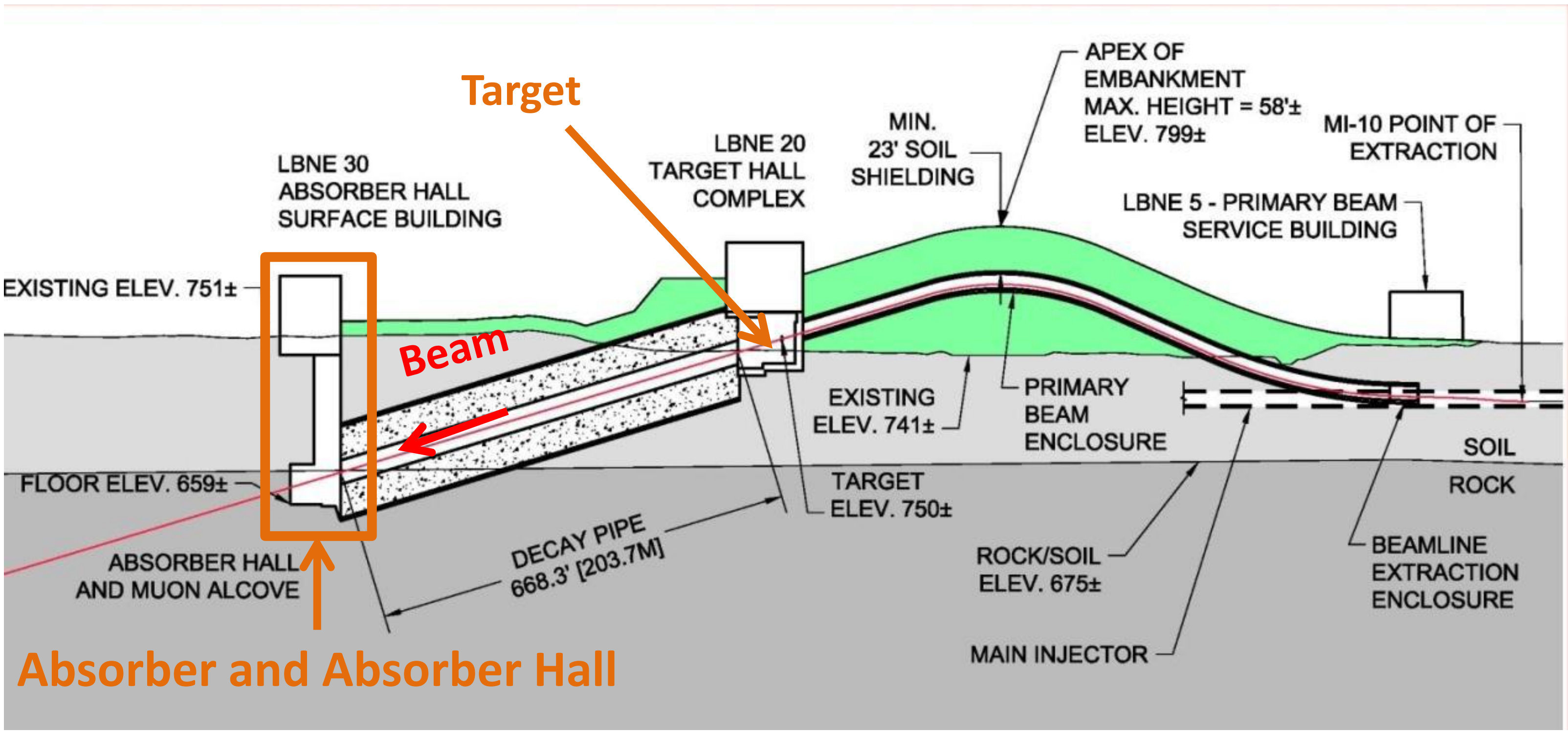
LBNE 2.4MW Absorber

NBI 2014

Presented by Brian Hartsell

Contributions by: Kris Anderson, Yury Eidelman, Jim Hylen, Nikolai Mokhov, Igor Rakhno, Salman Tariq, Vladimir Sidorov

LBNE Absorber - Introduction

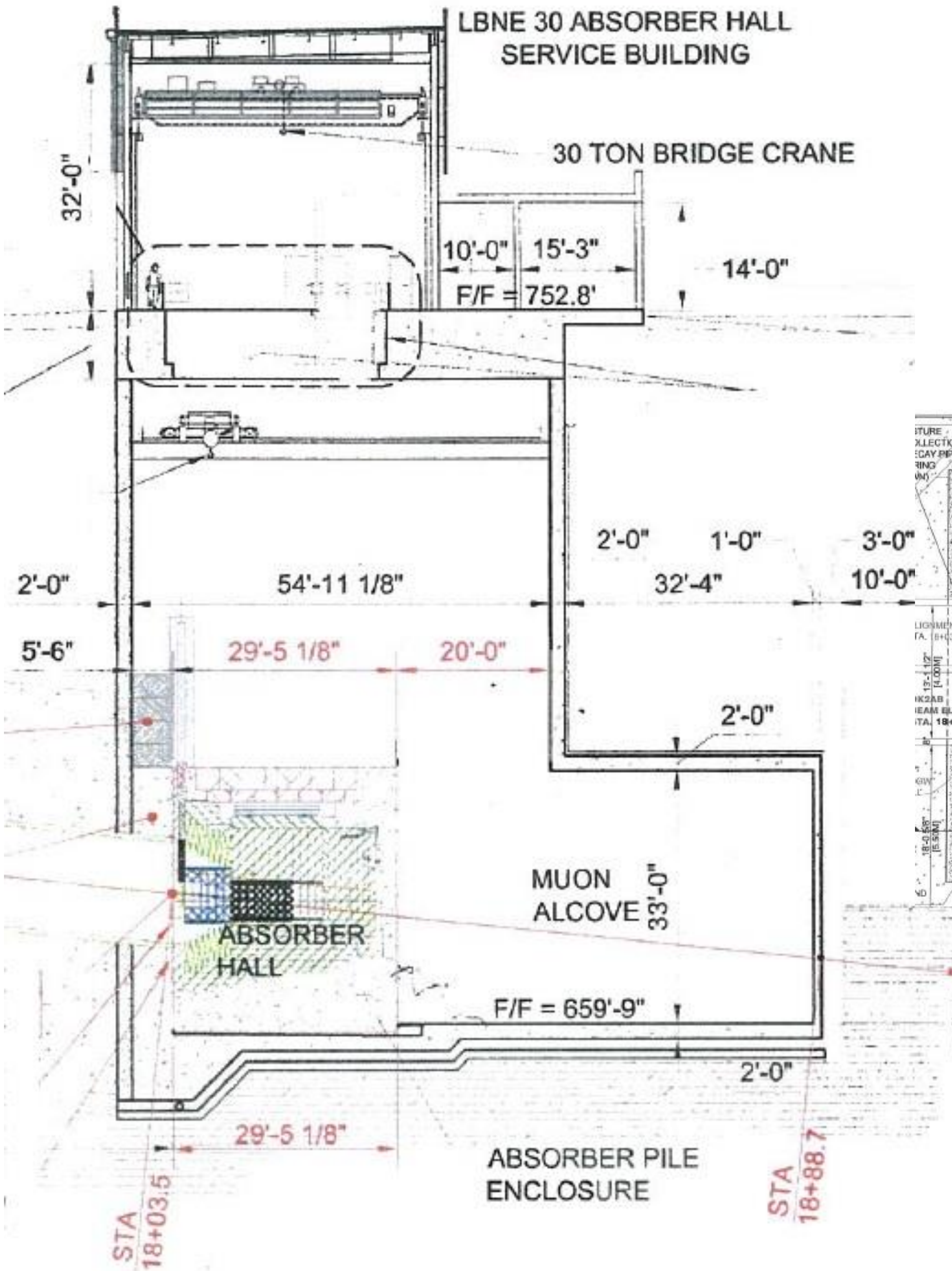


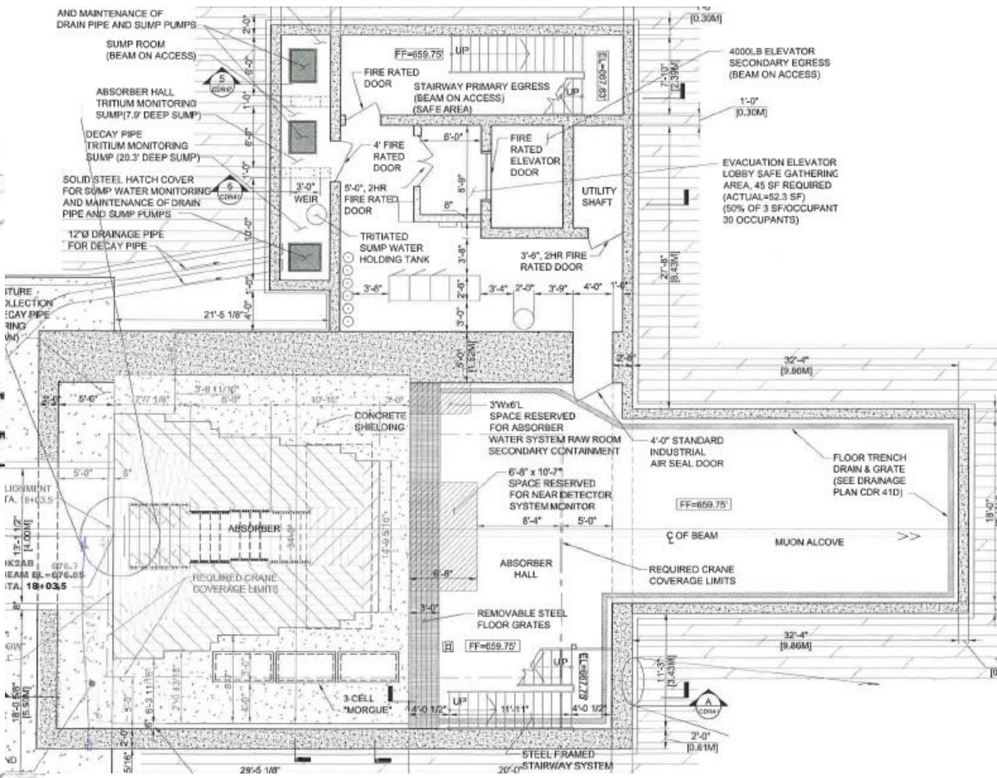
- Purpose of absorber (a.k.a. beam dump) is to stop left-over beam particles, and provide radiation protection to people and ground-water.
- Needs to absorb ~800kW of beam power when running at 2.4MW proton beam with water cooling.

