# The Radiation shielding analysis process for the ISIS Endeavour Programme

Steve Lilley

Science and Technology Facilities Council

ISIS Neutron and Muon Source

# Contents

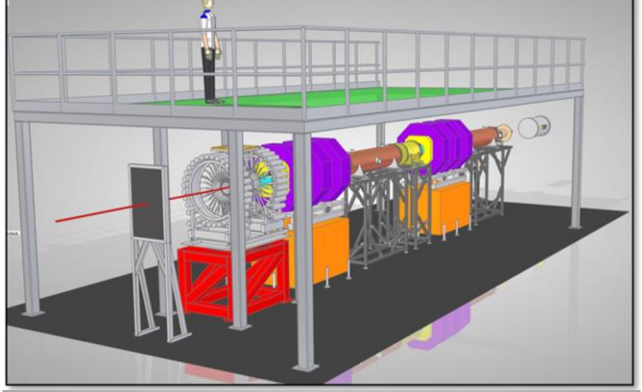
# The ISIS Endeavour Programme

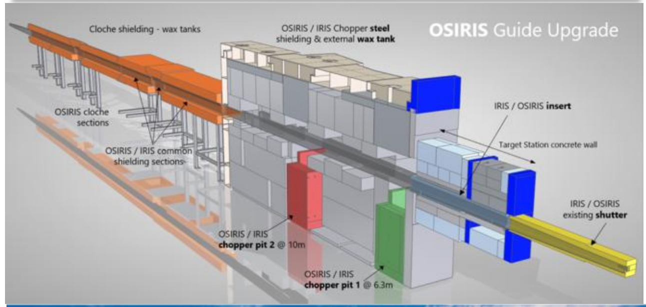
ISIS's primary instrument development programme

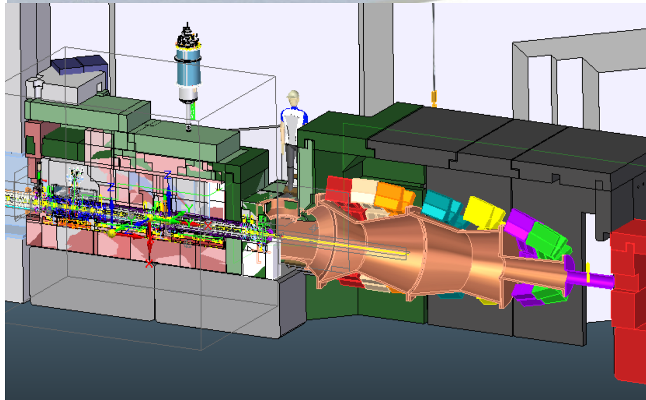
Total programme: £93M, 10 years (2023 – 2033)

8 or 9 large instrument projects (£5M - £15M each)

Funded from UKR Intrastructure Fund, STFC and ISIS international partners





Science and Technology Facilities Council

ISIS Neutron and Muon Source

# The ISIS Endeavour Programme

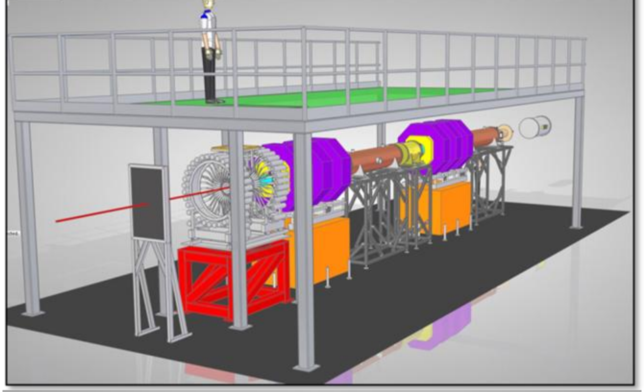
**Phase I:** SuperMuSR, HRPD-X – in implementation

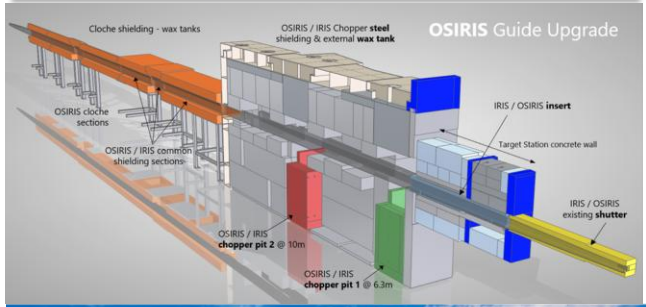
**Phase 2:** SANDALS-2, Mushroom, Wish-2, Tosca+, Osiris-2 – in implementation or soon will be

