

# Radiation Protection of FLASH2020+ at DESY

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**HELMHOLTZ**



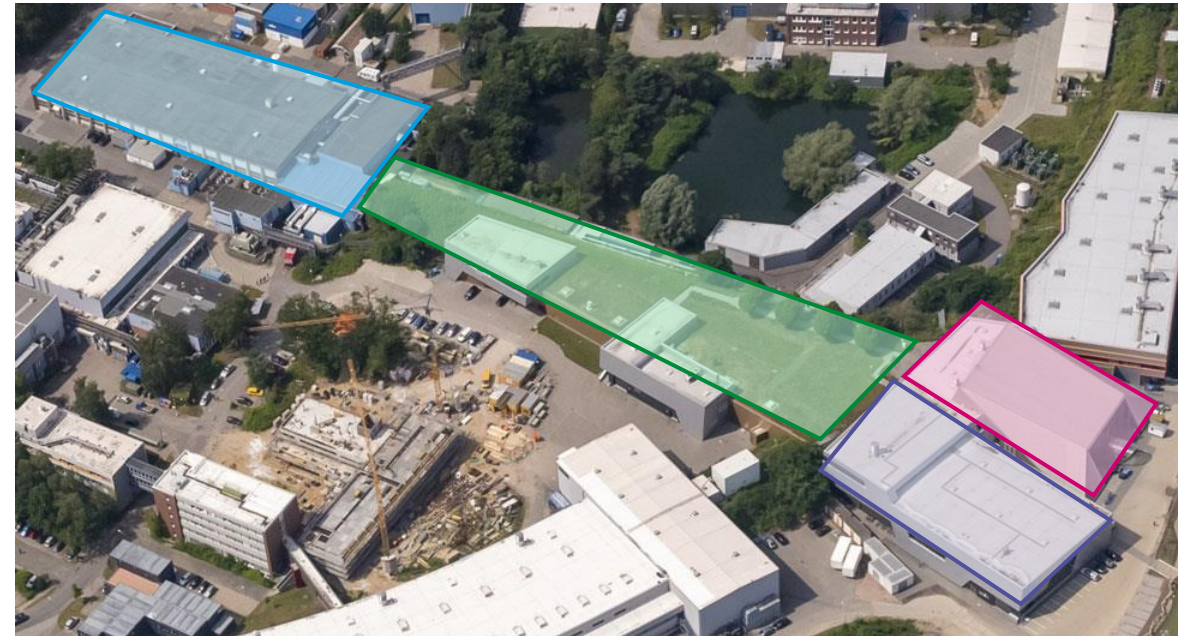
# Outline

- FLASH facility and FLASH2020+ upgrade
- Re-evaluation of local shielding in FLASH1
  - Normal operation
  - Accident scenarios
- Deconstruction and material release
  - Beam dump relocation
  - Challenges and near miss
- Future work & Conclusions

# The FLASH facility at DESY

Aerial view of the FEL facility and supporting infrastructure

- Electrons are generated in the **hall at the top left** and traverse through a **tunnel (grass-covered section)**, reaching energies of up to 1.6 GeV
  - Electrons pass through undulators in tunnel
- At the bottom right are the **Albert-Einstein hall of FLASH1** and the **Kai-Siegbahn hall of FLASH2**, where users run their experiments
  - Footpaths on the grass-covered section mean the space above the tunnel is publicly accessible
- After the tunnel (and undulators), photon beam transport components of FLASH cross the PETRA ring
  - Access to the PETRA ring is possible by DESY personnel during FLASH operation (Controlled Area)



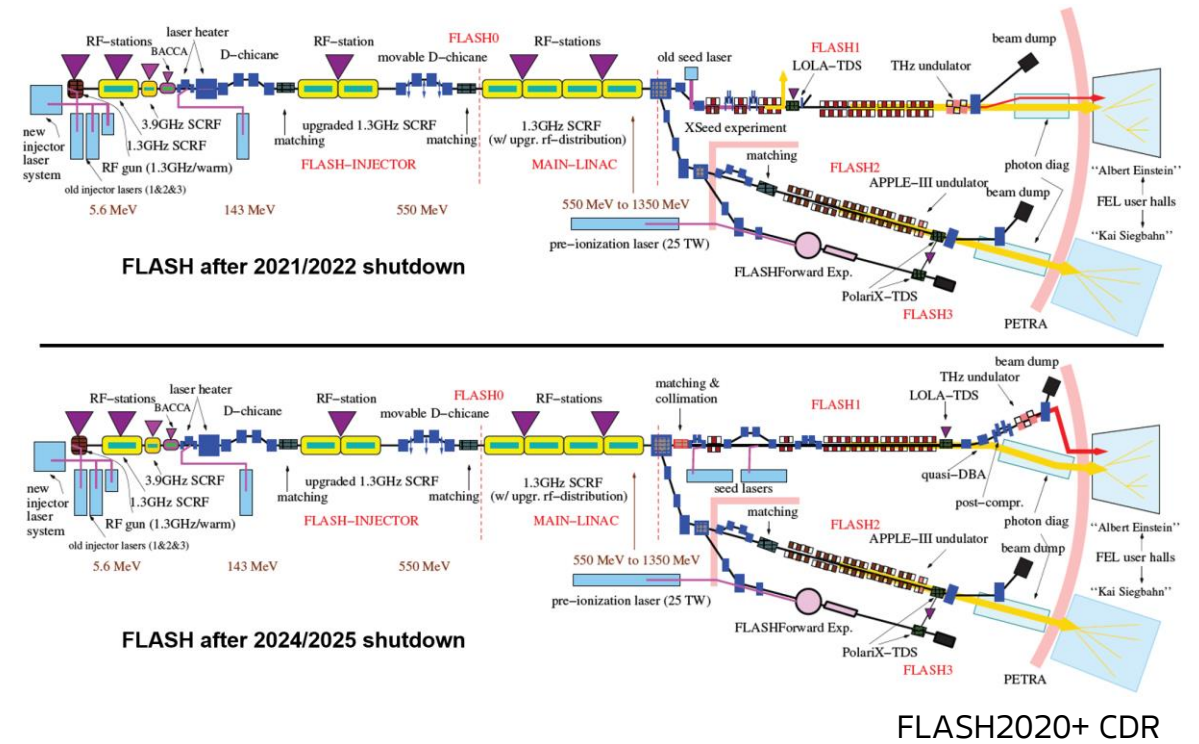
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# Upgrade of FLASH after 2024/2025 shutdown