Absorber Requirements

- Ability to handle full range of 2.4MW beam
  - 60 to 120 GeV
  - 1.5e14 ppp
  - 0.7 sec cycle time (60GeV) to 1.2 sec (120 GeV)
- Configured for the worst case decay pipe
  - 204m in length, helium filled
- Lifetime of 30 years, minimal maintenance
- Tolerant of any beam accident conditions

Absorber Hall





Absorber layout

- Poured concrete volume: 24000 ft^3
- Steel shielding: 5,000,000 lb
- Aluminum: 77000 lb

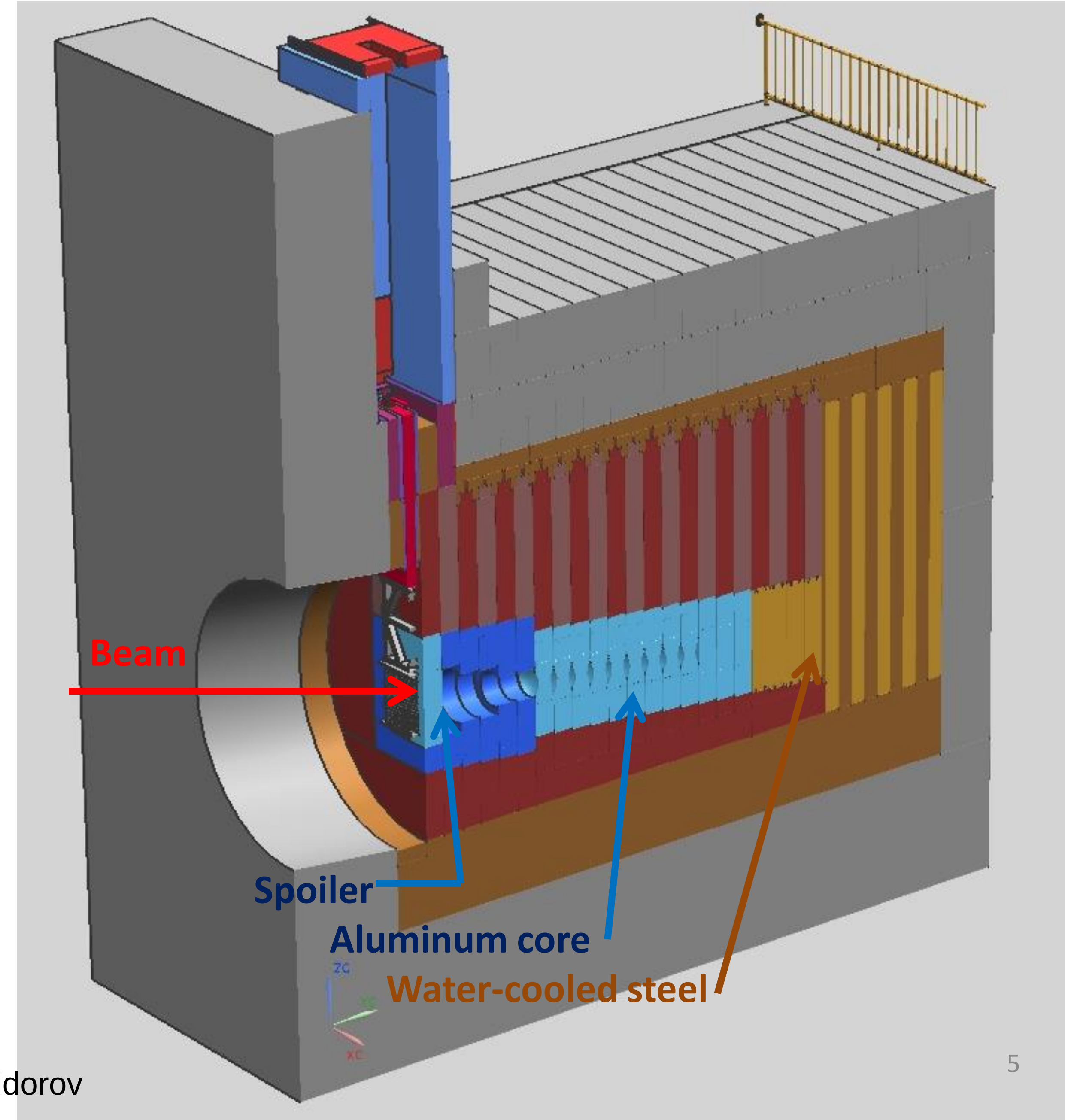


Image from: Vladimir Sidorov

Desirable material properties for core

- Good resistance to thermal impulse (combination of heat capacity, thermal expansion coefficient, modulus of elasticity and yield strength, ductility)
- Low density (to spread out shower, decrease energy deposition density)
- High thermal conductivity (to conduct heat to water cooling lines)
- High radiation damage resistance
- High corrosion resistance
- Tolerant of high temperatures
- Low toxicity (avoid mixed waste if possible)
- Good creep and fatigue resistance
- Reasonable expectation that it would last the life of the facility
- Conducive to modular design, to facilitate replacement of failed section if necessary
- Low cost

Slide from: Jim Hylen

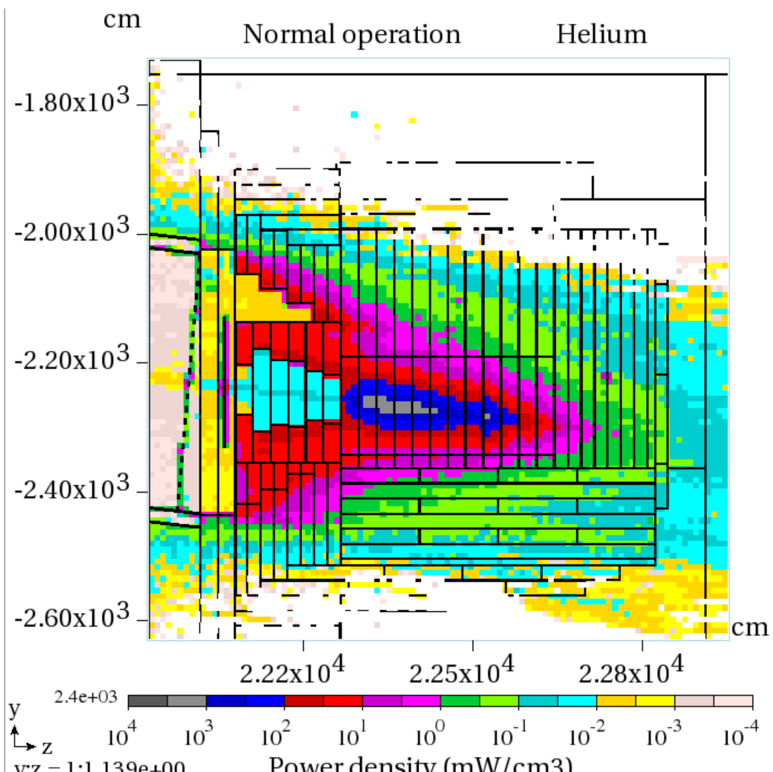
Material selection – look at low density materials

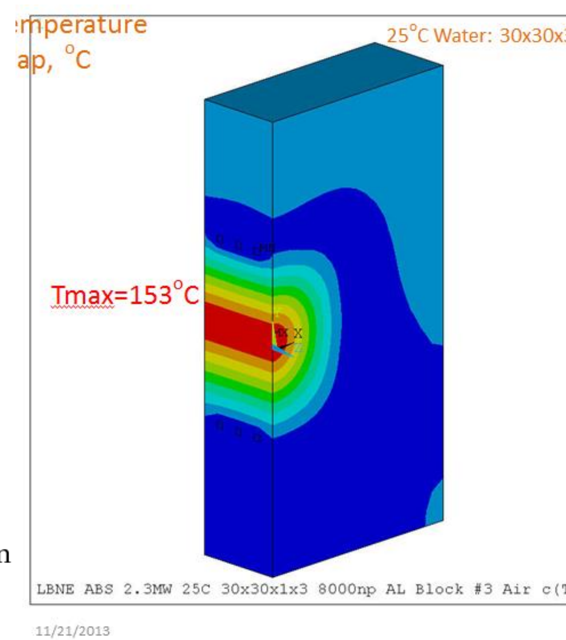
- Beryllium would be the ideal selection, except for cost and toxicity
- Graphite is a good material, but would probably have to be encapsulated and covered in an inert atmosphere since it oxidizes to a gas
- Aluminum
  - Forms a protective solid oxide layer as it oxidizes, preventing further oxidation
  - Allows for simple modular construction and the possibility for replacement – no need for encapsulation
  - Gun-drilled water lines provide simple connection of cooling water to core
  - Has excellent thermal conductivity
  - Is significantly more radiation resistant than graphite
  - Is not toxic
  - Is reasonably inexpensive
  - Has worked well for NuMI (we have experience)
- Issues for Aluminum
  - Need to keep temperature lower than other materials (avoid creep and fatigue)
  - Less resistance to thermal impulse

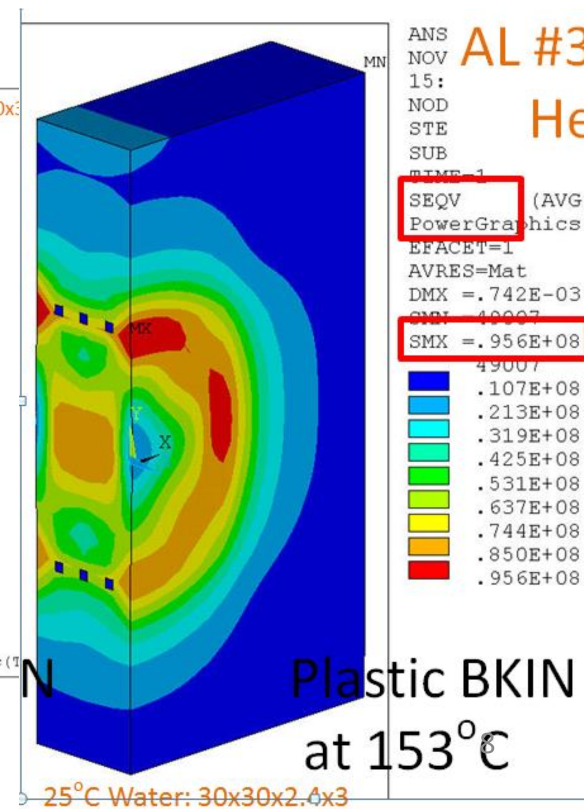
Slide from: Jim Hylen

Core Analysis – Previous Work

- Previously configured and analyzed (N. Mokhov, I. Novitski, I. Rakhno, I. Tropin) using a solid Al core
- Good start, room for further optimization and simulation updates