**Phase 3:** One or two more projects – being decided over the next few months

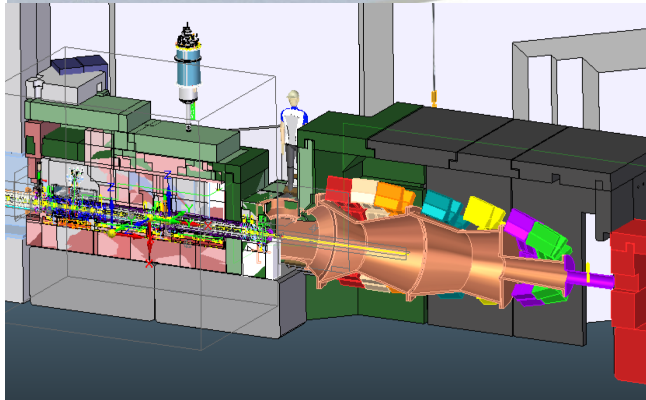
Science and Technology Facilities Council

ISIS Neutron and Muon Source

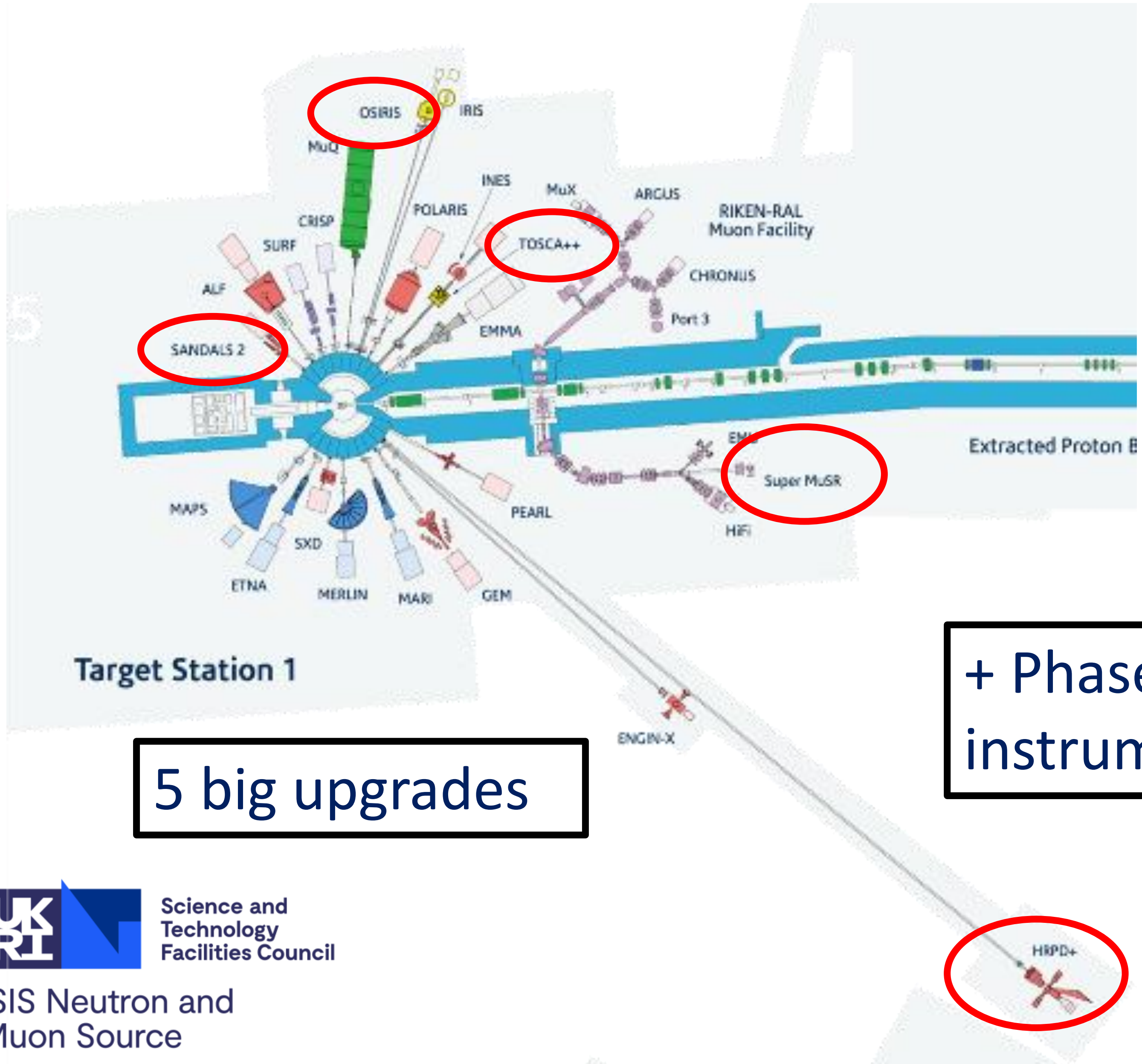








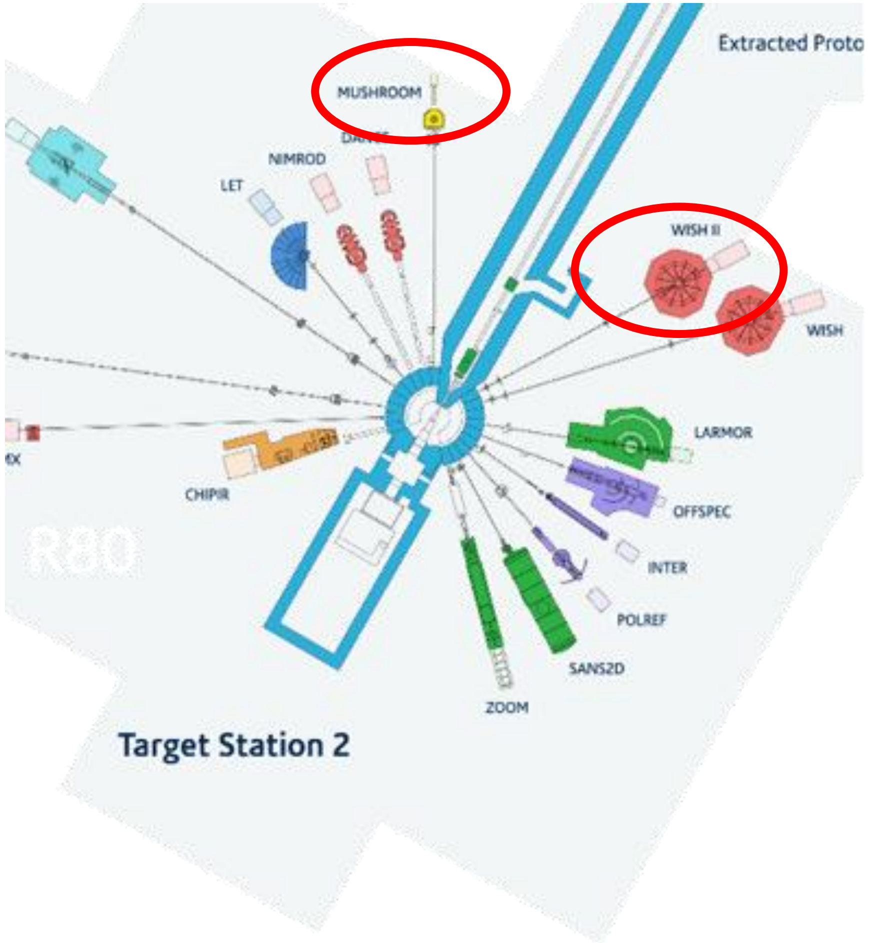
# The Endeavour Programme




5 big upgrades

+ Phase 3 instruments

2 new instruments




Science and Technology Facilities Council

ISIS Neutron and Muon Source

# Endeavour Shielding Opportunities

Design of several instruments at one time

- Common features
- Common process & approach
- Common standards
- Common shielding design between instruments
  - Along the guides and chopper pit regions
  - Common beam stops

Highly optimized bespoke
vs
Good enough, common known solution

# Shielding design principles

Radiation shielding is needed to:

- Protect staff, users and members of the public
- Reduce backgrounds
- Reduce radiation damage related failures

