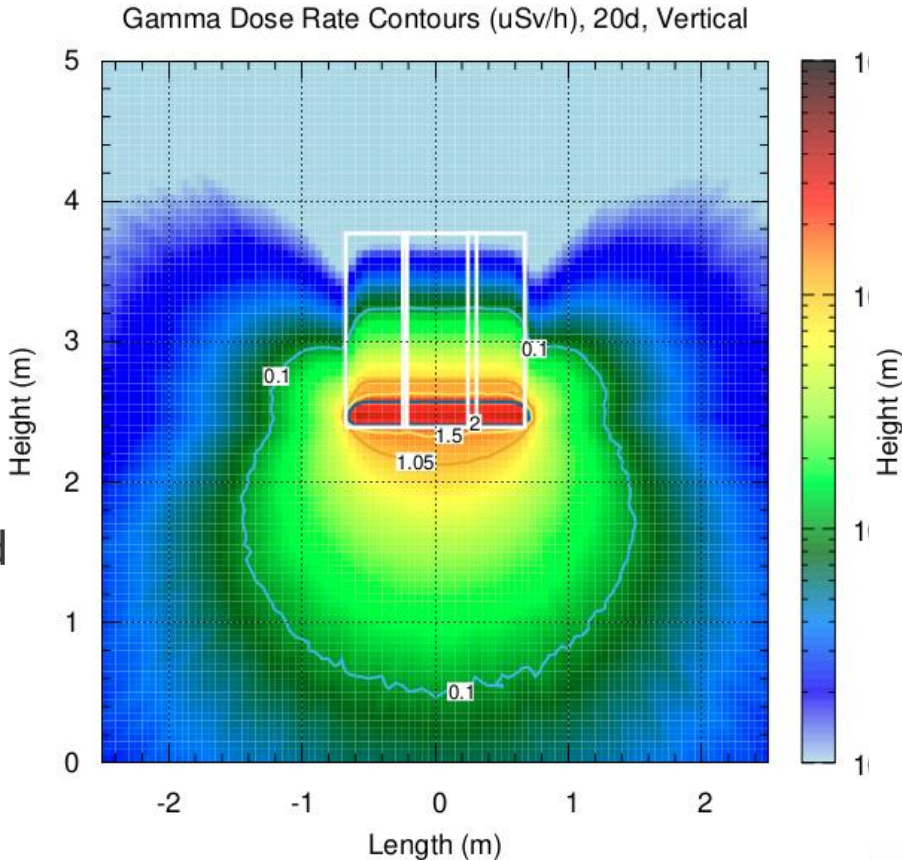


Comparison

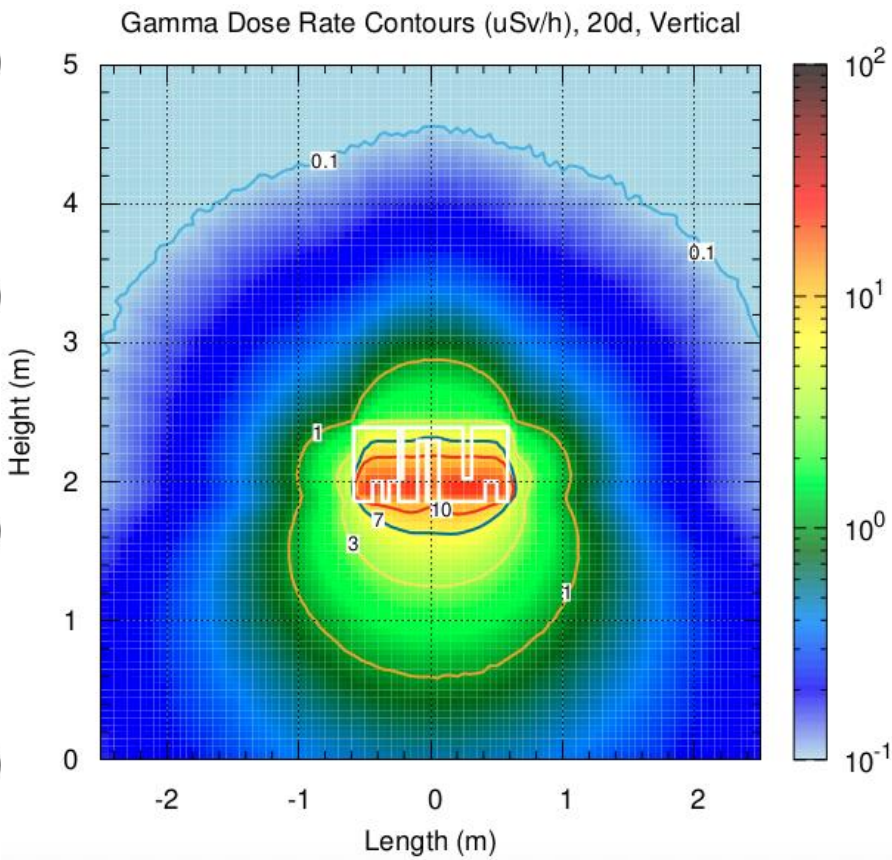
Extraction of Top and Middle Section

- ❖ Each segment was lifted into the container
- ❖ The container was then moved away from the IRP shaft.
- ❖ Dose rates were measured at the bottom of the exposed upper and middle IRP-2 segments

Upper Segment