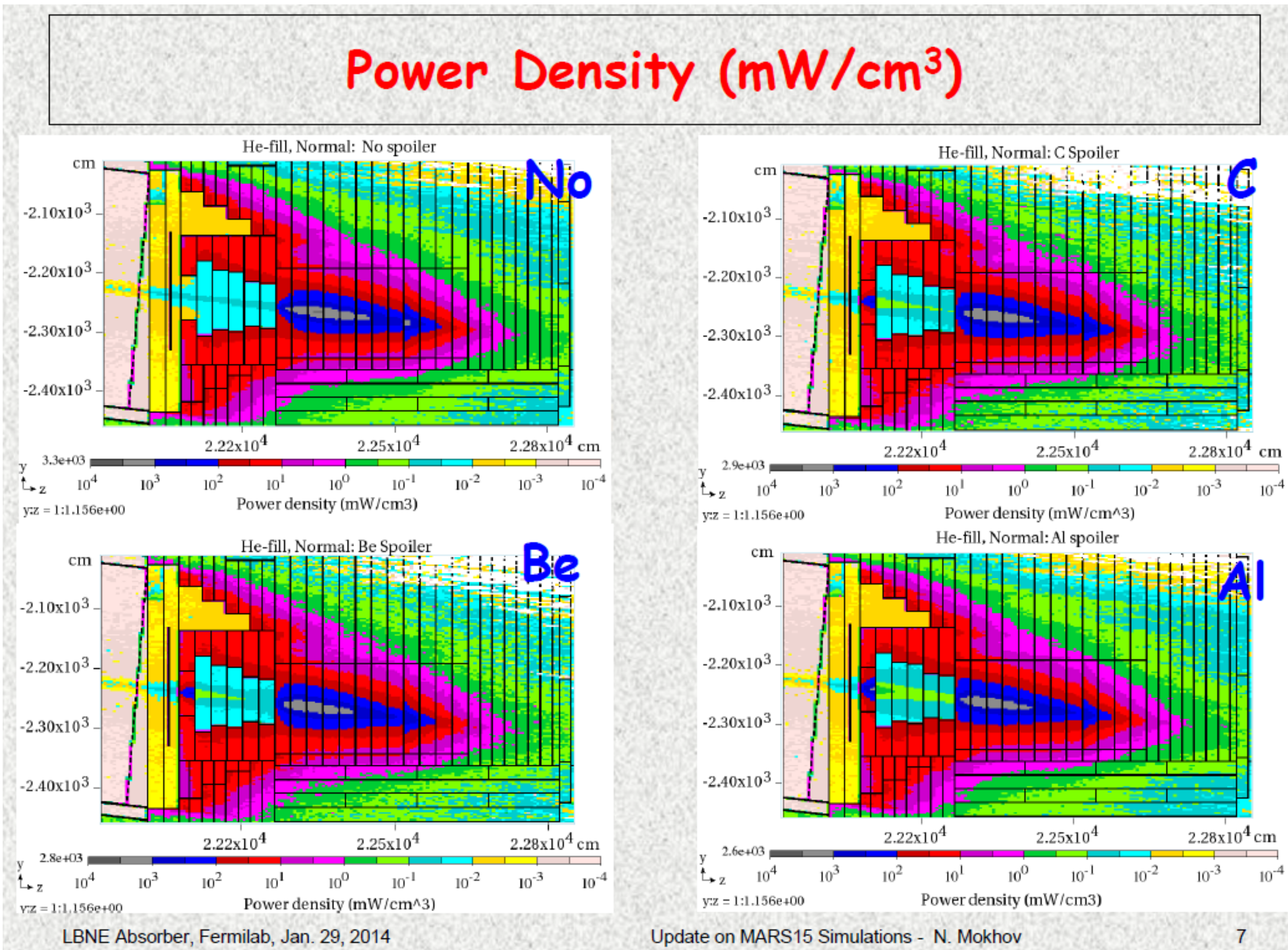
What do we want to achieve?

- Improvements to model
  - Convection at the water lines instead of fixed temperature
  - Cylindrical, gun drilled water line array

- Keep Al under 100C for creep and to preserve the temper
  - Probably on the conservative side, but that’s good for a 30 year life absorber..

Addition of a 'spoiler'

- Start the shower and allow it space to spread out, reducing peak energy deposition in the downstream blocks.



Addition of a 'spoiler'

- Addition of an Al spoiler shows a reduction in peak energy deposition to 75% of the previous no-spoiler case.

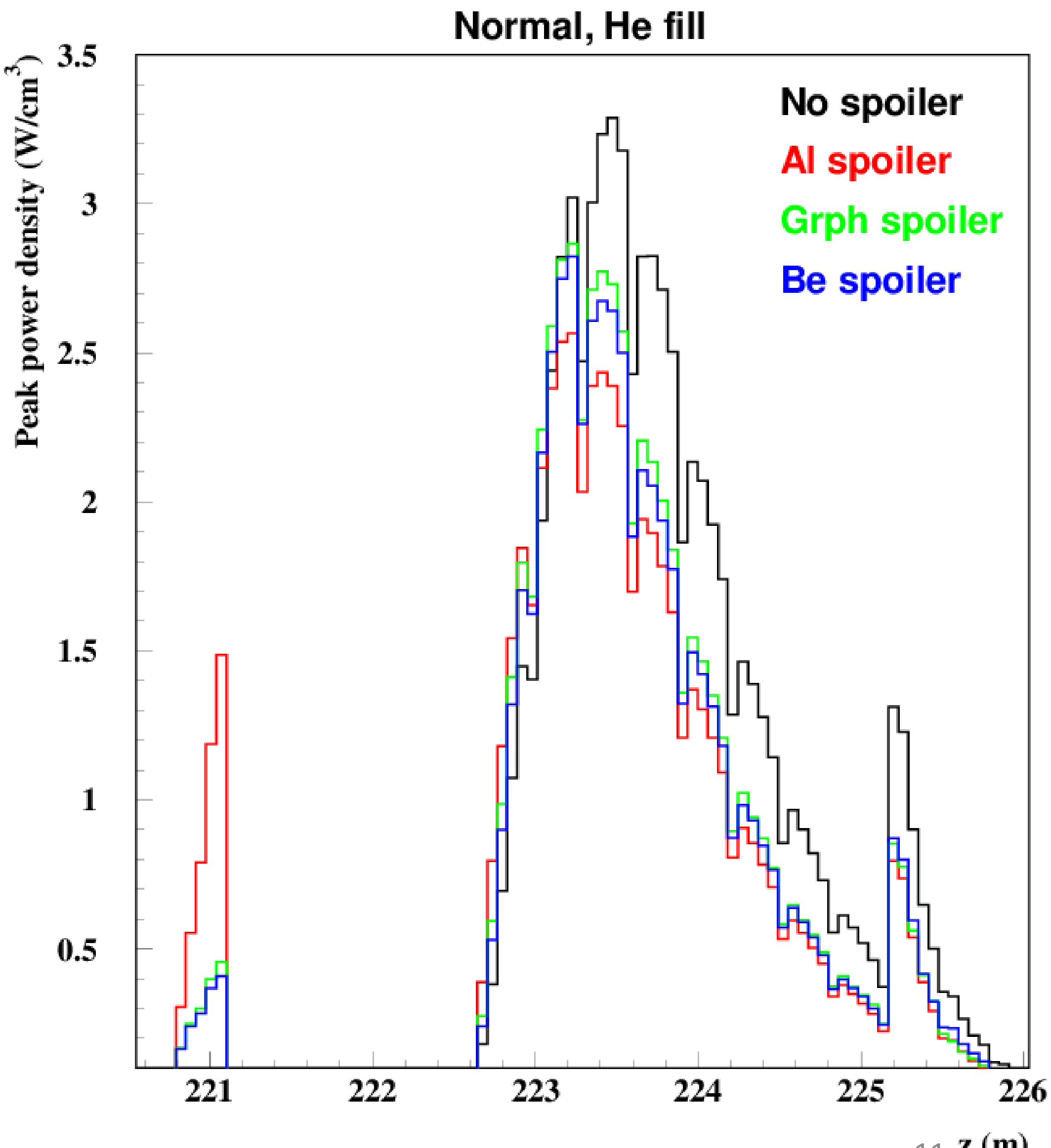
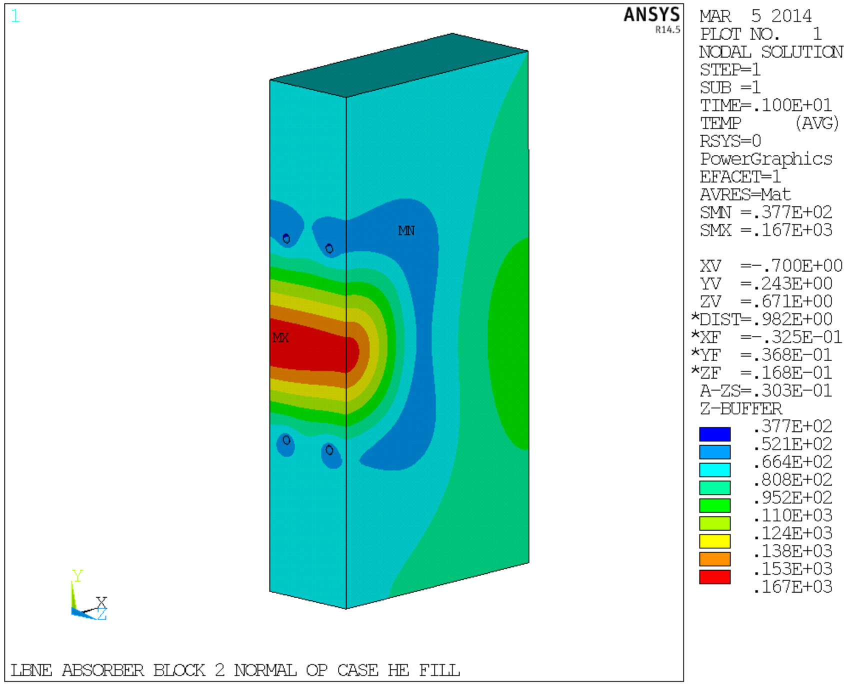


Image from: Nikolai Mokhov

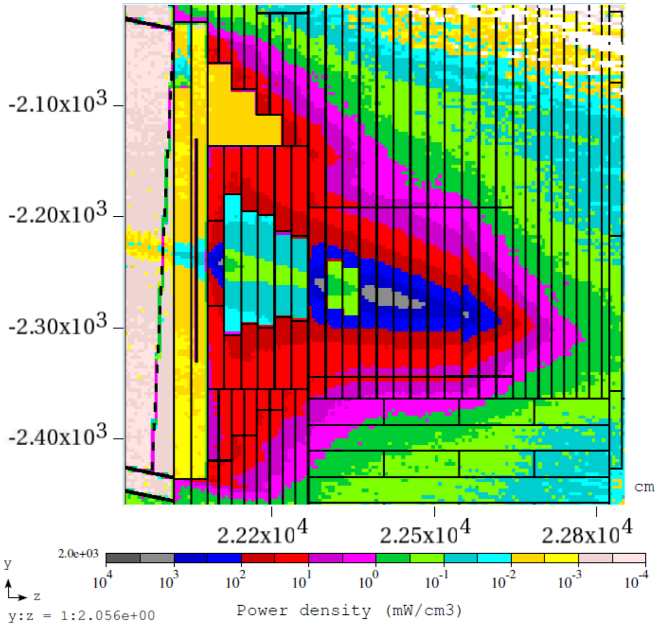
ANSYS Thermal Results – Single Spoiler

- Using realistic model conditions (convection coefficient on water lines, temperature dependent properties for Al, cylindrical water line geometry), peak temperature of 167C. Too high!