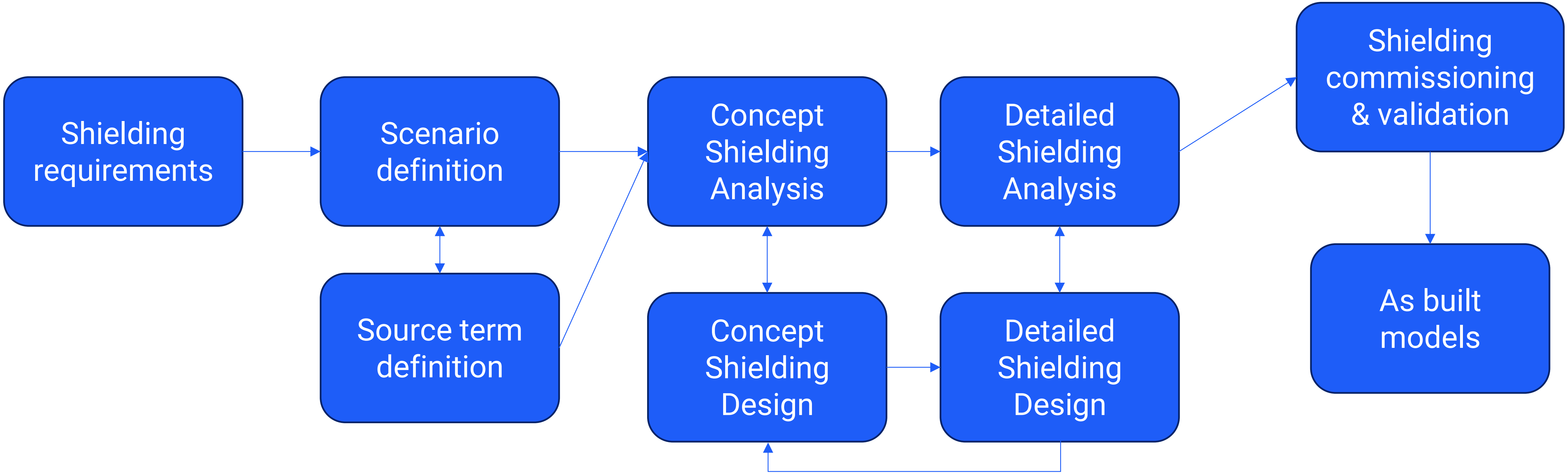
In ISIS we want the experimental halls to be ‘supervised areas’ which typically means less than 7.5 microSv/h.

We want the shielding analysis to be conservative.

We don’t want the shielding to be restrictive – the science and instrument capability should be maximized

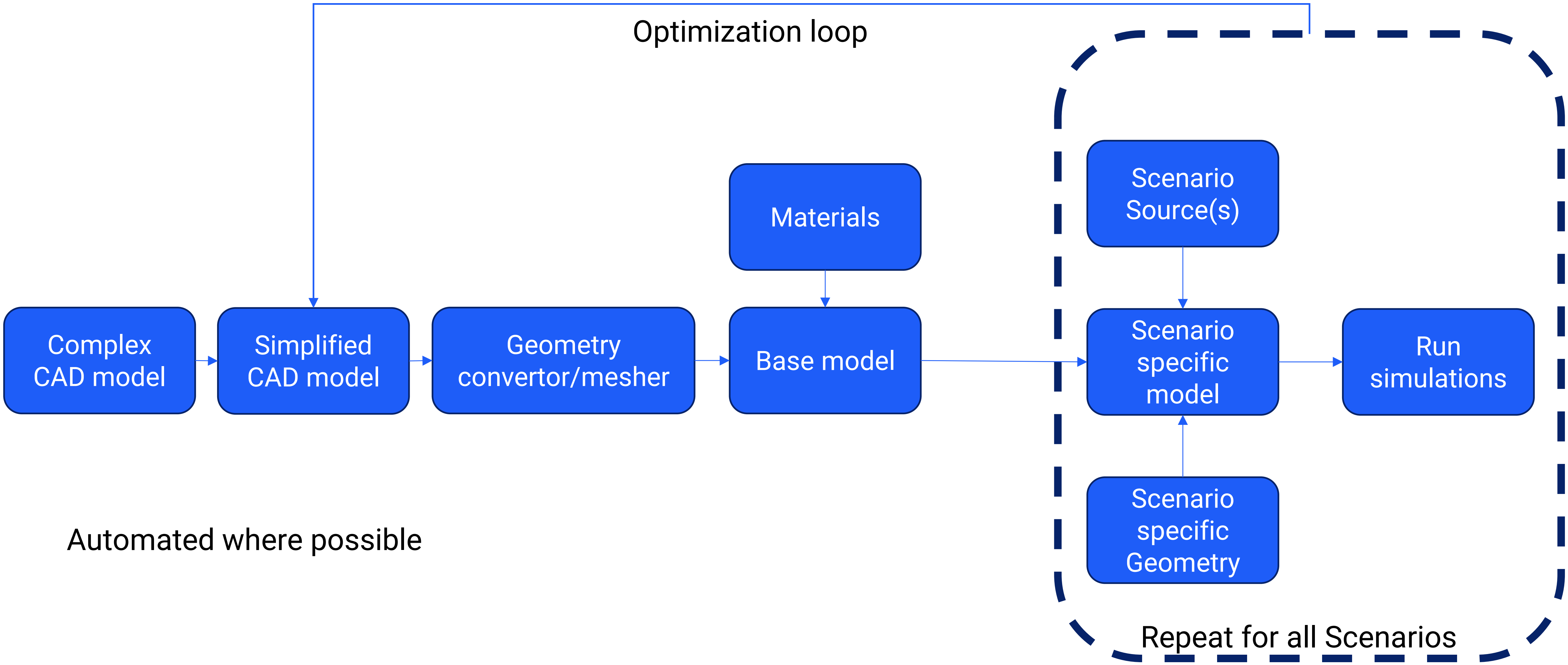
We want flexibility – try not to include science equipment unless clear justification.