Change from fixed-gap to variable-gap undulators

Lateral shift in FLASH1 photon transport line

- Electron beam still terminates at beam dump
  - Maximum beam energy of 1.6 GeV remains the same
  - Maximum beam power of 102 kW remains the same
- In terms of radiation safety, the major change is a lateral shift in the FLASH1 photon transport line
  - Also a lateral shift in the beam dump
- FLUKA used to re-evaluate positions of local shielding for a range of accident scenarios
  - Locations of interest:
    - Albert Einstein experimental hall (downstream)
    - Conference room space (above)



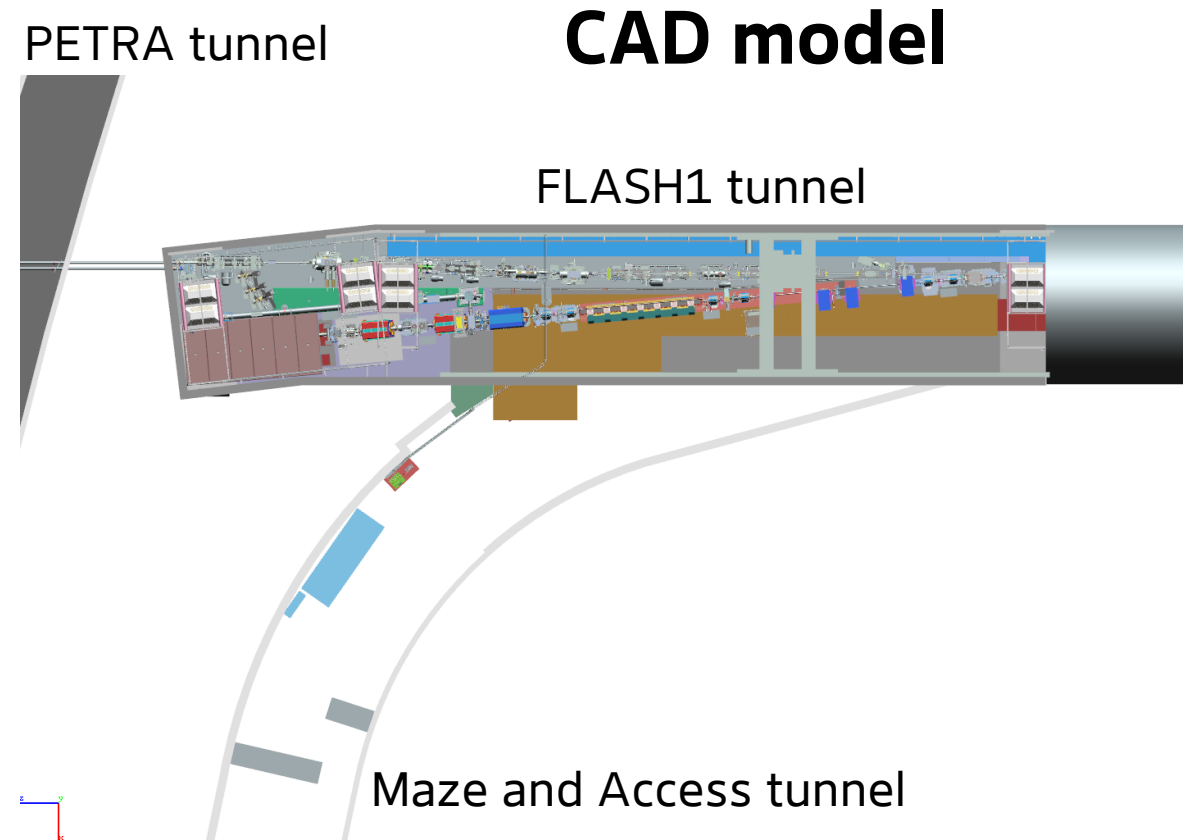
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# Methodology

## Obtaining the CAD model of the FLASH facility

- Close cooperation with FLASH2020+ mechanical engineers allows building of FLUKA model per project's coordinate system
- Advantage of knowing coordinates of all components
- Version control of CAD model via TeamCenter