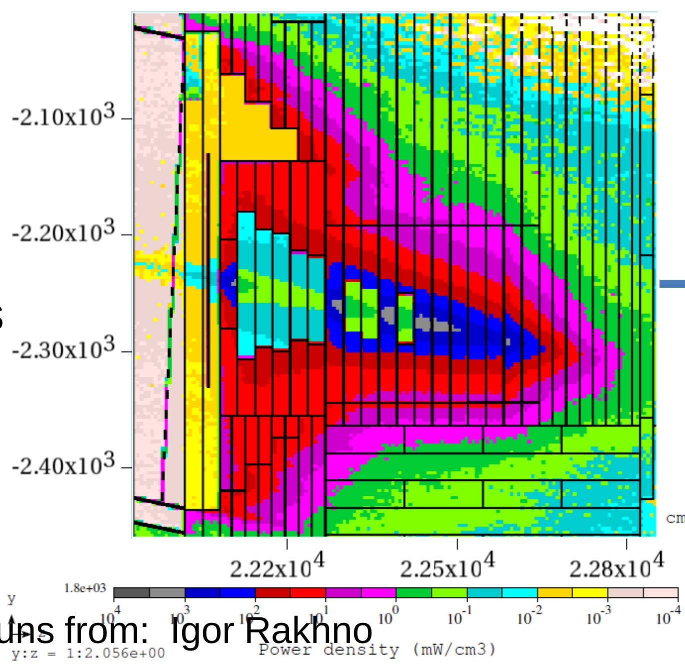


Iterations – multiple spoilers

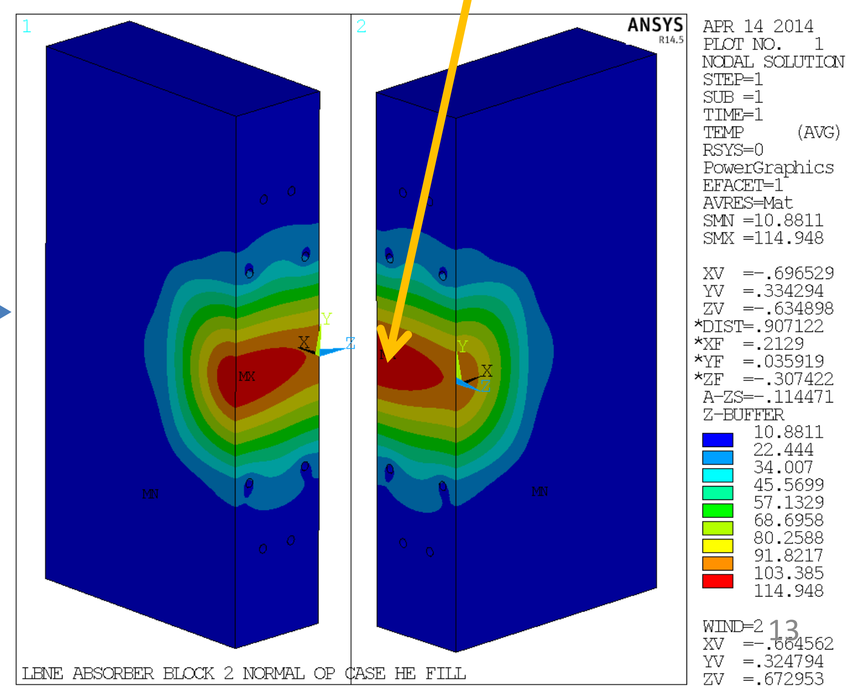
Two Spoilers



Three Spoilers

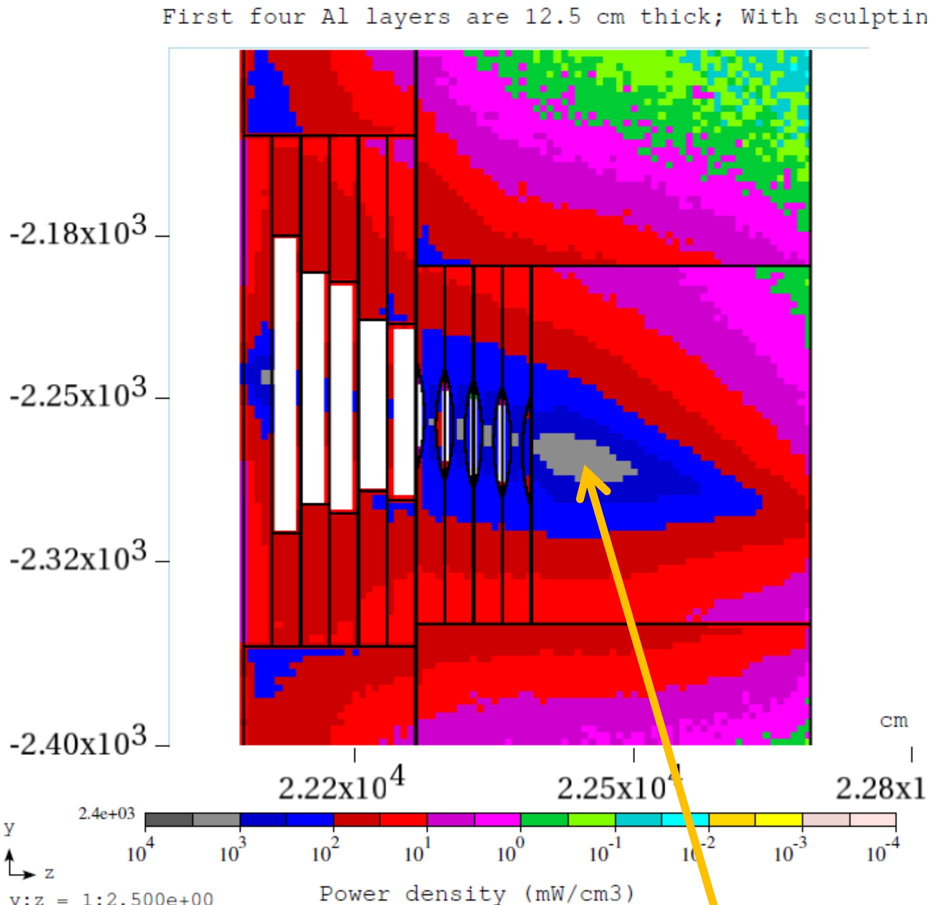


115C – getting closer



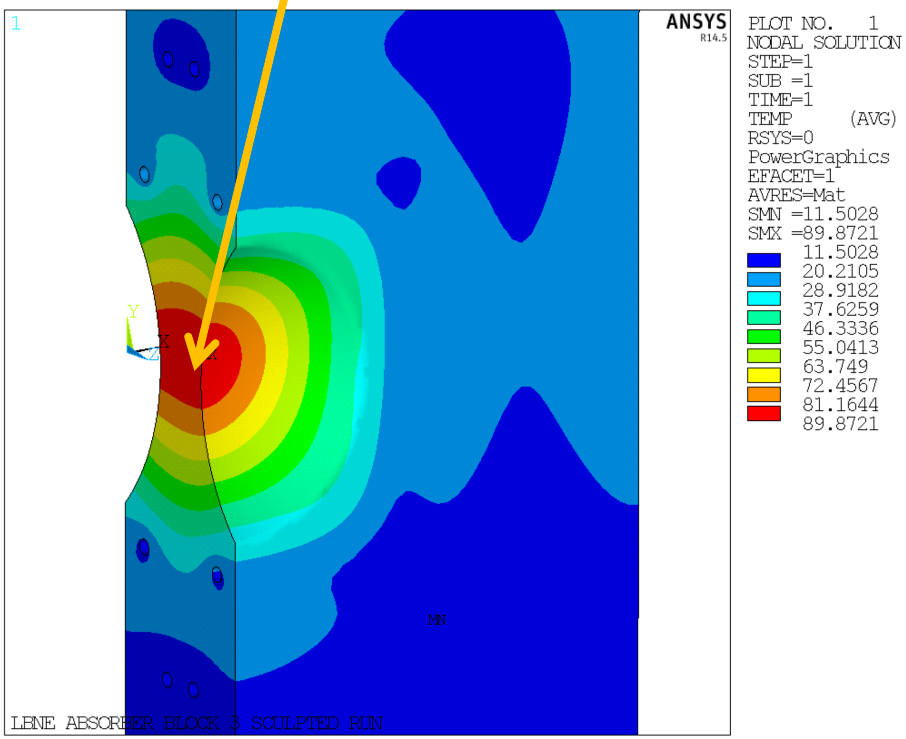
MARS runs from: Igor Rakhno

Iterations – Sculpting with Single Spoiler



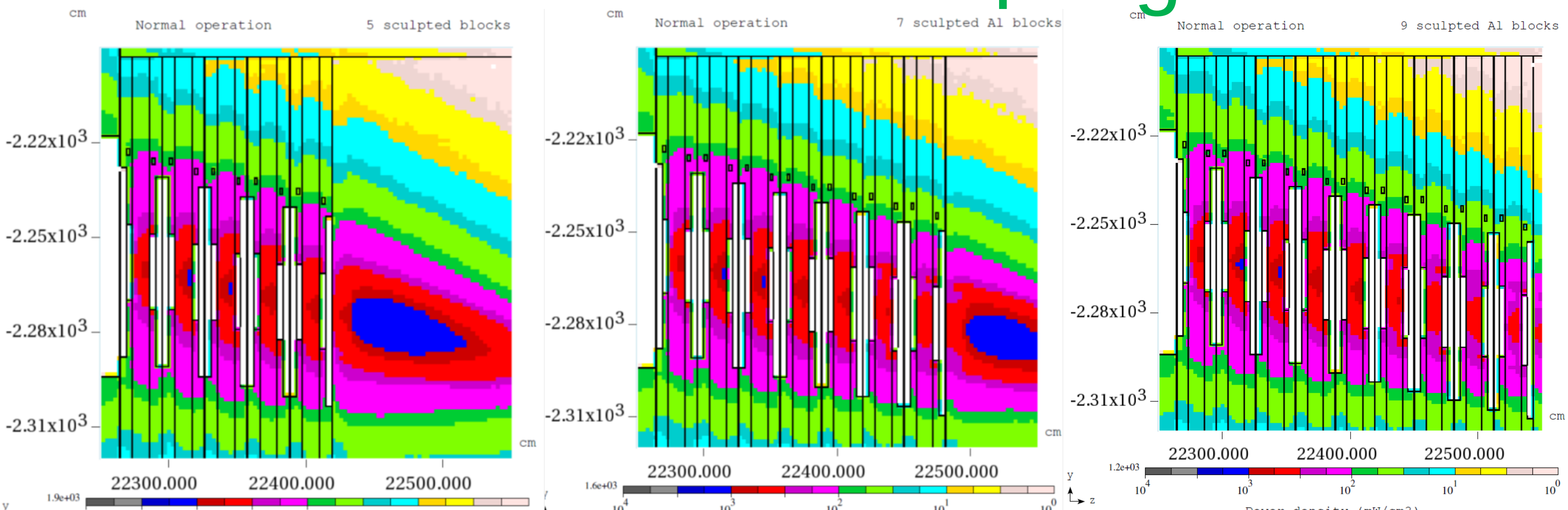
MARS runs from: Igor Rakhno

90C – success



But… the temperature here is too high.