# Shielding design process




Based on the UK Shielding forum process

# Simplified Shielding analysis workflow




Automated where possible

# Shielding design process – scenario definition

6 main shielding scenario categories initially considered:

- Empty beam – all choppers, jaws, shutters open
- Highly absorbing sample – maximum conversion to gamma
- Highly scattering sample – maximum neutron flux on walls
- Scatter/absorbing points along the beam – closed choppers, jaws etc which may be worst case for local areas of the beam
- Closed shutter
- Reasonably foreseeable cases not covered above

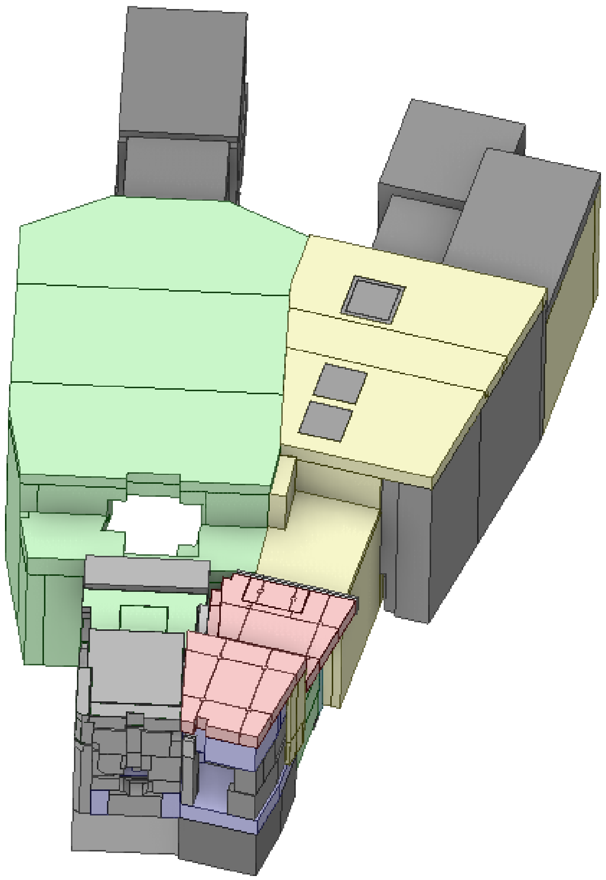
Typically need extra temporary scenarios for phased building or part upgrades

# Shielding challenges for Endeavour

Heavily constrained

- space – surrounding instruments and infrastructure limited options
- instruments are getting bigger – inner shielding space is being reduced
- target dose rates being reduced

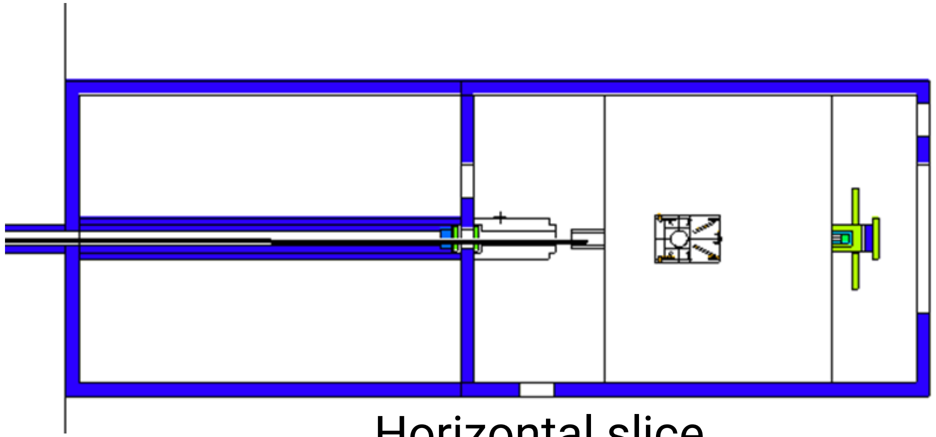
- Old instruments – very mixed quality of drawings, CAD models and materials data,
- Some data and drawings on microfiche with hand written notes
- Often staged upgrades mean a real mix of old drawings, 3D CAD, at various levels of detail.
- Difficult to know ground truth, as-built – very rarely one.
- We have existing radiation dose and flux measurements – but need to be interpreted
- Is ALARP is effectively demonstrated if match current radiation levels?