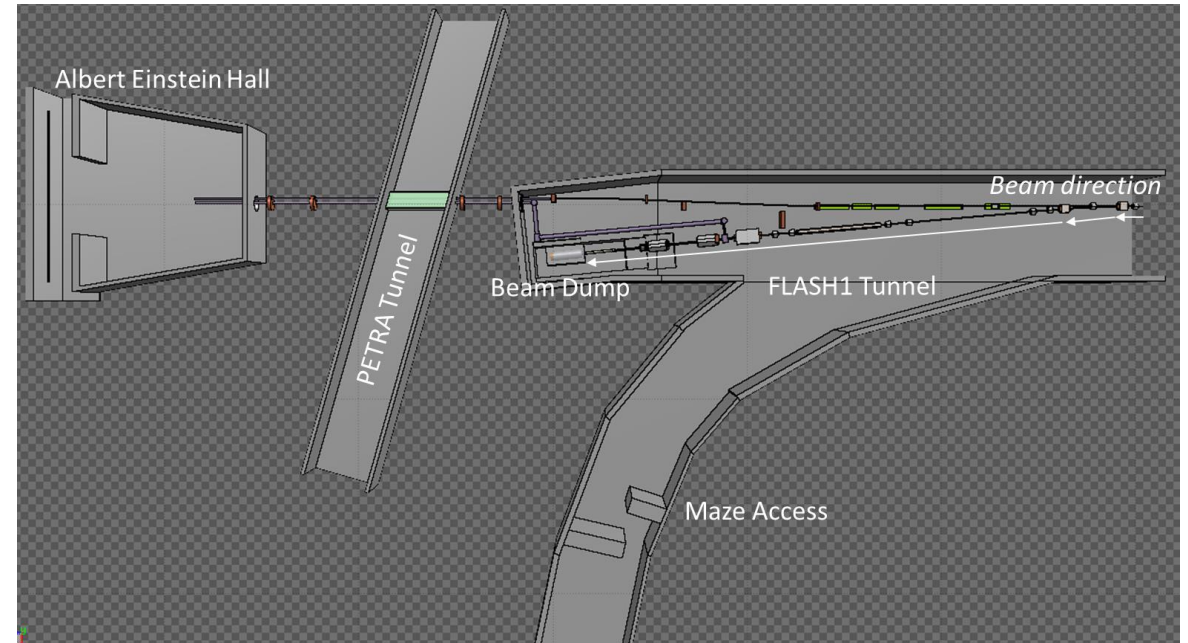


# Methodology

## Modeling the tunnel into FLUKA

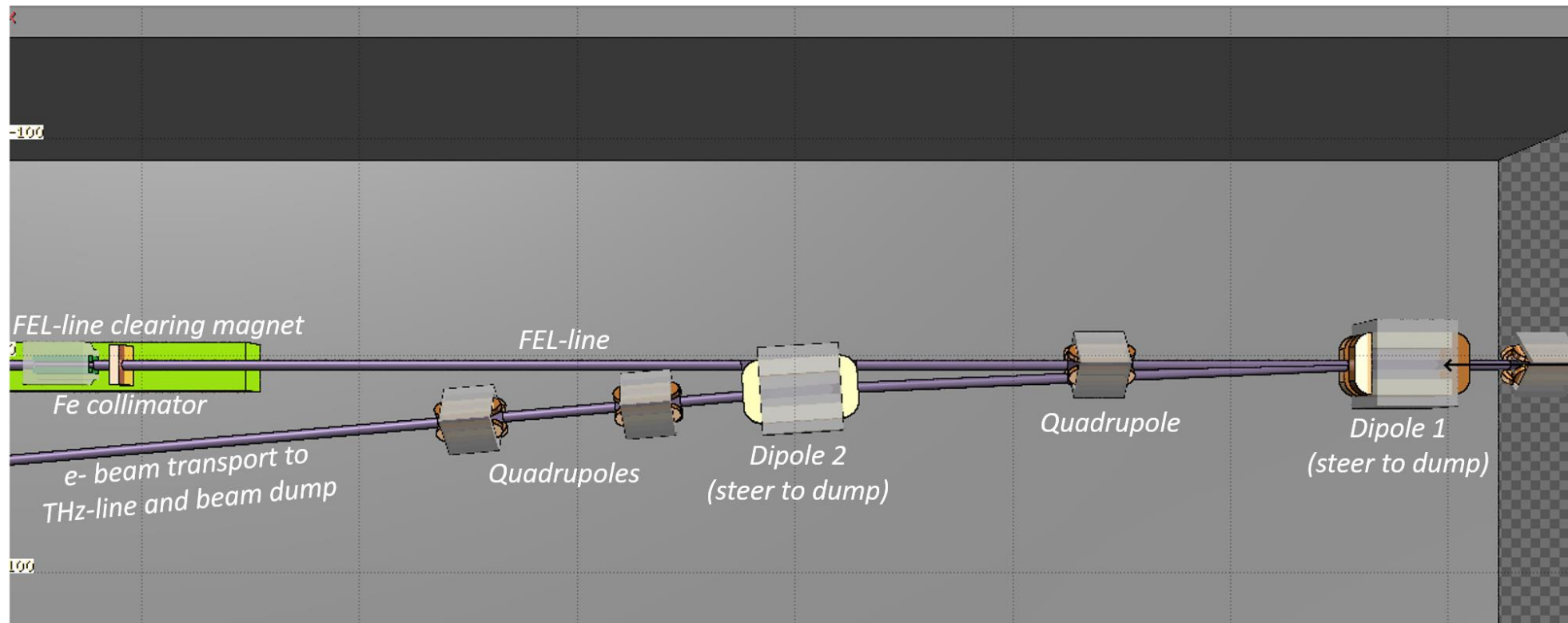
- FLUKA model includes FLASH1 tunnel and its access tunnel, PETRA tunnel, and Albert Einstein experimental hall downstream
- Major components along transport lines are modeled:
  - Magnets, pipes, shielding, beam dump, etc.
- Magnetic fields implemented:
  - Electron beam correctly steered to beam dump (normal operation)
  - Magnetic fields turned ON/OFF or set at "partial strength" → beam does NOT reach dump (accident)

## FLUKA model



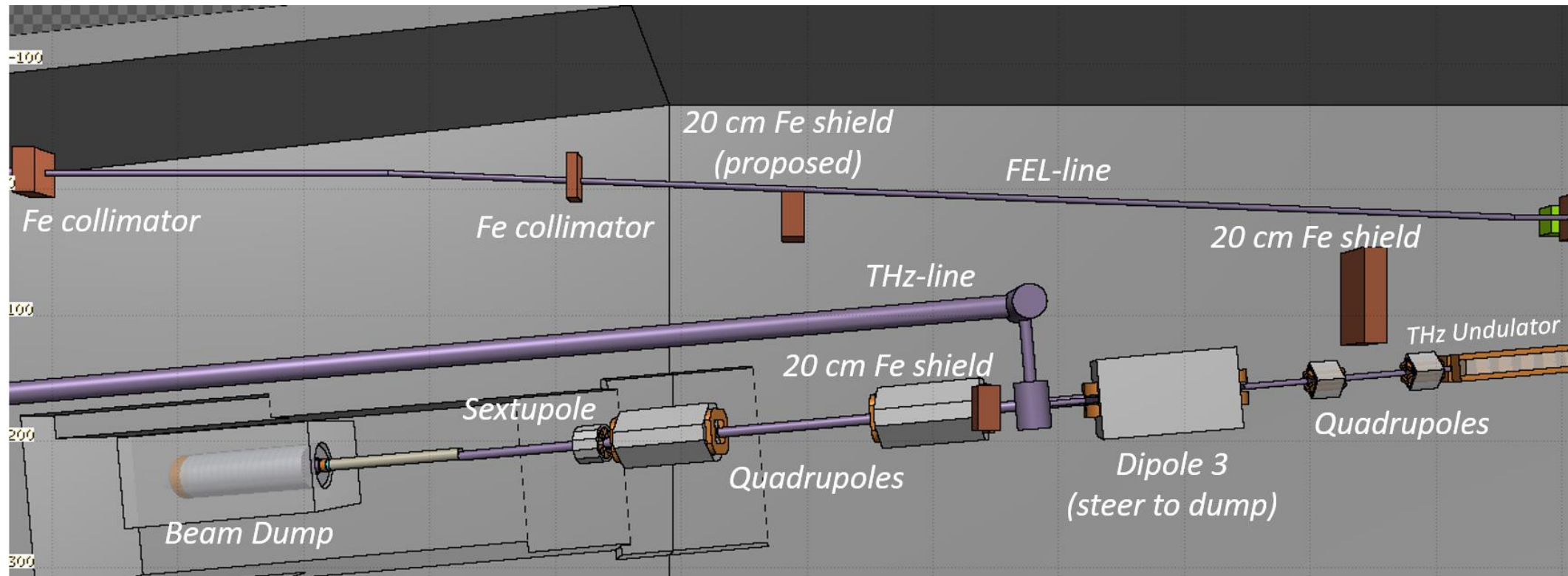
# Closer look at FLUKA model

FLUKA model includes major components (magnets, pipes, shielding, beam dump, etc.)