Iterations - Sculpting

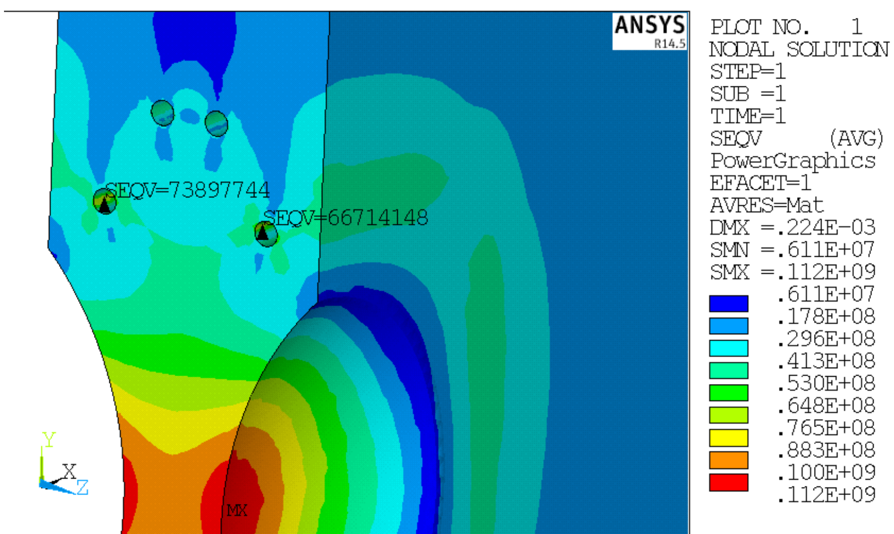


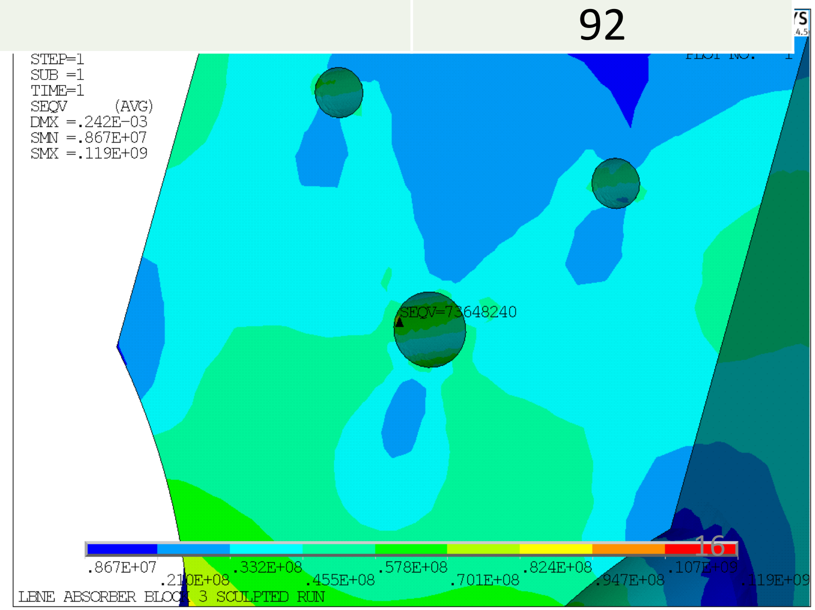
MARS runs from: Igor Rakhno

Spoiler details & number of sculpted Al blocks	In spoiler	In sculpted Al	In solid Al, downstream of sculpted Al	In 1st Fe block
Al 12” & 4	1.1	1.2	2.1	0.8
Al 12” & 5	1.1	1.1	1.9	1.1
Al 12” & 7	1.1	1.2	1.6	2.2
Al 12” & 9	1.1	1.2	1.0	5.3

Water line and sculpting optimization

Description	Max Water Line VM Stress
4-1" WLs In-Line at 30cm (Original config presented 7/7)	112
Down-Up-Up-Down (30cm/35cm spacing)	94
Down-Up-Up-Down (30cm/40cm spacing)	74
V configuration	
Base (1.5" Dia WL, 30cm Large WL, 40cm Small WLs)	73
Base w/ 1.25" Dia Large WL	90
Base w/ 1.0" Dia Large WL	80
Invert V - Small WLs at 30cm, Large at 35cm	92

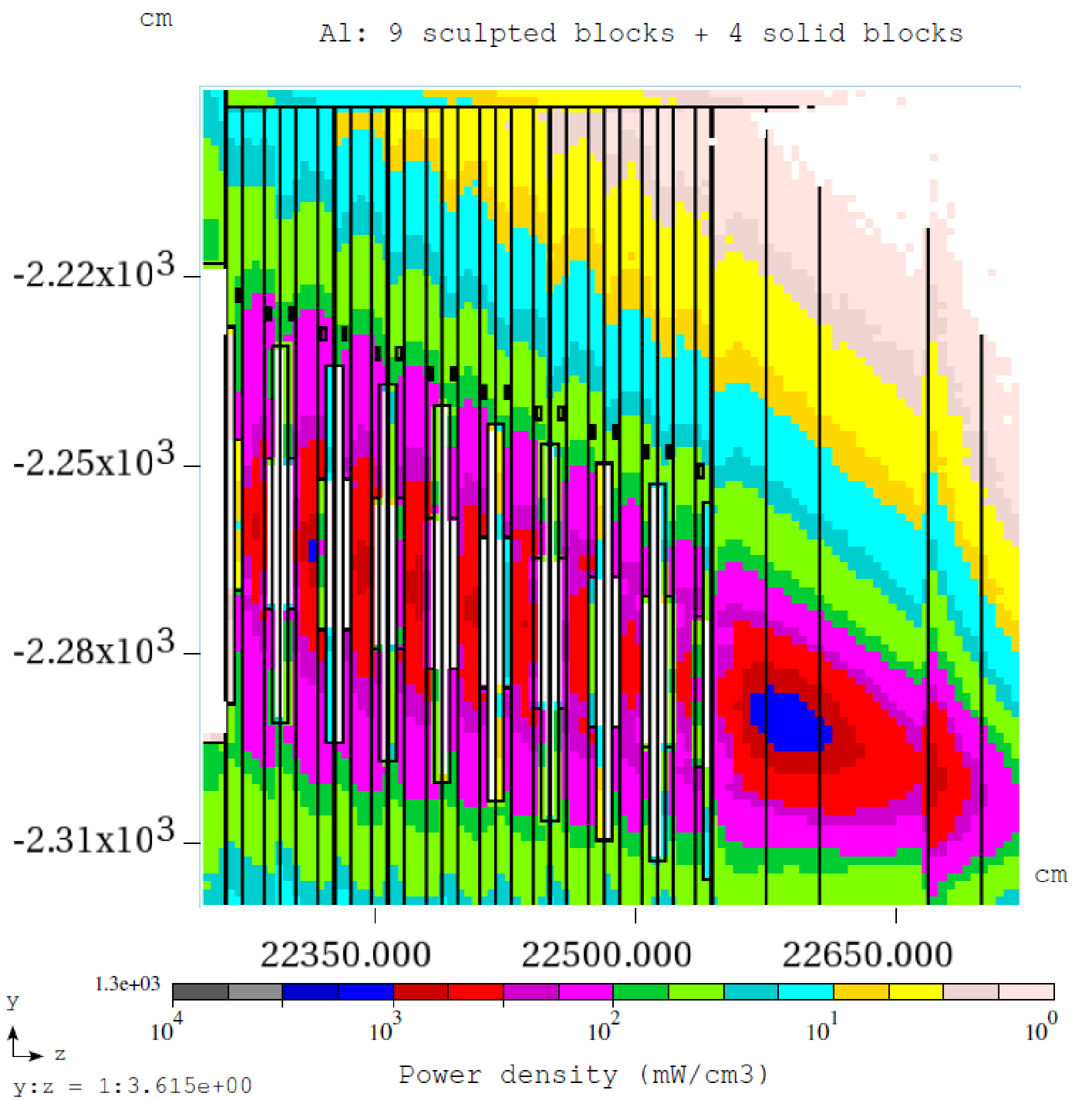




Final Configuration

- 9 sculpted blocks
- 4 full Al blocks

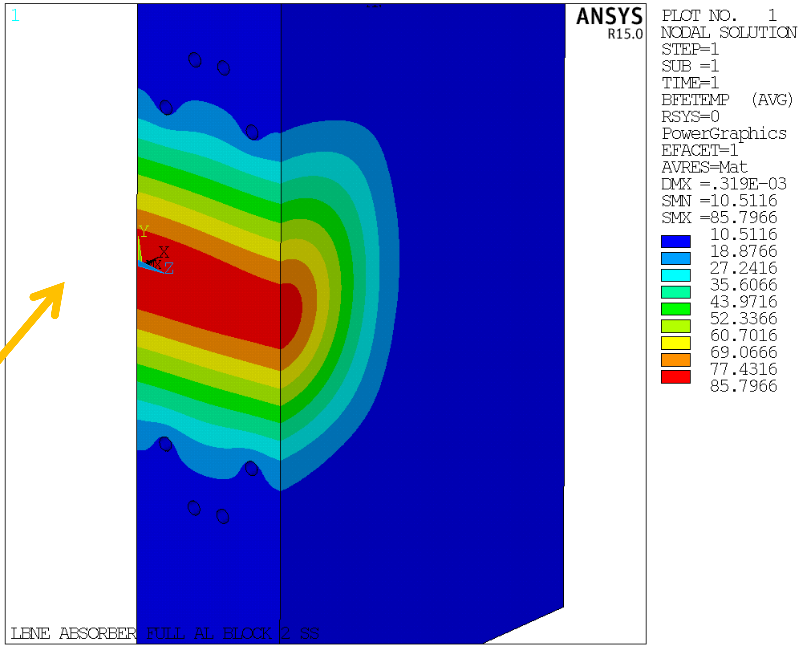
- Lengthened by 5' from the CD1 baseline configuration

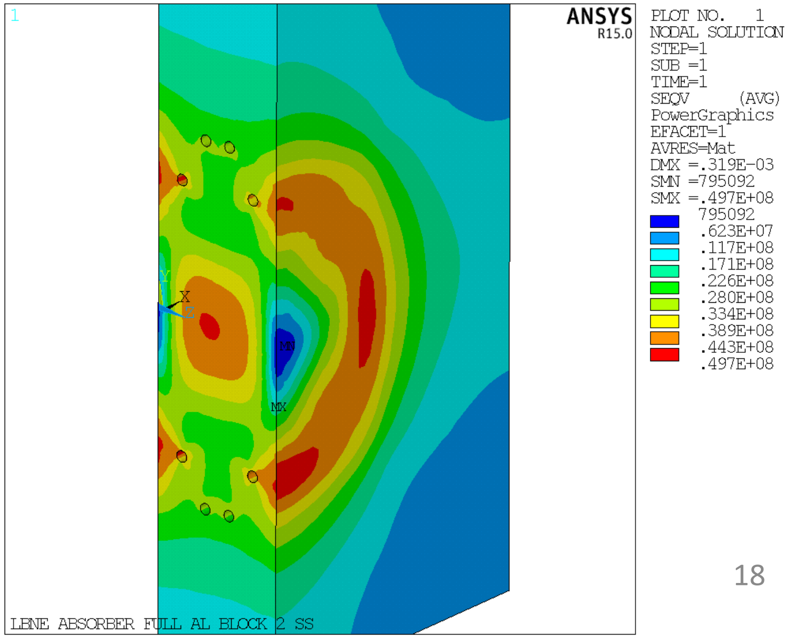


MARS runs from: Igor Rakhno

Final Configuration - Analysis

- Thermal and structural analysis for maximum energy deposition areas: sculpted block, core block, and steel block.