# Upgrade project example – HRPD-X

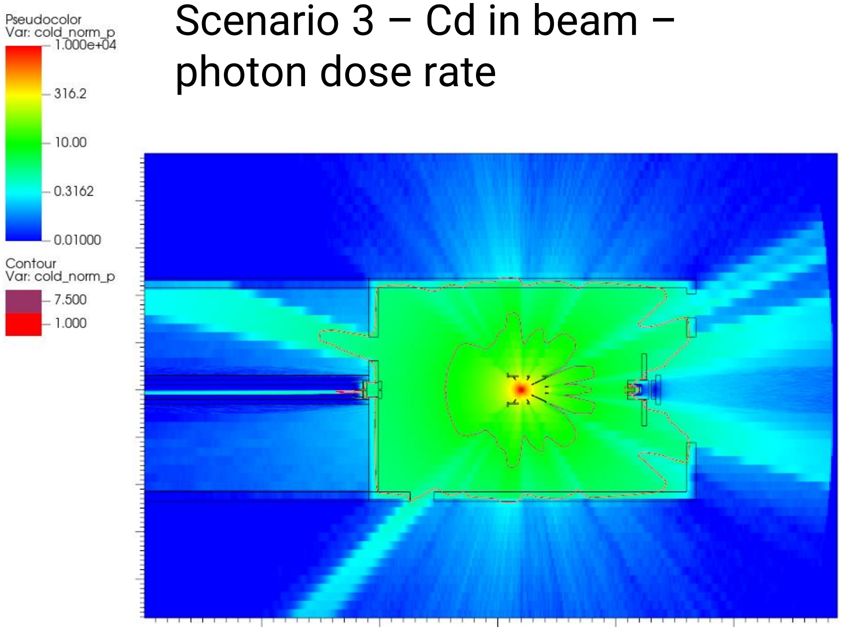
Only upgrading the sample and detector building
Roughly 100m guide length
Main source is cold neutrons calculated with MCNP + McStas
Decent CAD model but model mostly built by hand
Simplified vacuum vessel added via CAD conversion

4 scenarios considered – only 2 really drive the shielding
- Cd in the beam
- strong neutron scattering represented by water