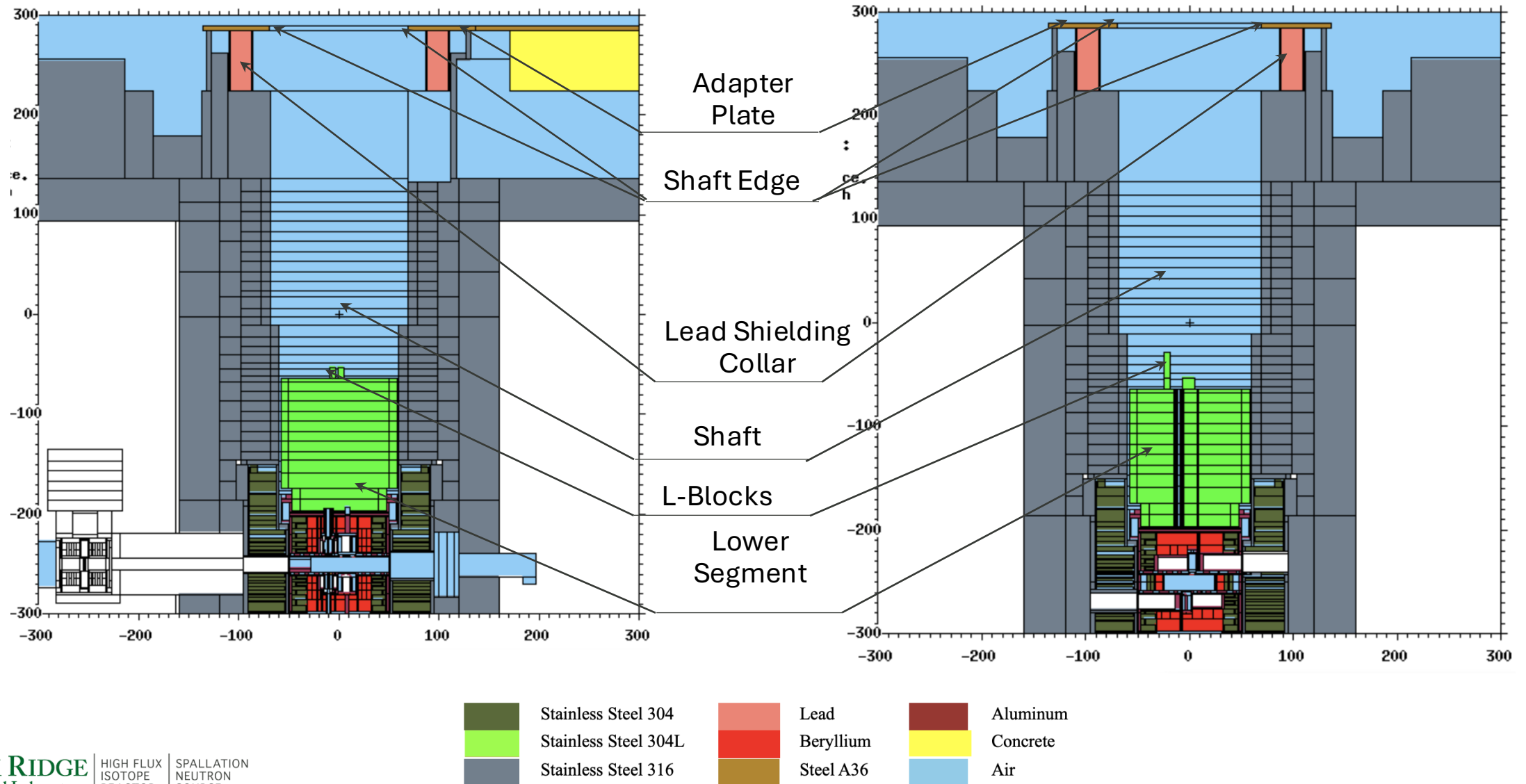
Middle Segment



Description	Measured dose rate at .3 m distance, $\mu\text{Sv/h}$	Calculated dose rate at .3 m, $\mu\text{Sv/h}$	Calculated dose rate at 0.025 m, $\mu\text{Sv/h}$	Ratio, Measured/Calculated
Bottom of exposed upper IRP	1.75	1.00	1.50	1.75
Bottom of exposed middle IRP	8.00	10	7.00	1.15