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# Electron beam loss scenarios

## Scenarios inside the FLASH1 tunnel

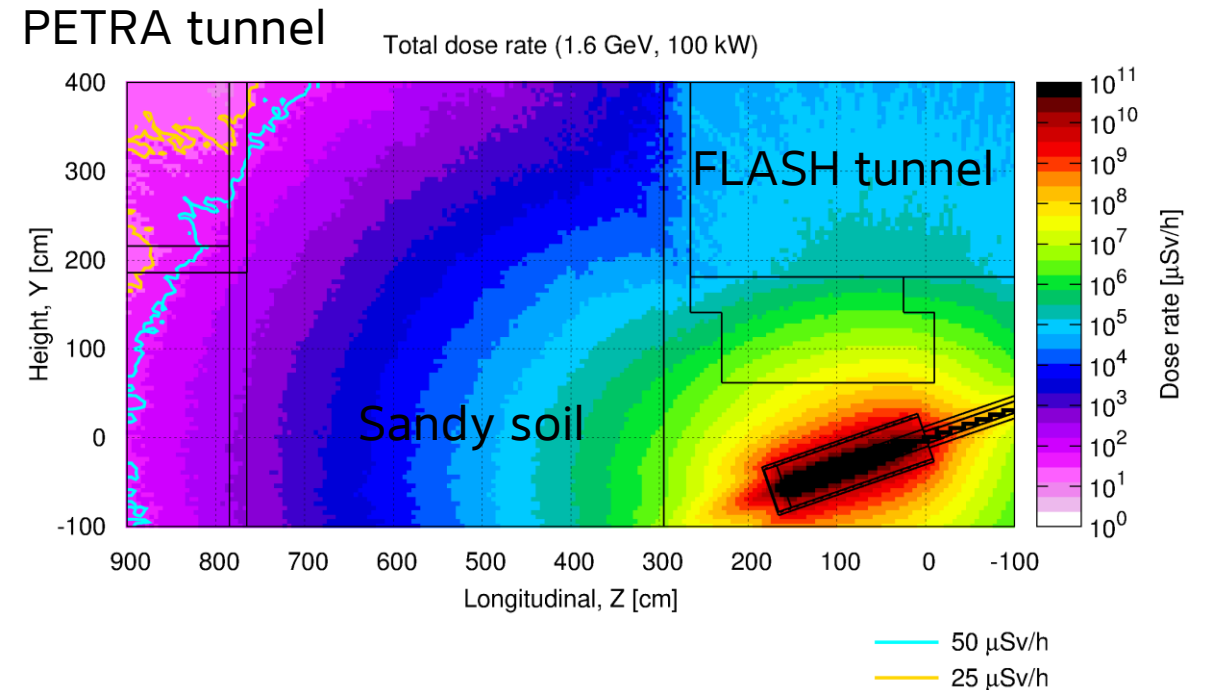
- FLASH electron parameters:
  - Beam energy of 1.6 GeV (max)
  - With ~100 kW
  - $4 \times 10^{14}$  e-/s
- Recall lateral shift in FLASH1...
  - Crucial to re-evaluate positions of local shielding to intercept stray "rays" due, especially for accident scenarios
  - Accident scenarios cover a wide variety of bending dipole malfunctions (table on right)

Scenario	Status	Description
Normal operation	All normal	Electrons to dedicated beam dump
Accident 1 <b>(Worst case)</b>	Thin target interaction	Electrons intercepted by malfunctioning valve upstream bending dipoles
Accident 2	Dipole 1 OFF	Electrons continue down photon line and steered to floor by permanent magnet
Accident 3	Dipole 2 OFF	Electron beam lost on components in tunnel
Accident 4	Dipole 3 OFF	Electrons NOT vertically deflected down to beam dump
Accident 5	Dipole 1 & 2 with incorrect fields	Electrons under-steered and lost on transport components

# Normal operation

## Dose rate at PETRA tunnel downstream

- Electron beam steered towards its intended beam dump
- PETRA tunnel downstream from FLASH tunnel:
  - ~6 m horizontal distance between two tunnels
  - ~4 m vertical distance between bottom of FLASH1 beam dump and PETRA tunnel
- Possible to access this section of the PETRA tunnel during shutdown/maintenance at the same time when FLASH is in operation
  - PETRA tunnel is a Controlled Area
  - Unlikely occurrence, low occupancy

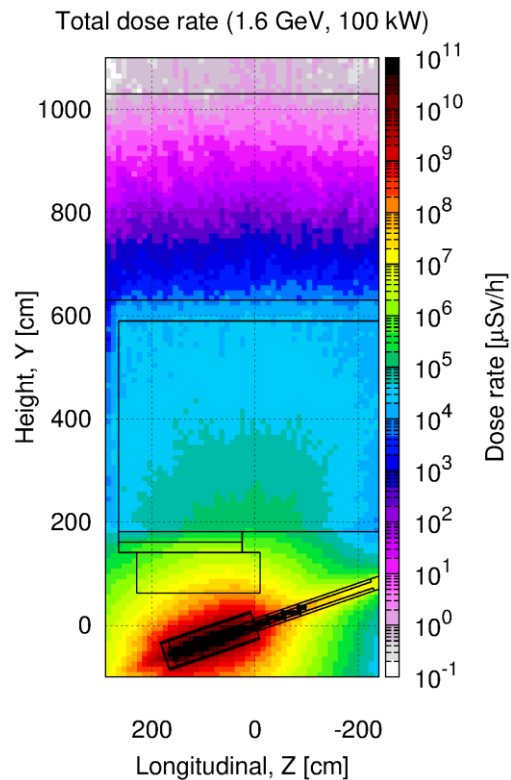


# Normal operation

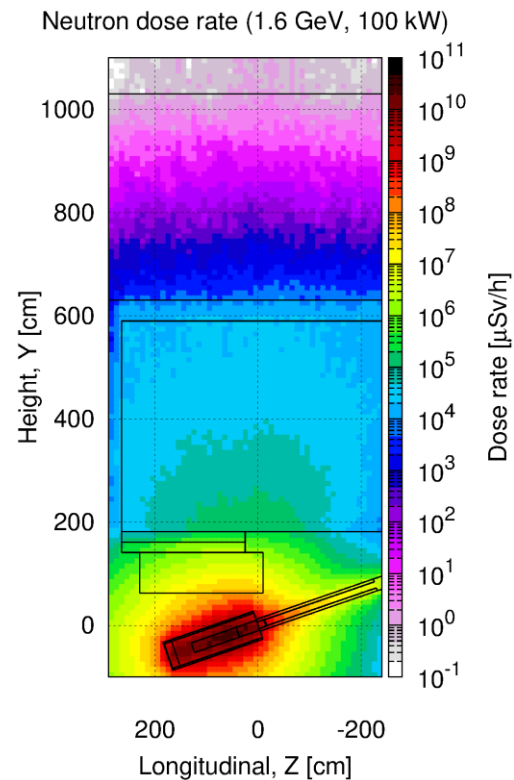
Dose rate at footpath above FLASH tunnel