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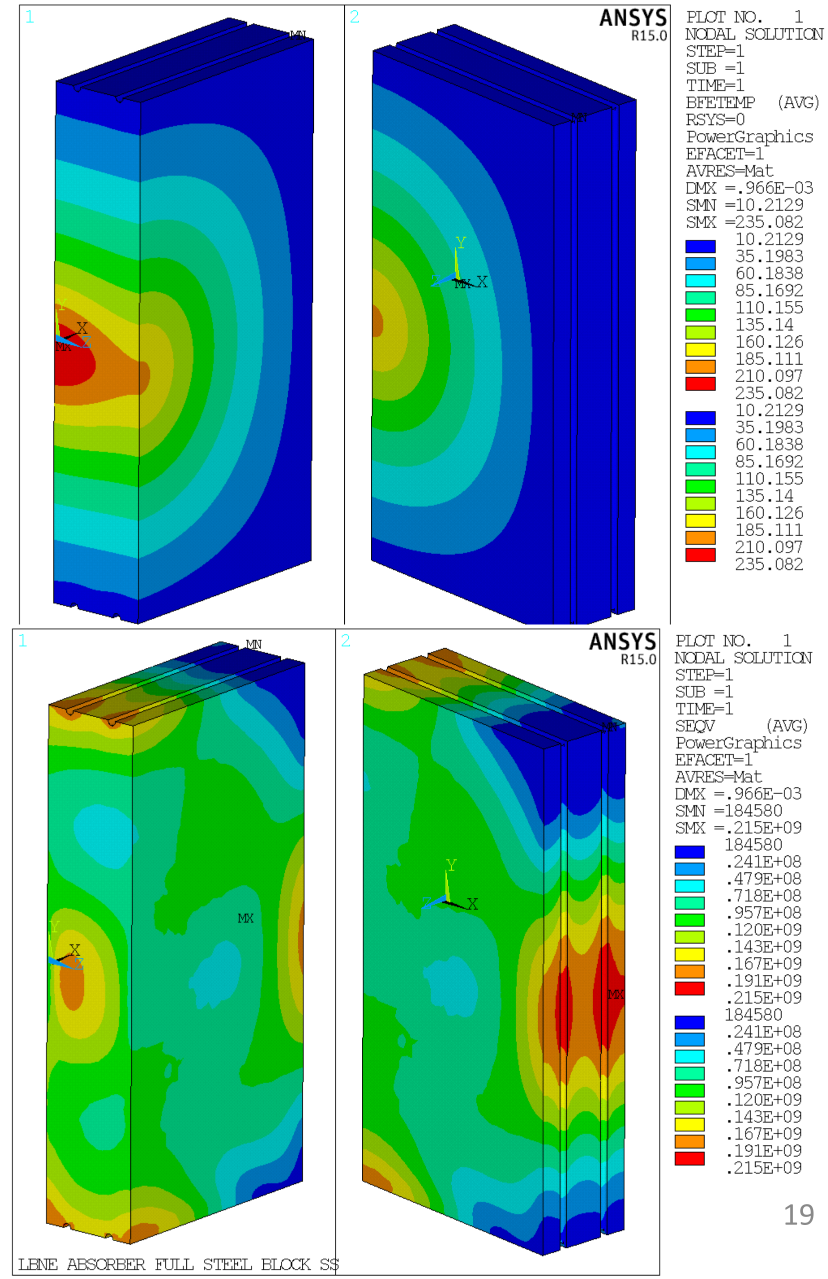
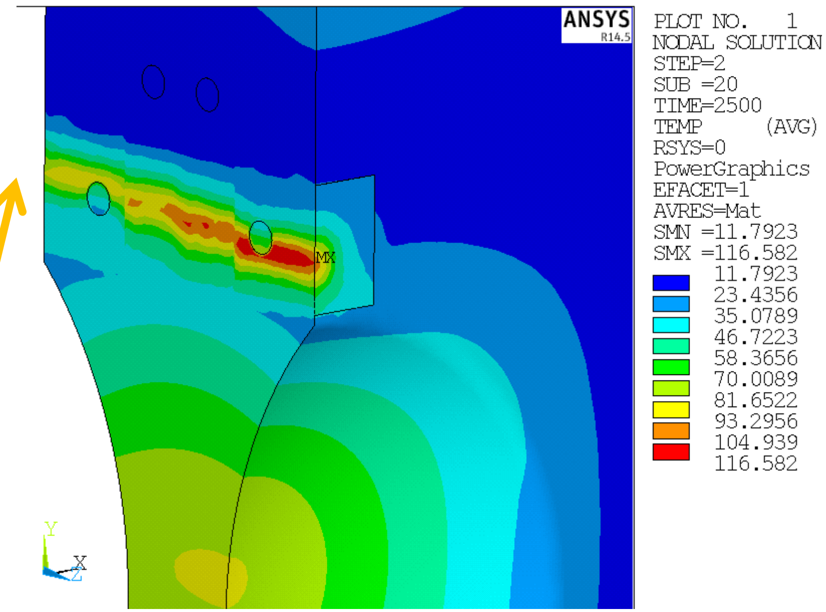
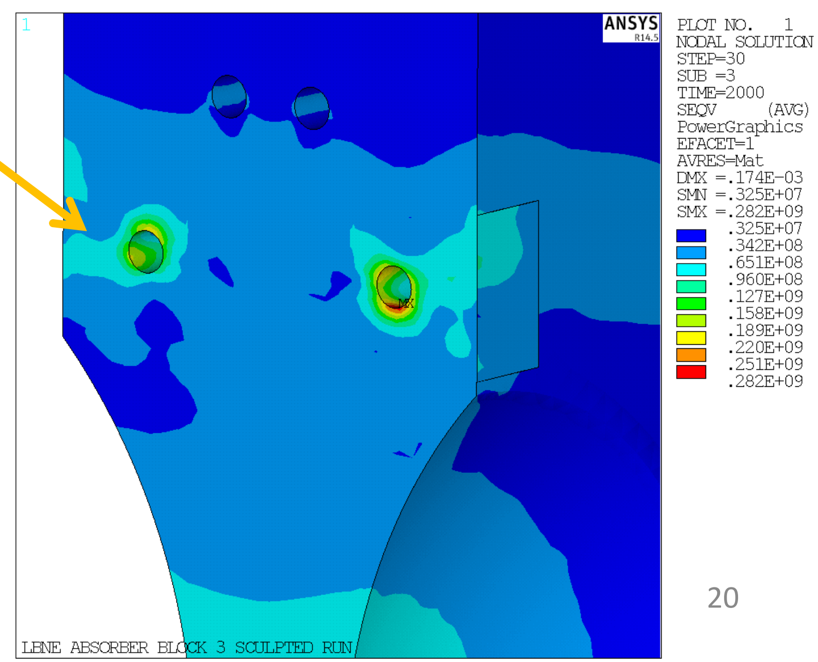


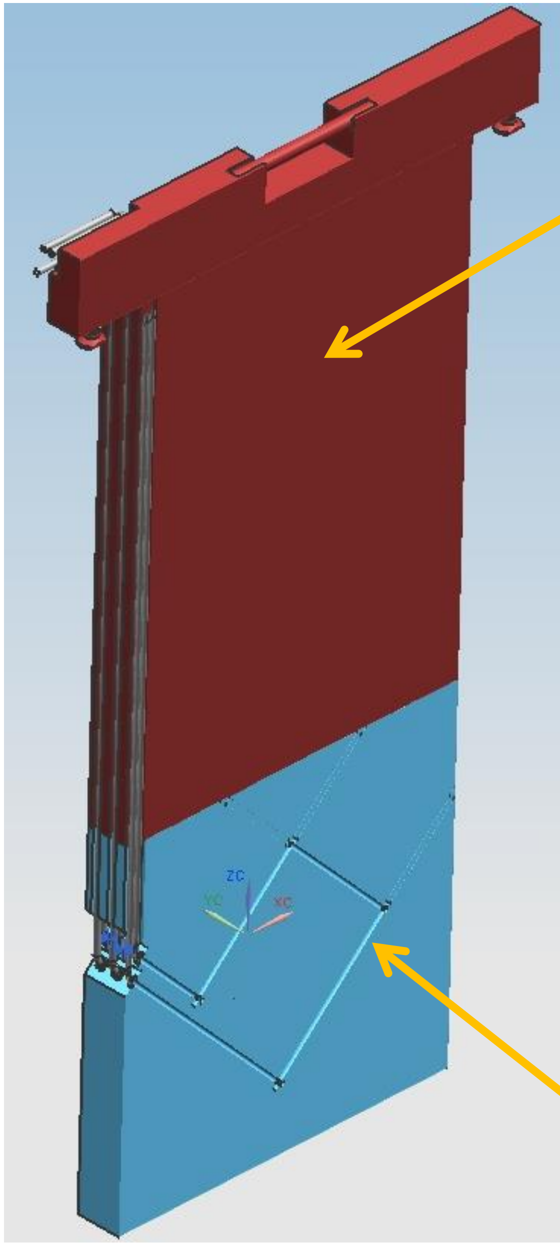
Accident conditions

- Two cases:
  - On-axis: Target is ‘missing’ and beam travels through the sculpted area of the core. (Results not yet available)
  - Off-axis: Beam is mis-steered around the target but misses the baffle. Worst case for the absorber is hitting the water line.