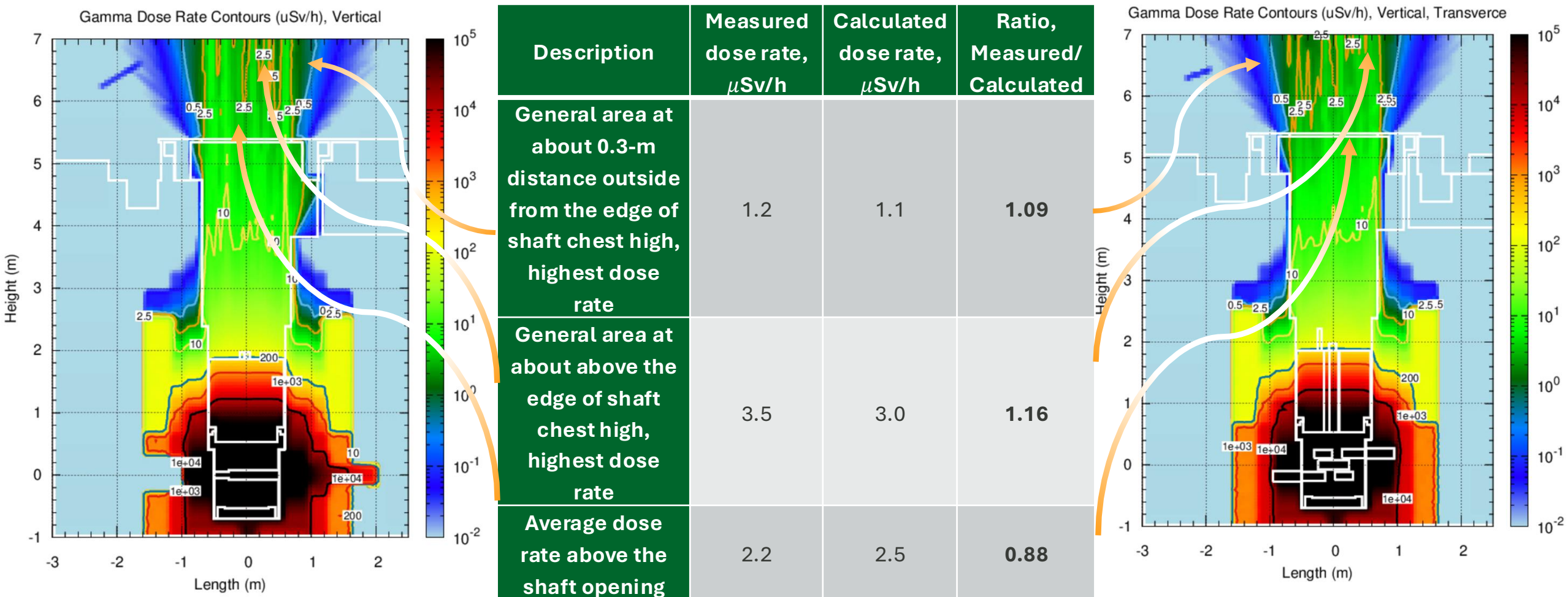
Comparison

Open Shaft with Lower Segment in the Shaft



Comparison

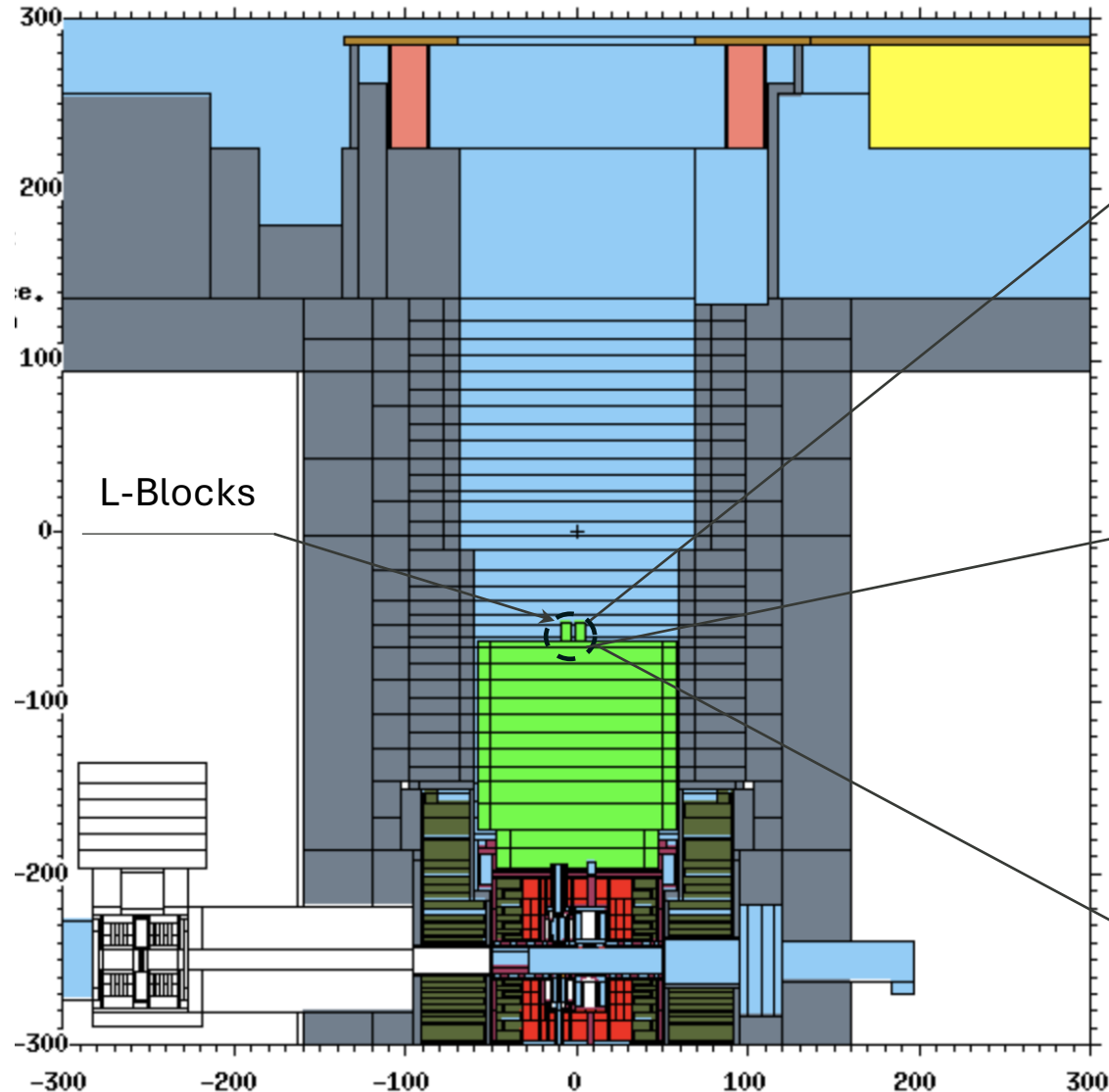
Open Shaft with Lower Segment in the Shaft



Comparison

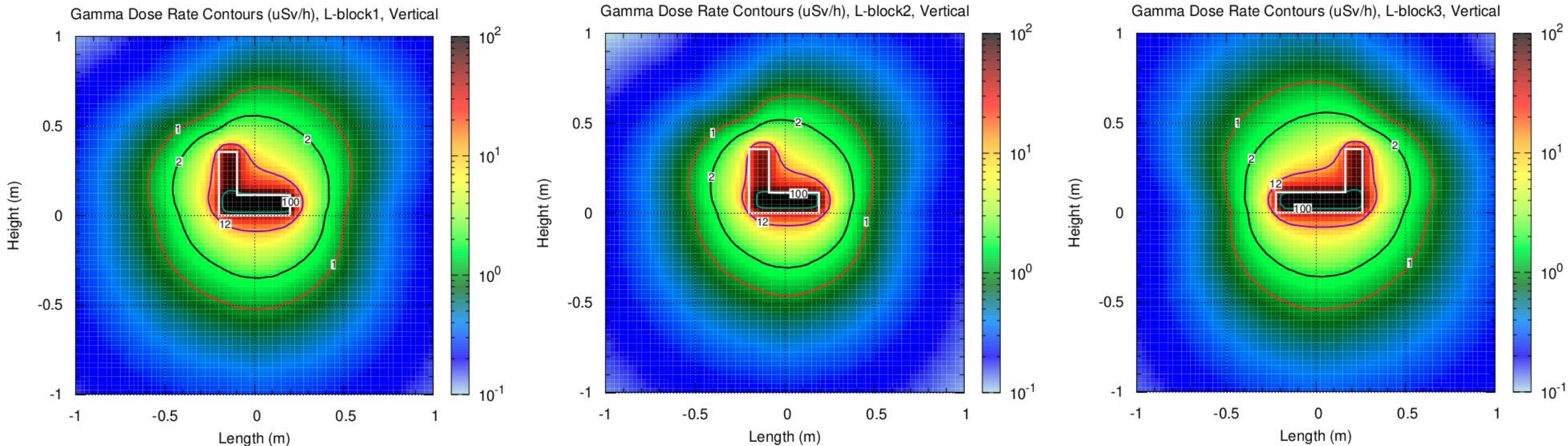
- ❖ Three L-blocks were positioned on top of the lower-segment shield block
- ❖ Providing mechanical stability and to protecting the piping
- ❖ The blocks were individually extracted
- ❖ Residual dose rate was measured separately for each block