- Applying neutron & photon filters to total dose...
- Neutron dose dominant above 4 m soil:  $1 \mu\text{Sv/h}$
- Area dosimeter stationed to monitor

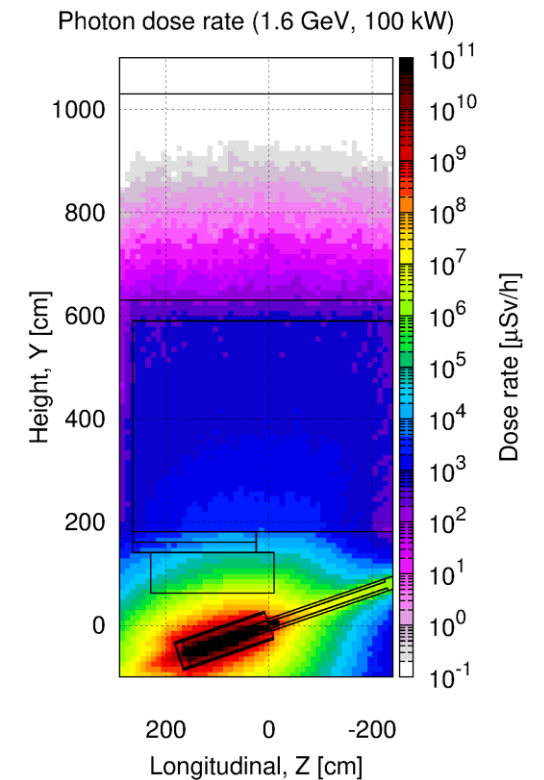
### Total dose



### Neutron dose



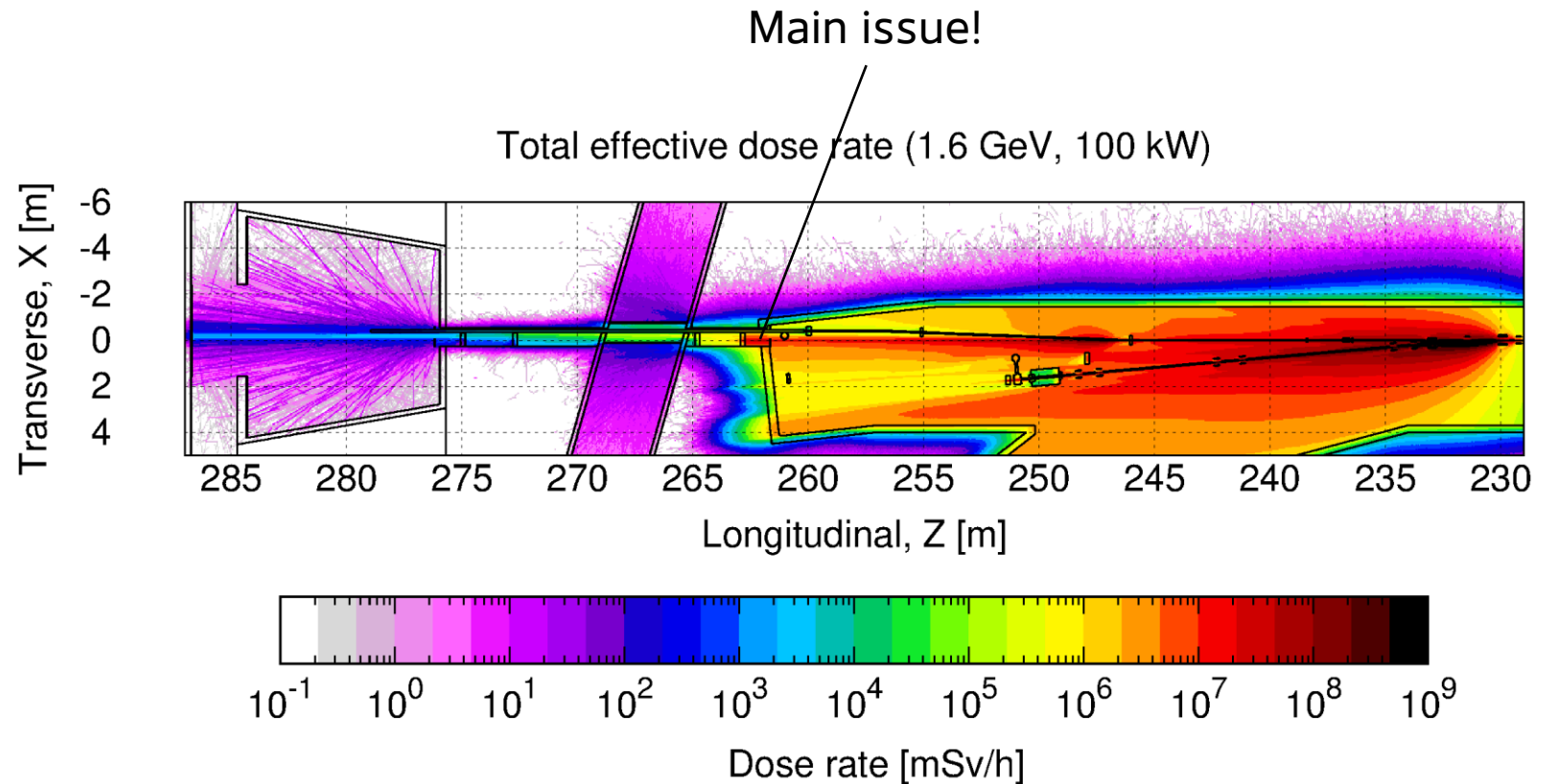
### Photon dose



# Accident scenario 1

Malfunctioning vacuum valve upstream first bending dipole (worst case)