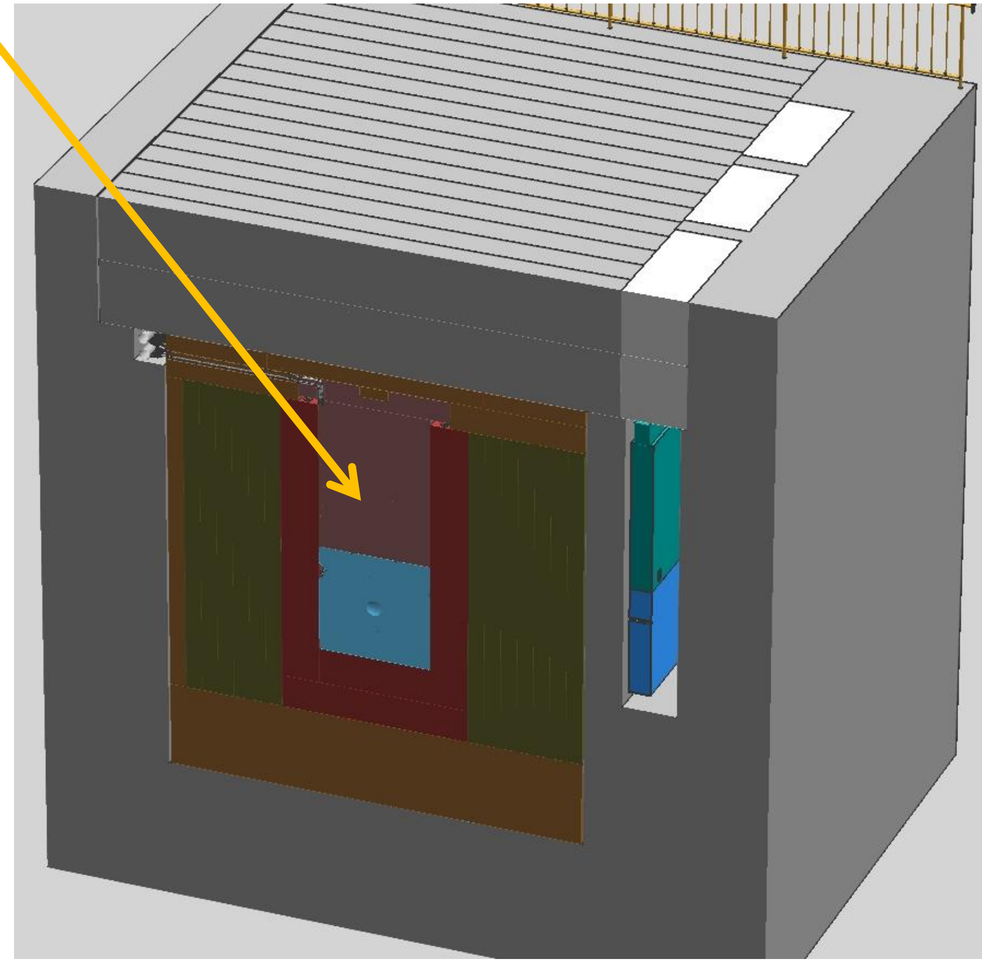




Mechanical design



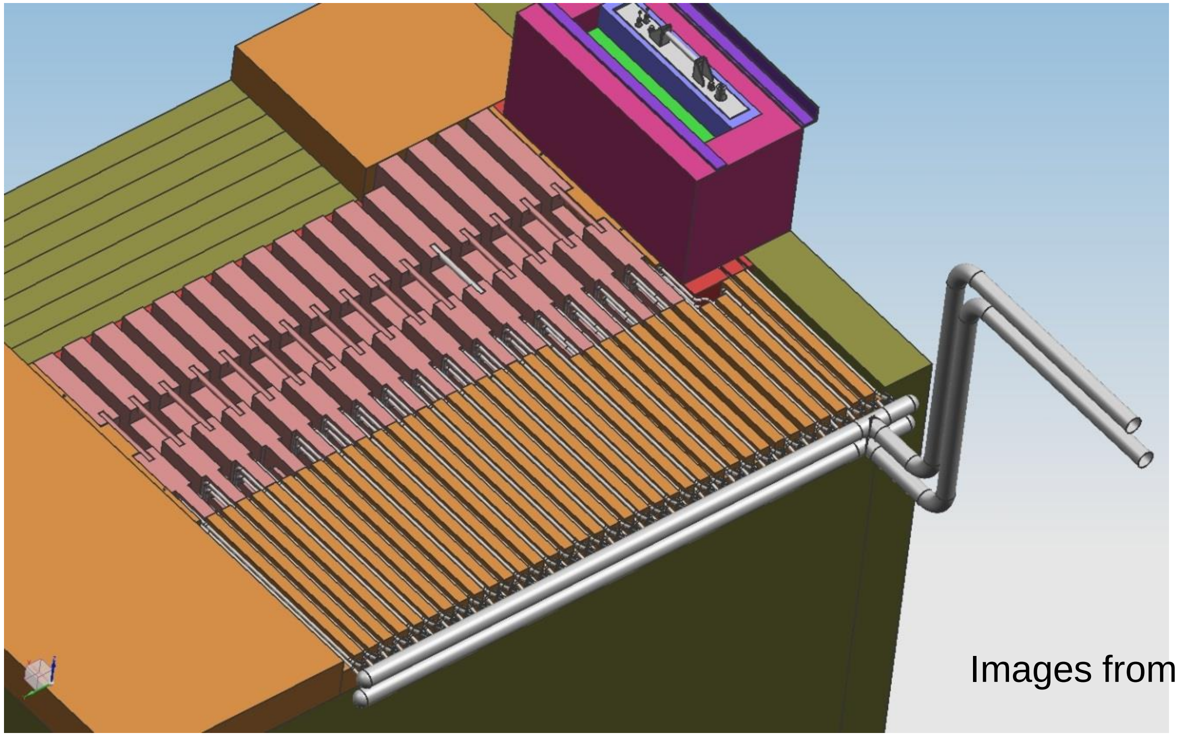
Each block is removable and replaceable



Images from: Vladimir Sidorov

Gun drilled water cooling loops

Mechanical design



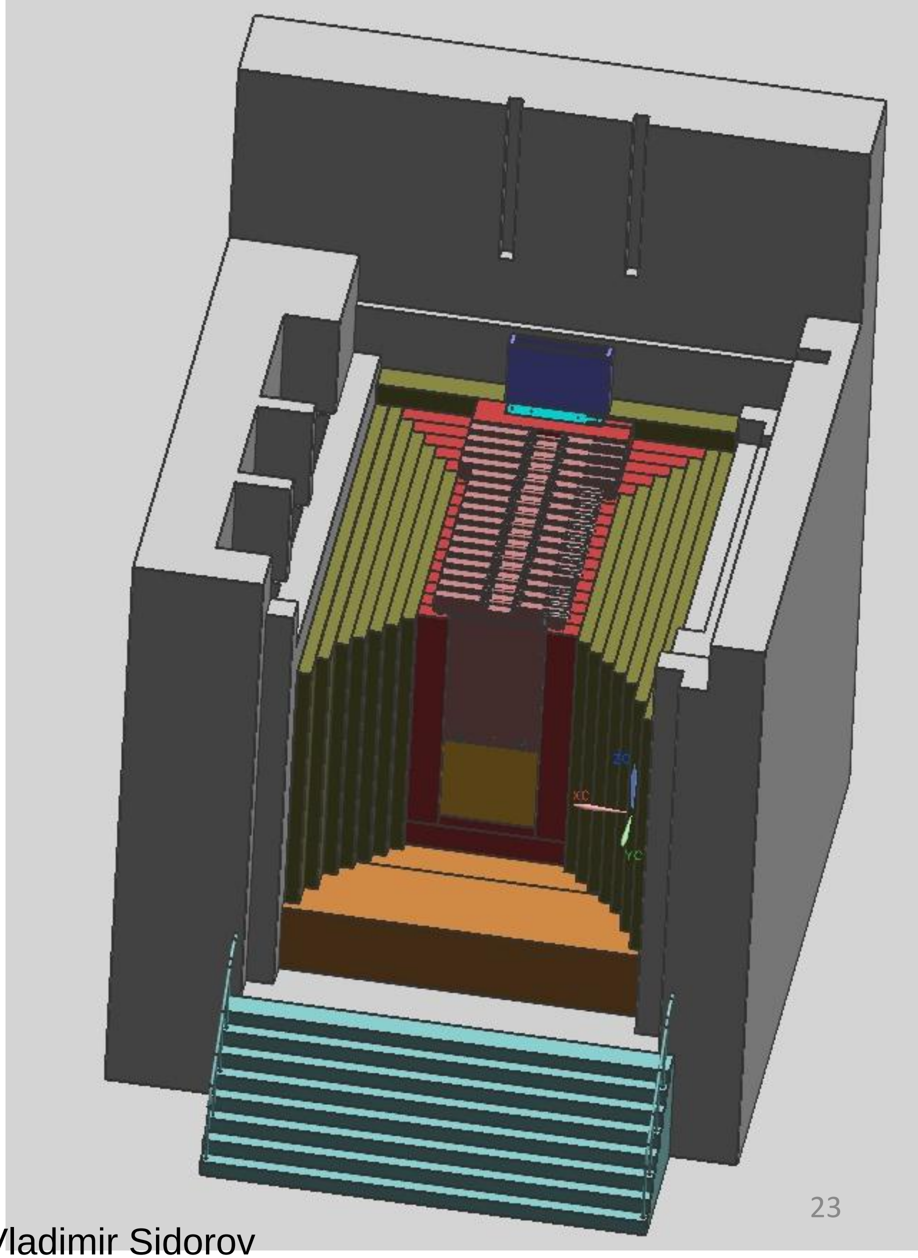
Images from: Vladimir Sidorov

- 8-1” diameter water lines (4 in/4 out) leading to each block.
- Flow rate of 20gpm to each line

Mechanical design

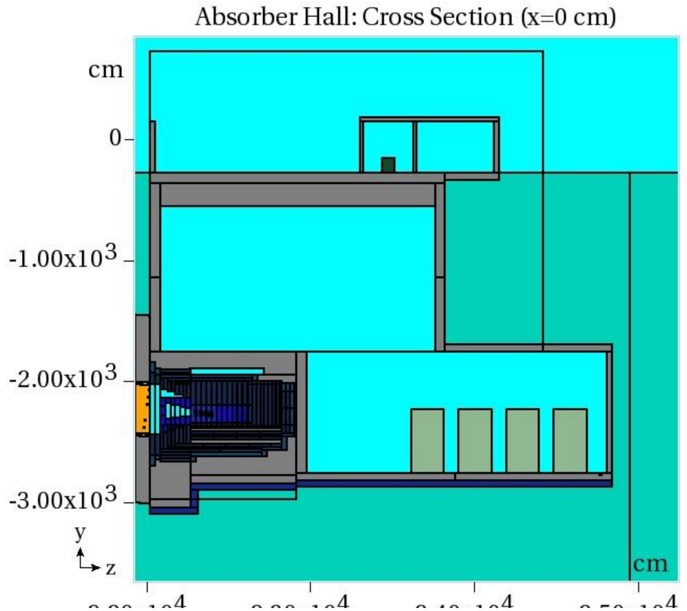
- Stackup of core blocks, outer steel shielding, and concrete shown on image at the right.

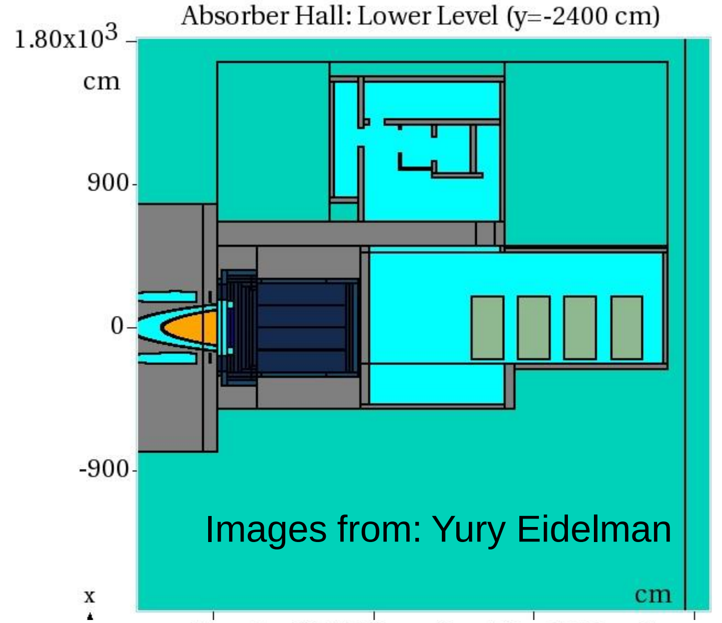
- Morgue areas shown on the left side.