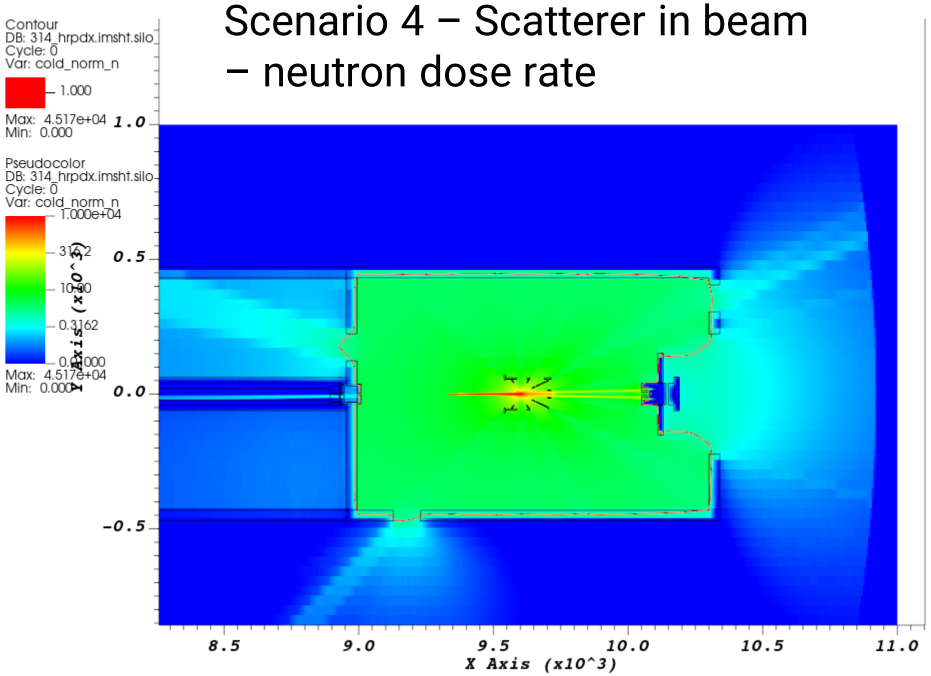


Horizontal slice

Scenario 3 – Cd in beam – photon dose rate




Scenario 4 – Scatterer in beam – neutron dose rate



# Upgrade example - HRPDX

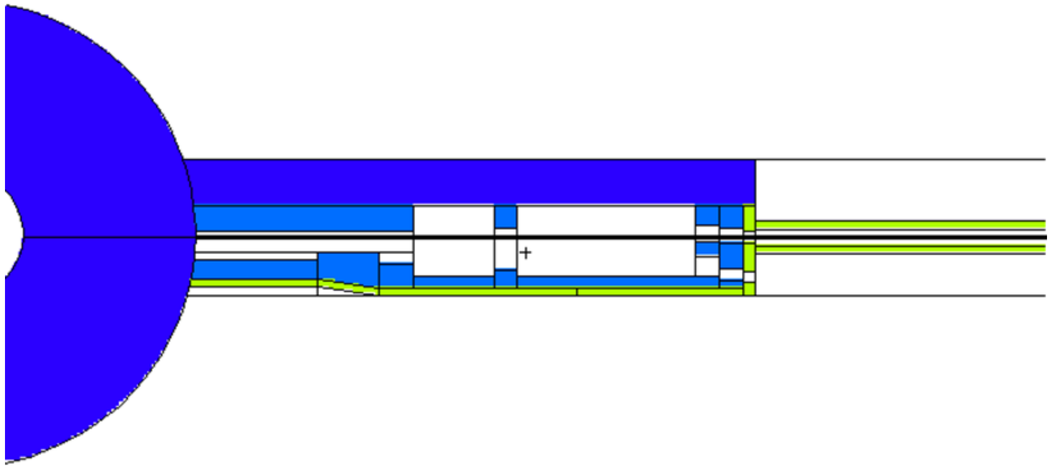
Extra scenario - Temporary shielding needed for during construction