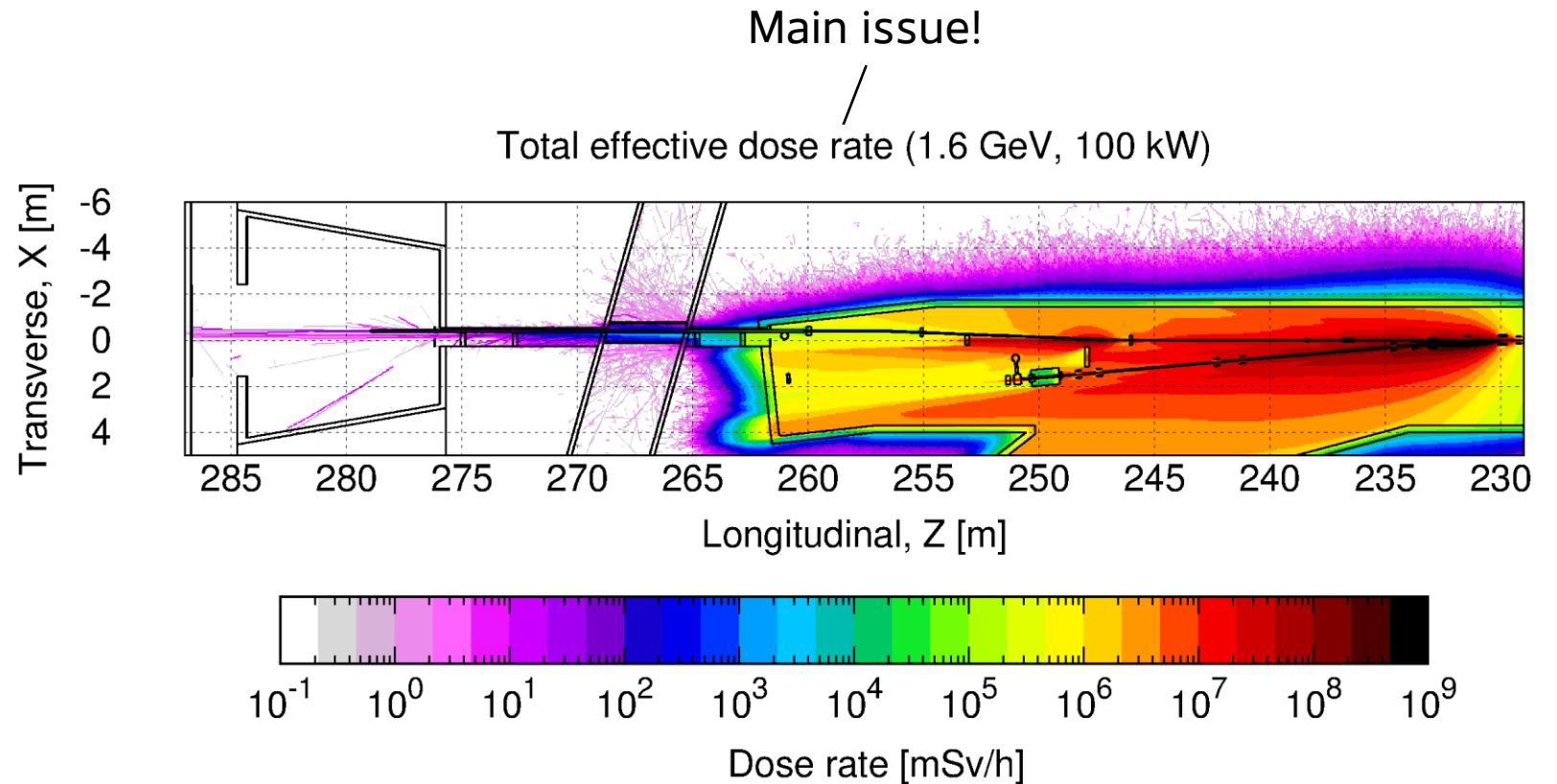
- Electron scattered on thin target before the before bending dipole
- Scattered electrons and forward  $0^\circ$  bremsstrahlung from thin target beam loss stream down FEL-line and into duct between FLASH1 and PETRA tunnels
- **Hundreds of mSv/h and even few Sv/h** dose rates in PETRA tunnel and Experiment Hall (!!)
- **Solution: Additional 20 cm Fe shield** to attenuate this ray and bring dose to few mSv/h



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Malfunctioning vacuum valve upstream first bending dipole (worst case)

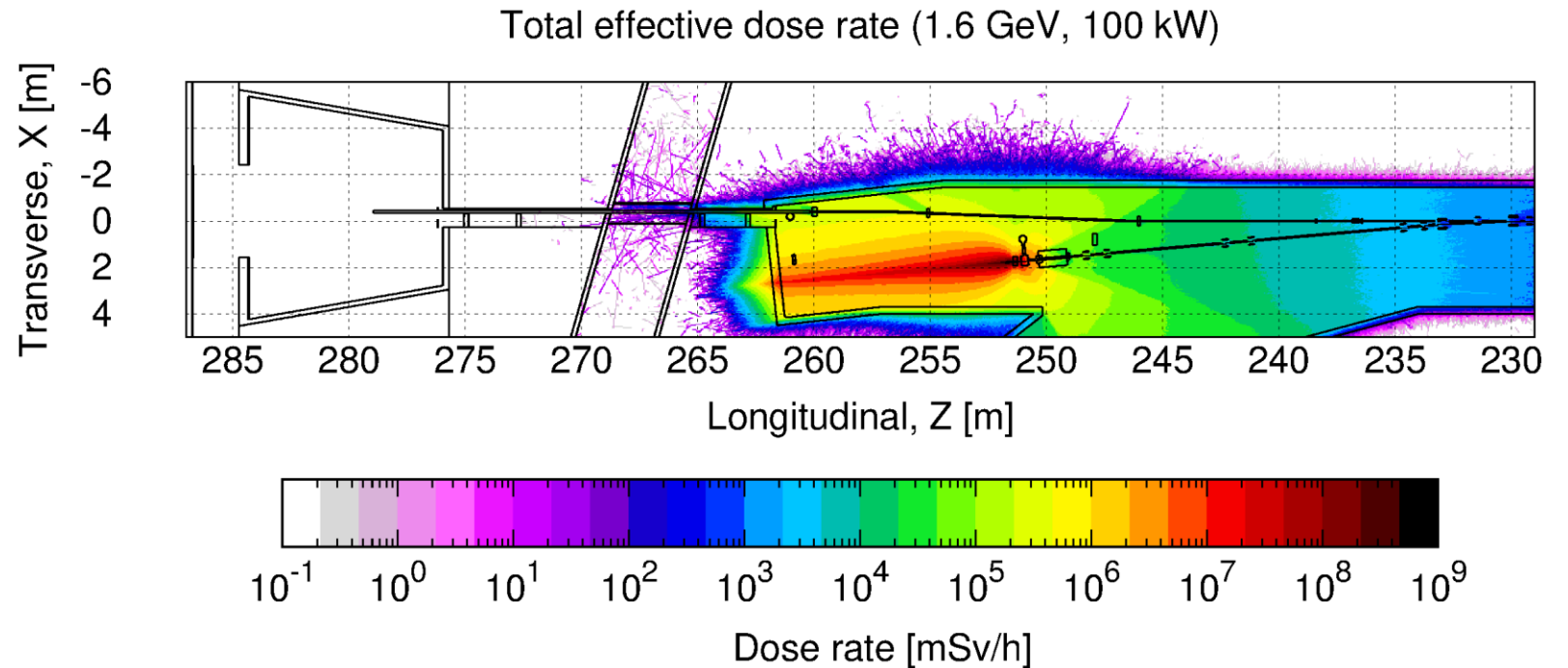
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# Accident scenario 4