L-Blocks



Comparison

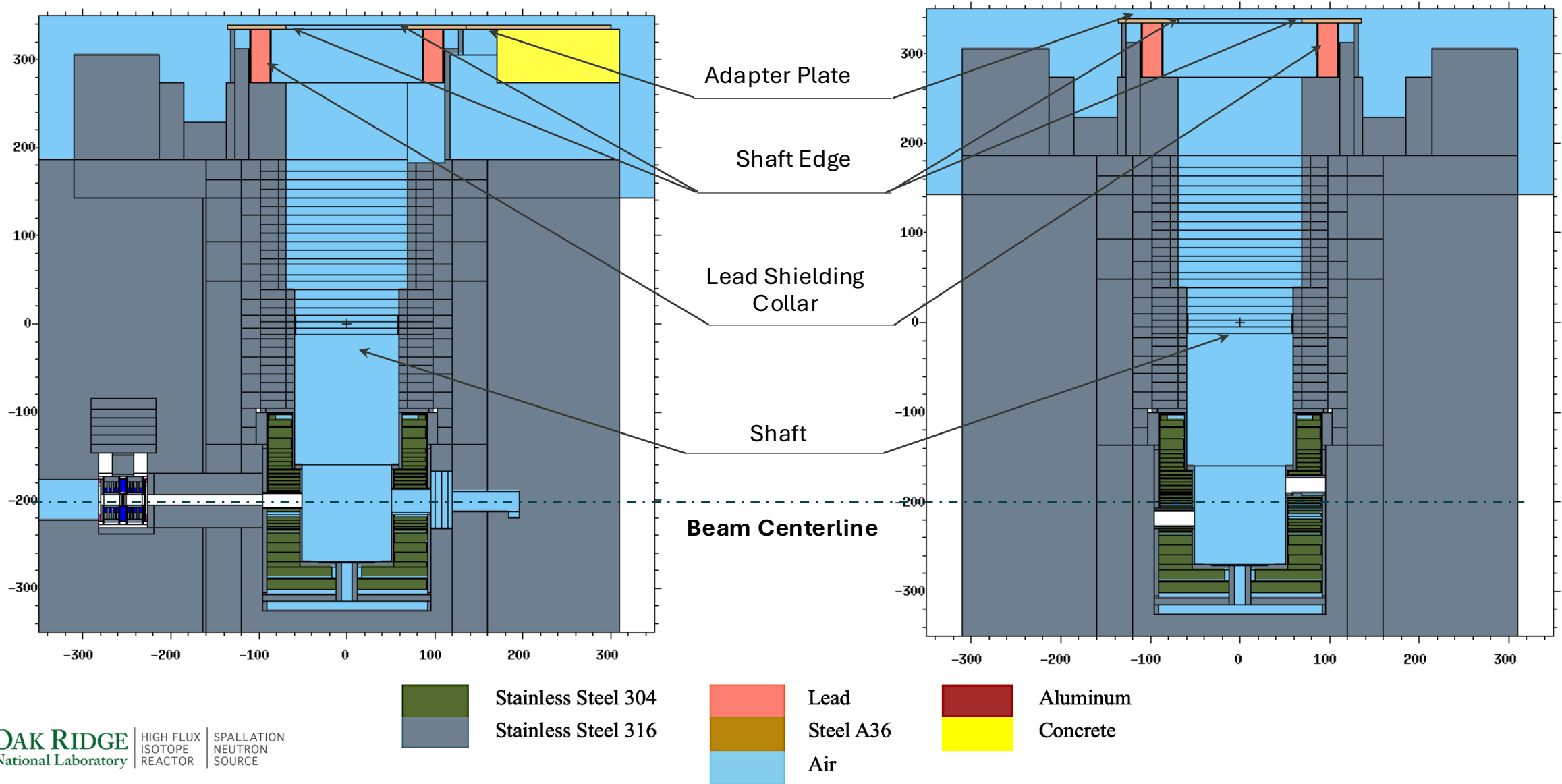
L-Blocks



Block	Measured dose rate at contact, $\mu\text{Sv/h/h}$	Measured dose rate at 0.3-m, $\mu\text{Sv/h/h}$	Calculated dose rate at contact, $\mu\text{Sv/h/h}$	Calculated dose rate at 0.3-m, $\mu\text{Sv/h/h}$	Measured/Calculated at contact	Measured/Calculated at 0.3-m
L-block 1	6	1.80	12	1.80	0.50	1.00
L-block 2	6	1.80	12	1.70	0.50	1.06
L-block 3	8	2.00	13	2.10	0.62	0.95