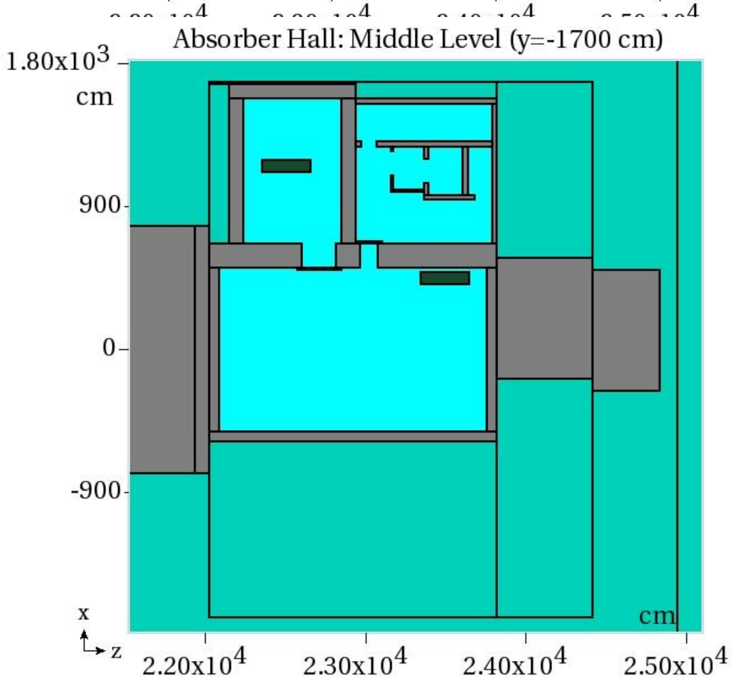
Images from: Vladimir Sidorov

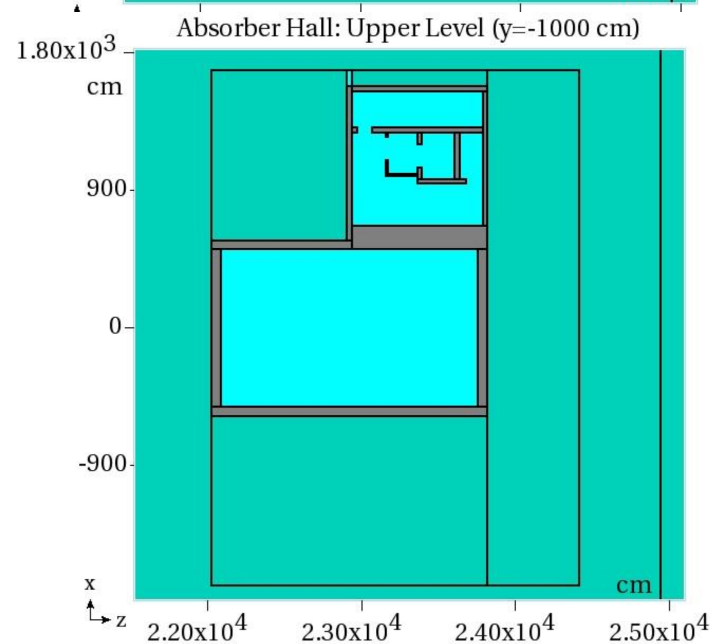
Radiological - Geometry



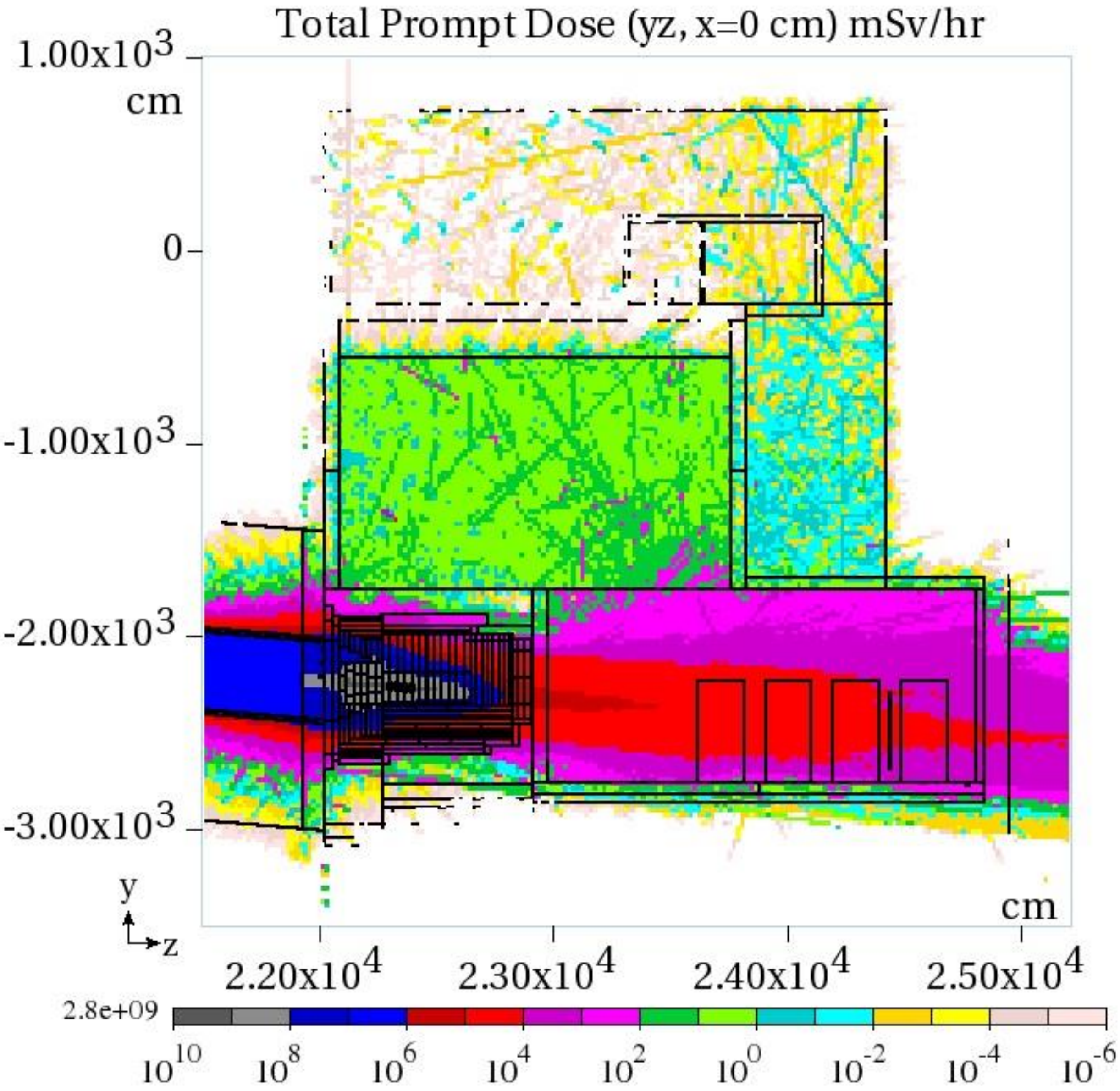


Images from: Yury Eidelman





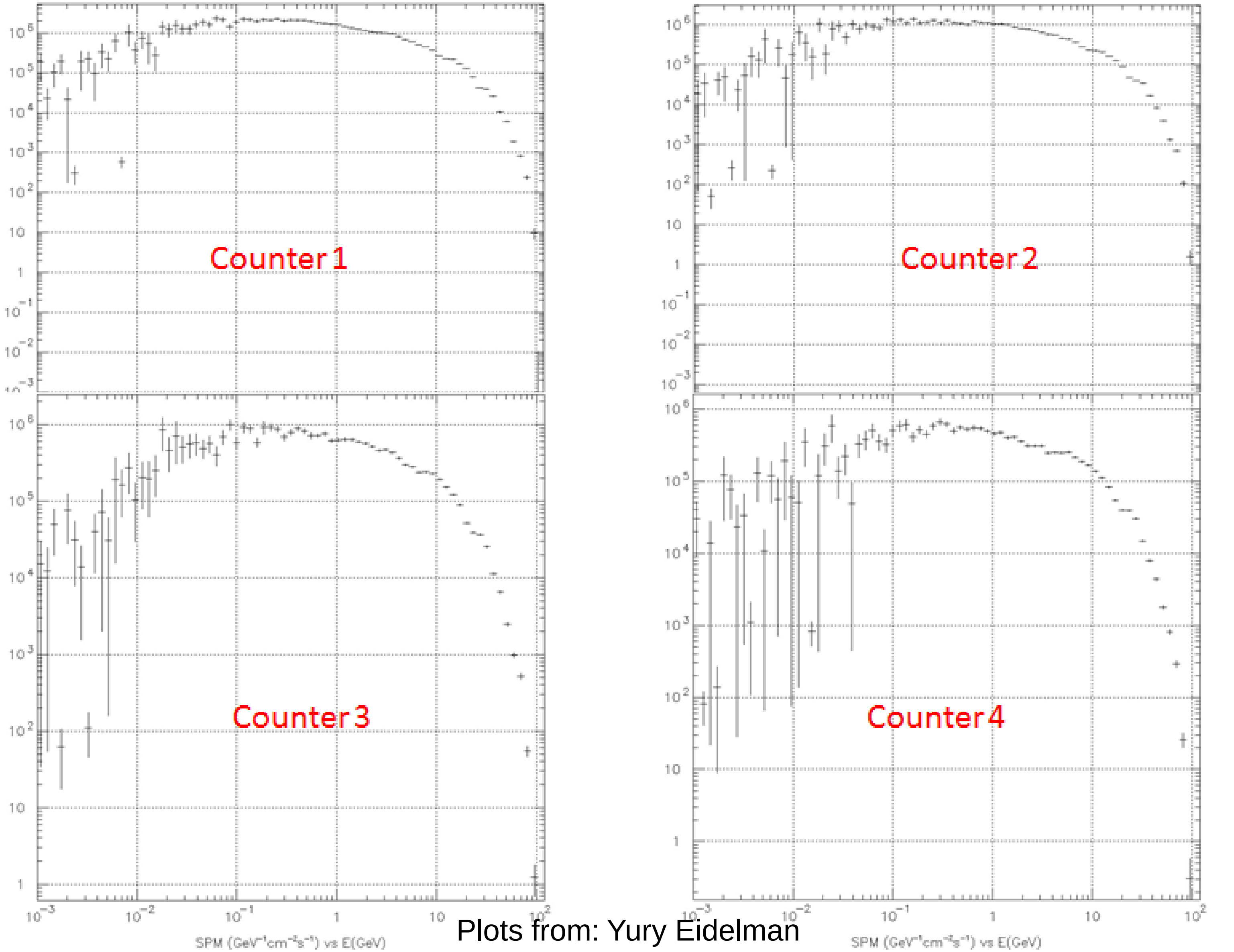
Radiological – Prompt Dose



Images from: Yury Eidelman

Radiological – Muon Monitor

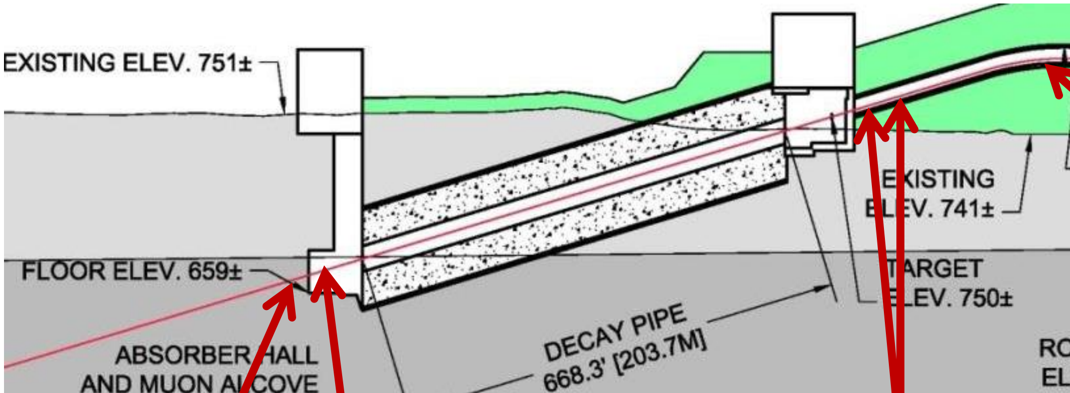
Muon Spectra (160M Incident Particles)



Plots from: Yury Eidelman

Safety Systems

Three independent systems provide redundancy
to pull beam permit quickly in non-normal condition



- **Beam position monitors** upstream of target
  - Pull beam permit after 1 beam spill if proton trajectory is off, misses target
- **Thermocouples** in absorber core
  - with thermocouple on-axis in shower, provides fast response (detect Energy deposition in thermocouple itself)
- **Muon monitor** after absorber combined with **Toroid proton monitor** before target
  - Can pull beam permit after 1 beam spill, if muon response is not proportional to number of protons in spill

Slide from: Jim Hylen

Conclusions and To-Do

- A viable Al core configuration has been rapidly developed through multiple iterations in only 9 months.
- Now that the core configuration has been finalized, work on the radiological and mechanical design portions can continue more quickly and with greater certainty.
- Additional analysis needs to be done for the 60 GeV case.
- Upcoming core review in November.