Bending dipole 3 has no field strength and fails to steer beam to dump

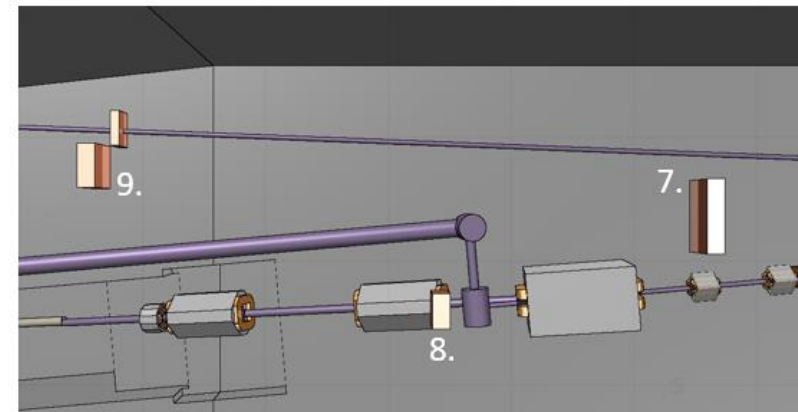
- Solution: Electrons hit the 20 cm Fe shield located at  $Z = 251$  m
- Bremsstrahlung shower very forward-pointing into end of FLASH1 tunnel
- The Fe shield + earth are enough to reduce dose to PETRA tunnel



# Local shielding for accident scenarios

Dimensions and specifications based on CAD model's coordinates

7. Fe shield: center @ X,Y,Z = (0.654 m, 0 m, 248.235 m)
  - 85 cm wide x 50 cm tall x 20 cm thick
8. Fe shield: center @ X,Y,Z = (1.733 m, 0 m, 251.345 m)
  - 40 cm wide x 50 cm tall x 20 cm thick
9. Fe shield: center @ X,Y,Z = (0.075 m, 0 m, 255.380 m)
  - 50 cm wide x 50 cm tall x 20 cm thick



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# Deconstruction

Large majority of components removed (and a new paint job)



# Material release

Tremendous amount of potentially activated material to be surveyed

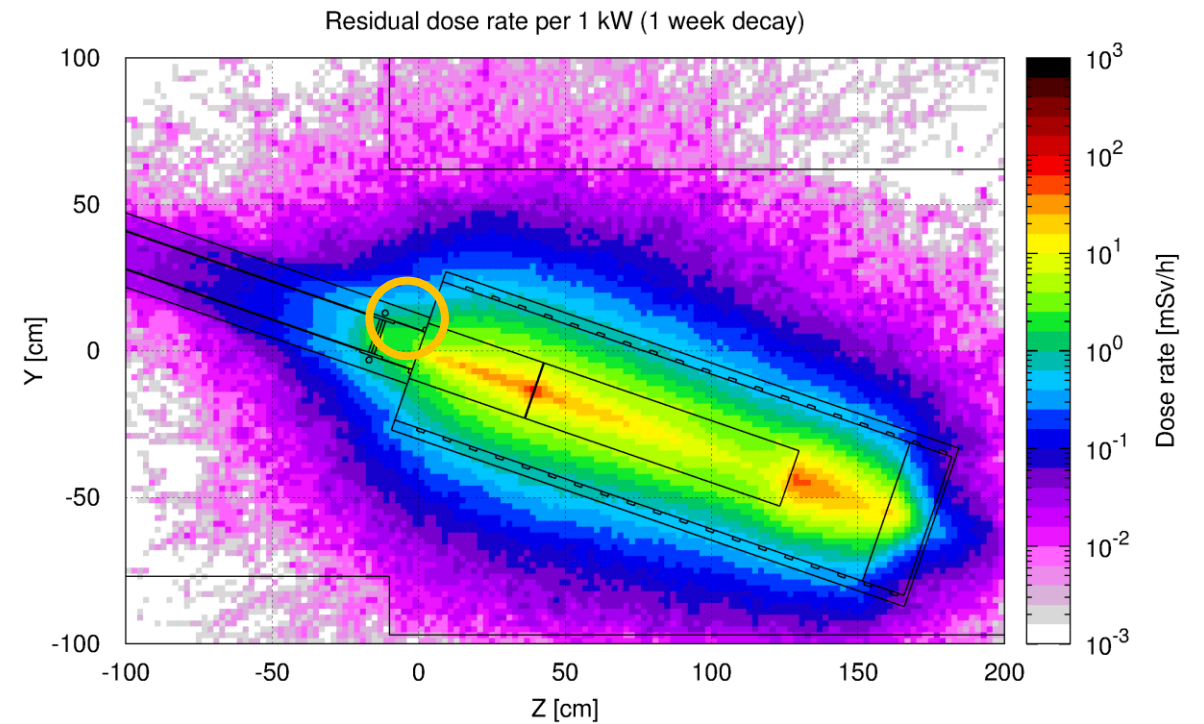
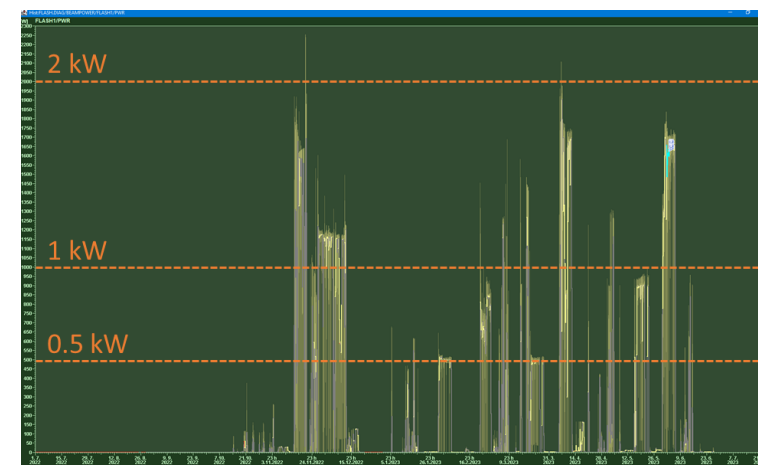
- Demanding effort:
  - Responding to ticket system
  - Volume and amount of material
  - Cables cut into 1 meter lengths and surveyed on flat surface
- In the end:
  - About 100 tons of material removed from FLASH1 tunnel
  - About 80 tons required survey for release by 3 colleagues DESY radiation protection team
  - Less than 5 tons stored in radioactive material storage hall