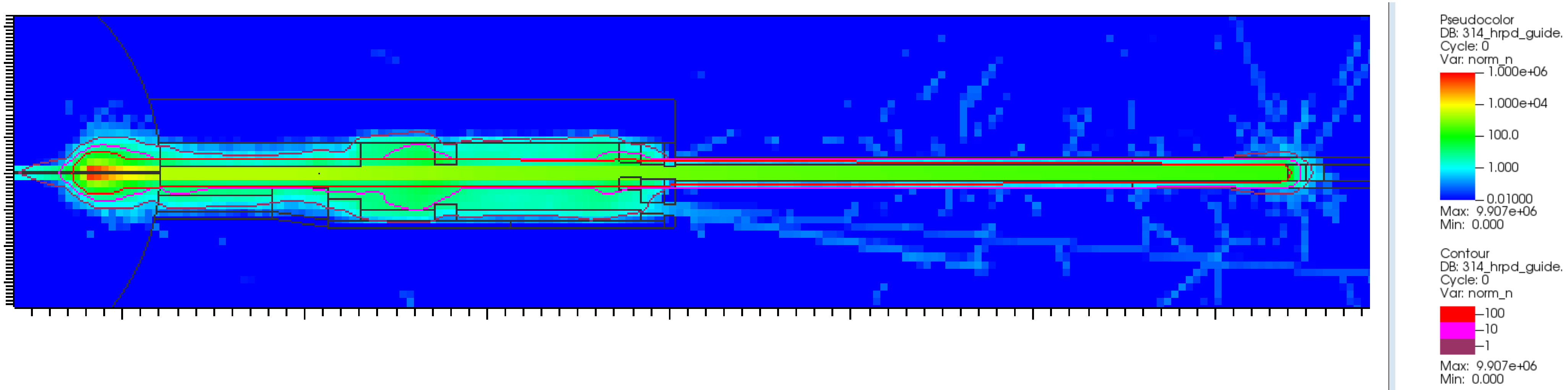
Needed a model of the front end

Old 2D drawings available and not bad quality from early 2000s guide upgrade

Built by hand

Derived fast neutron source at monolith exit

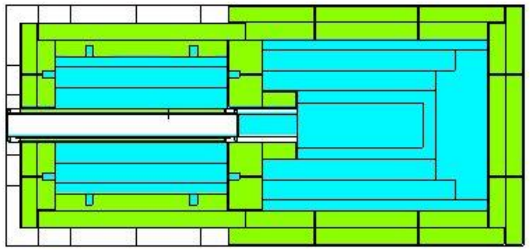


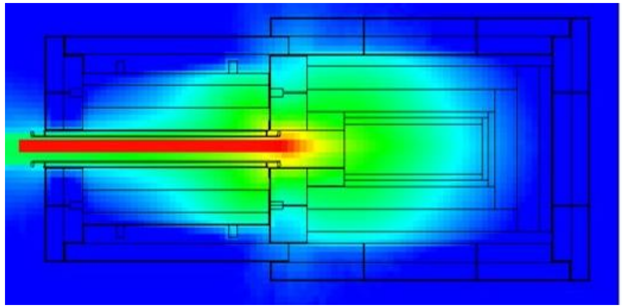


# Managing Uncertainty

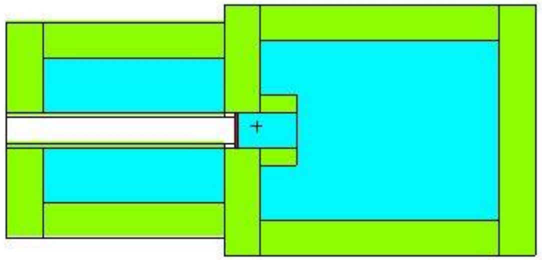
- Generally very conservative approach
  - Low dose targets, conservative source terms and scenarios,
  - Conservative modelling approach – significantly less material considered than reality
  - Do need to consider all contributions
- Typical uncertainties
  - Monte Carlo Statistical uncertainty – managed by a target of 10% relative error at the dose target dose rate contour
  - Nuclear data uncertainty – generally low but need to be aware of nuclear data issues with key materials e.g. Cd gamma production
  - Modeling uncertainties
    - Geometry
    - Materials
    - Physics models
    - Source model – probably the largest uncertainty
  - Cross talk and backgrounds
- Sensitivity studies to support assumptions as needed

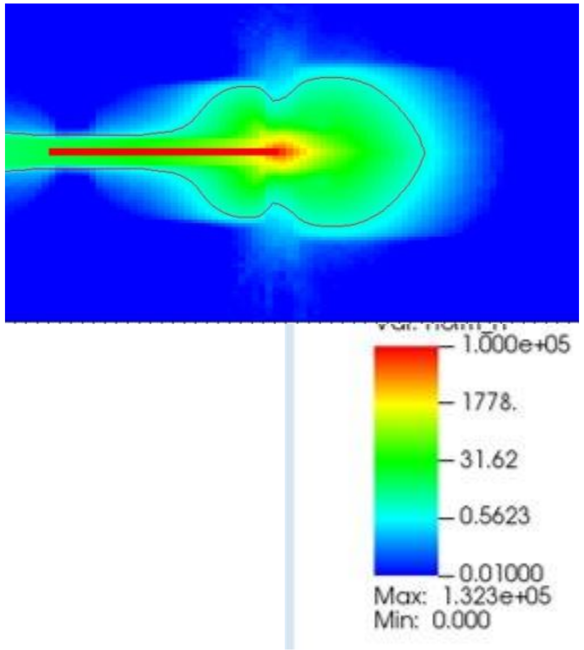
# Managing Uncertainty – sensitivity studies





- Different nuclear data libraries
  - Typically not a large difference for most common shielding materials
  - Beware of missing prompt photon production e.g. Cd in ENDFBVIII – see Miller et al.
- Difference in physics models
  - Mostly impacts source generation
  - Typically we see 20% in neutron production between models
- Geometry assumptions
  - Currently studying different approaches to modelling wax tanks
    - Fully detailed vs fully homogenized vs shell model





# Lessons learnt

- Working with the engineers to get a good analysis quality CAD model – prepared guidelines – what is important and what details can be discarded – at what stage in the design
- Cd nuclear data is not great – several key libraries don't have the photon production
- Hard not to be very conservative
  - Scenarios that we cannot rule out but are not how the beam line typically operates
  - Not including large parts of the scientific equipment can lead to issues − but gives greater flexibility
  - Source terms − max beam power, max opening sizes etc.
- Scope always creeps – always a late change or extra hole or temporary scenario

# Summary

- Endeavour project is entering a key phase with multiple instrument designs underway
- A common set of shielding principles and process has been adopted
- Some opportunities for common shielding is possible
- But each instrument needs some bespoke shielding
- HRPD-X shielding analysis is complete and the concrete is being poured.
- Uncertainty comes in many forms – we use a conservative approach with margin built in often – rather than try quantify all uncertainties
- Where needed we do sensitivity analysis