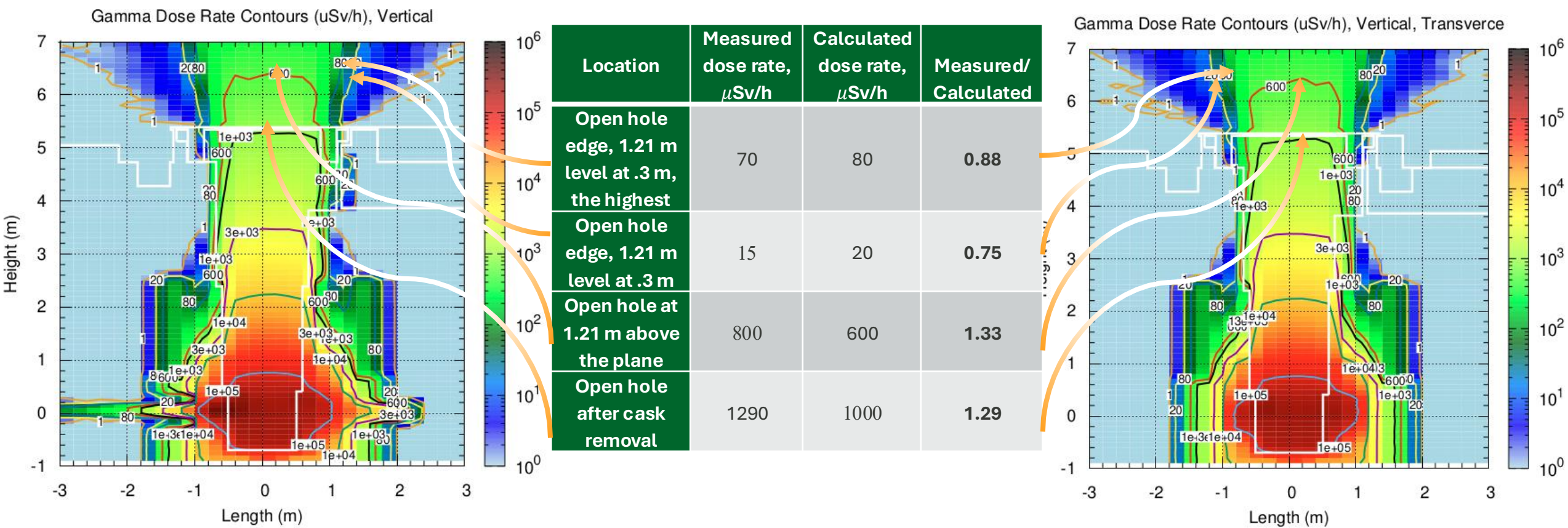
Comparison

Empty Shaft



Comparison

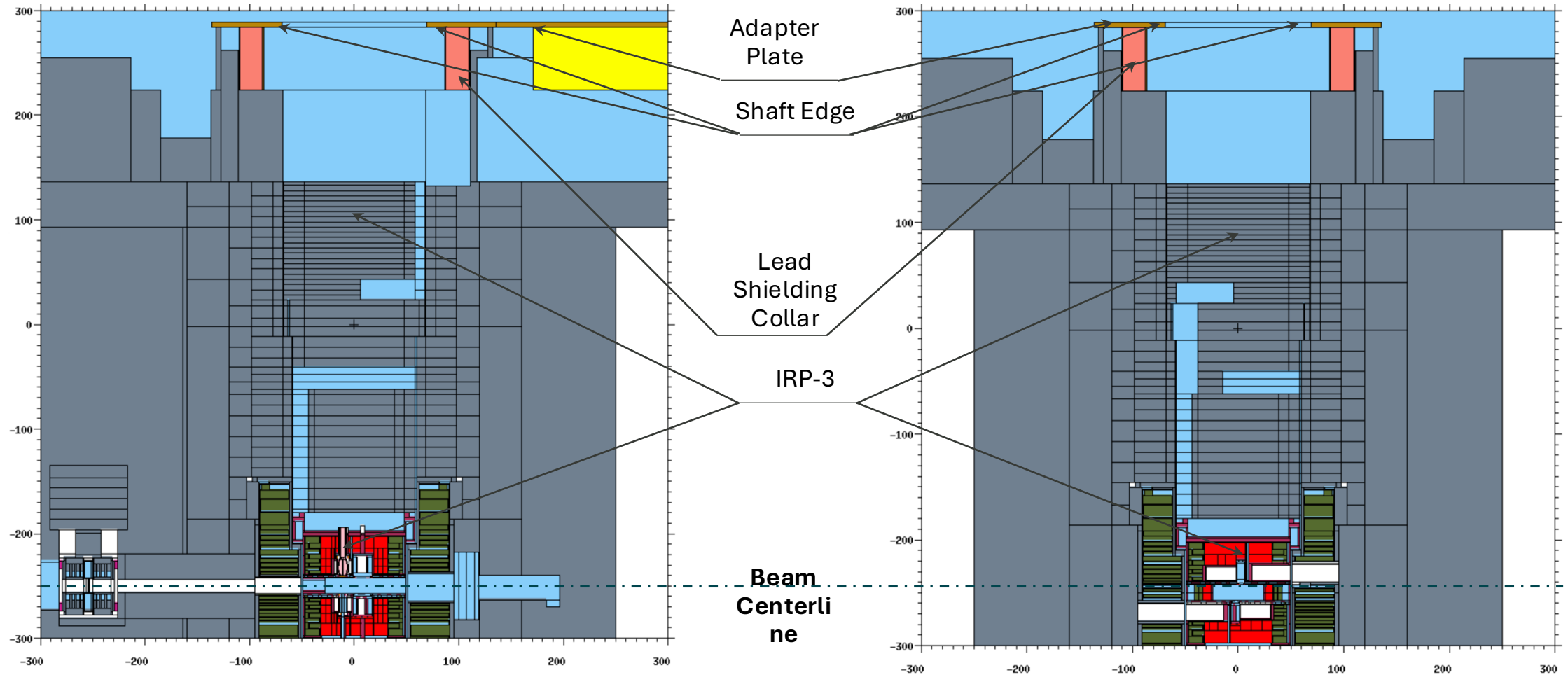
Empty Shaft



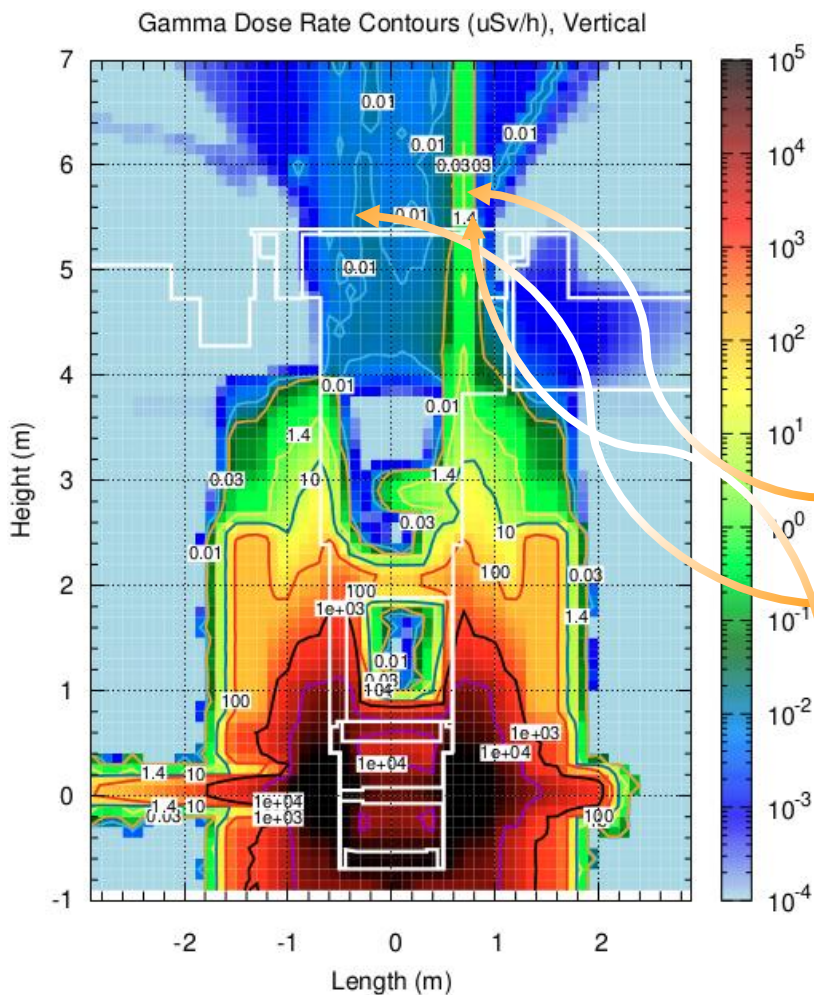
Comparison

IRP-3 installed

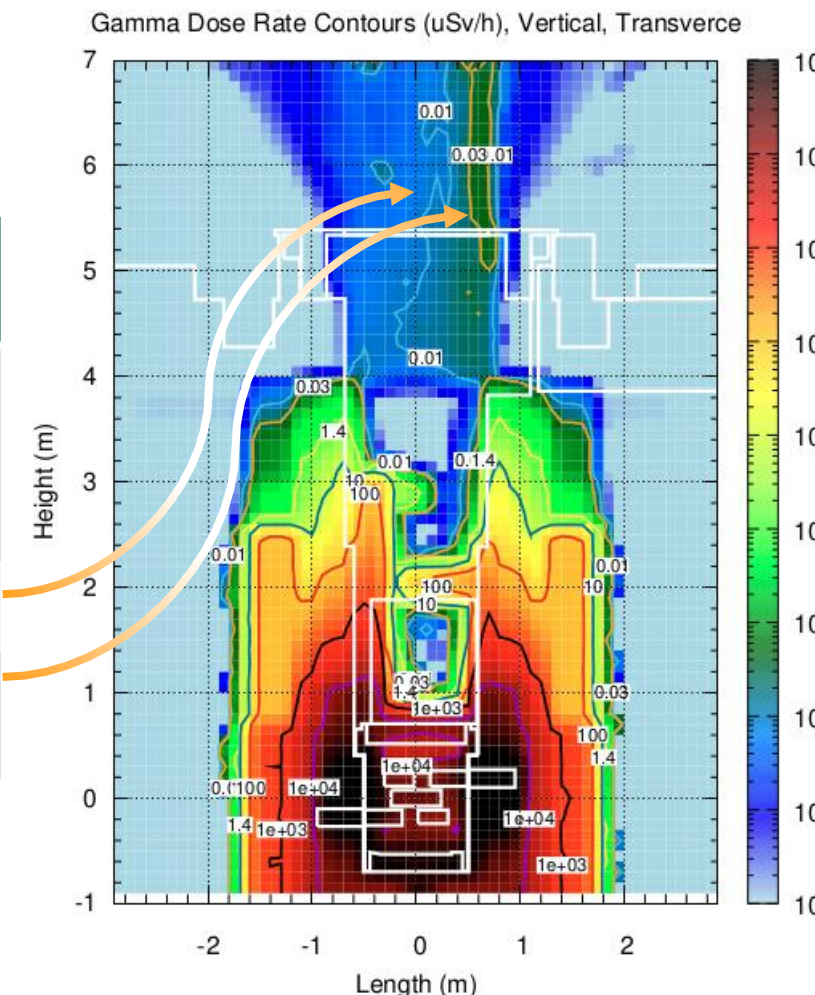
- New IRP-3 was installed in the shaft
- The shielding geometry above the plug in IRP-3 differs slightly from that of IRP-2



Comparison



Location	Measured dose rate, $\mu\text{Sv/h}$	Calculated dose rate, $\mu\text{Sv/h}$	Measured/Calculated
Small shine location above pipe chassis (~0.05-m in diameter)	1.50	1.40	1.07
New IRP installed - hole general area	0.01	0.01	1
New IRP installed - shine at edge of hole	0.04	0.03	1.3



Conclusions

- Residual dose rates were calculated to support the IRP exchange process.
- Detailed geometric models and source-term estimates for each step.
- Calculated and measured dose rates agreed within a factor of 1.5 for the top segment, when evaluated from the bottom of each segment.
- For all other cases, agreement was within approximately 30%.
- This level of agreement is considered reasonable for dosimetry analyses.
- The main sources of uncertainty included:
 - ❖ material characterization
 - ❖ geometric simplifications
 - ❖ cross sections
 - ❖ detector positioning and detector response during measurements
- **The comparison indicates that the analytical approach provides a reliable and technically sound representation of radiological conditions during the IRP exchange process.**