# Beam dump relocation

## Residual dose rate a concern

- Based on operational history of FLASH1:
  - Up to 2 kW periodically, but not the entire year
  - Average power of ~0.2 to 0.3 kW over 14.5 years
- FLUKA calculations provided estimate on residual dose rate at beam pipe at entrance to dump
  - Decision for cooldown time of 2 weeks
  - Closest contact point of entombed dump
    - Conservative estimate (1 kW): ~1  $\mu\text{Sv/h}$
    - Measured: 0.5  $\mu\text{Sv/h}$
- Beam dump interim storage at radioactive material storage hall and then moved back to FLASH1 tunnel



# Challenges

What did not go quite as well as expected

- Additional holes in FLASH1 tunnel shielding needed for infrastructure...but started leaking water from surrounding soil into the tunnel
  - → Engineering solution to prevent water leakage
- Unauthorized demolition of concrete inside beam dump pit (due to discovery of 10 cm additional concrete)
  - → Contractors unaware of potential activation
  - → Immediate stop and running concrete debris samples in gamma-spec
  - → Activation found in concrete BUT all radionuclides below release limits...near miss!
  - → Work permit required for any concrete work



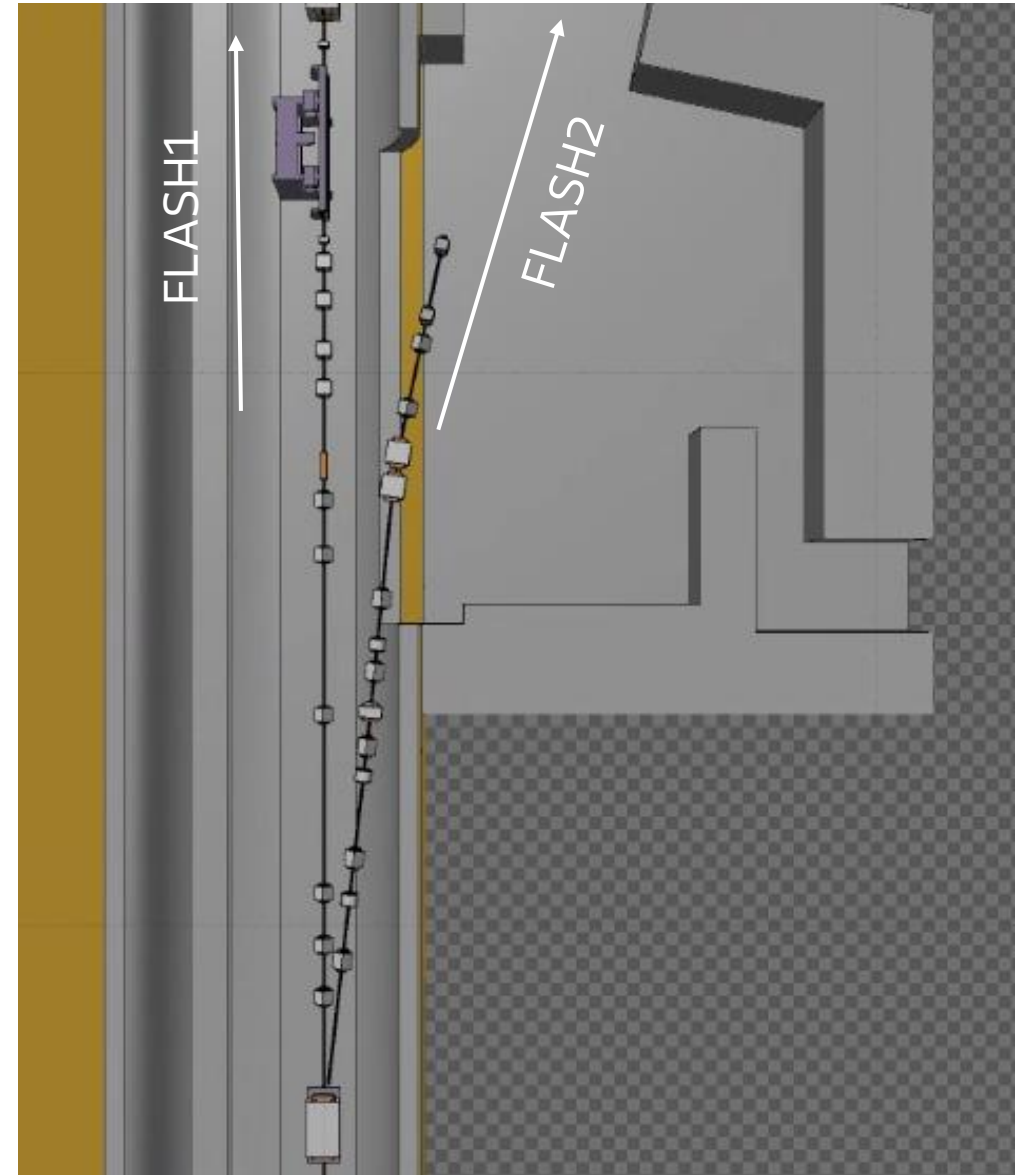
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# Future work

## Optimizing area dosimetry and local shielding

- Expanding model of FLASH1 tunnel upstream to include remainder of FLASH facility
- Using the new model to perform additional studies:
  - Characterize activation and dose environment at known beam loss locations at bunch compressors
  - Optimize local shielding for such losses
    - Protection of equipment and electronics
  - Optimize area dosimetry positions
    - Protection of personnel outside tunnel



# Conclusions

- FLASH2020+ upgrade project ongoing
  - Tunnel no longer empty and quite full again
  - Commissioning planned for August 2025
- FLUKA to analyze radiation hazards
  - Evaluating local shielding to cover accident scenarios
  - Addition of new local shielding to tunnel
  - Residual dose rate estimated (2 weeks cooldown)
- Decommissioning of FLASH1
  - 100 tons removed from tunnel
  - 80 tons surveyed for activation
  - ~5 tons stored in radioactive material storage hall
- Lessons learned from near miss with concrete demolition
  - Stricter work planning when contractors are involved

