Target chase, decay and absorber cooling for LBNE

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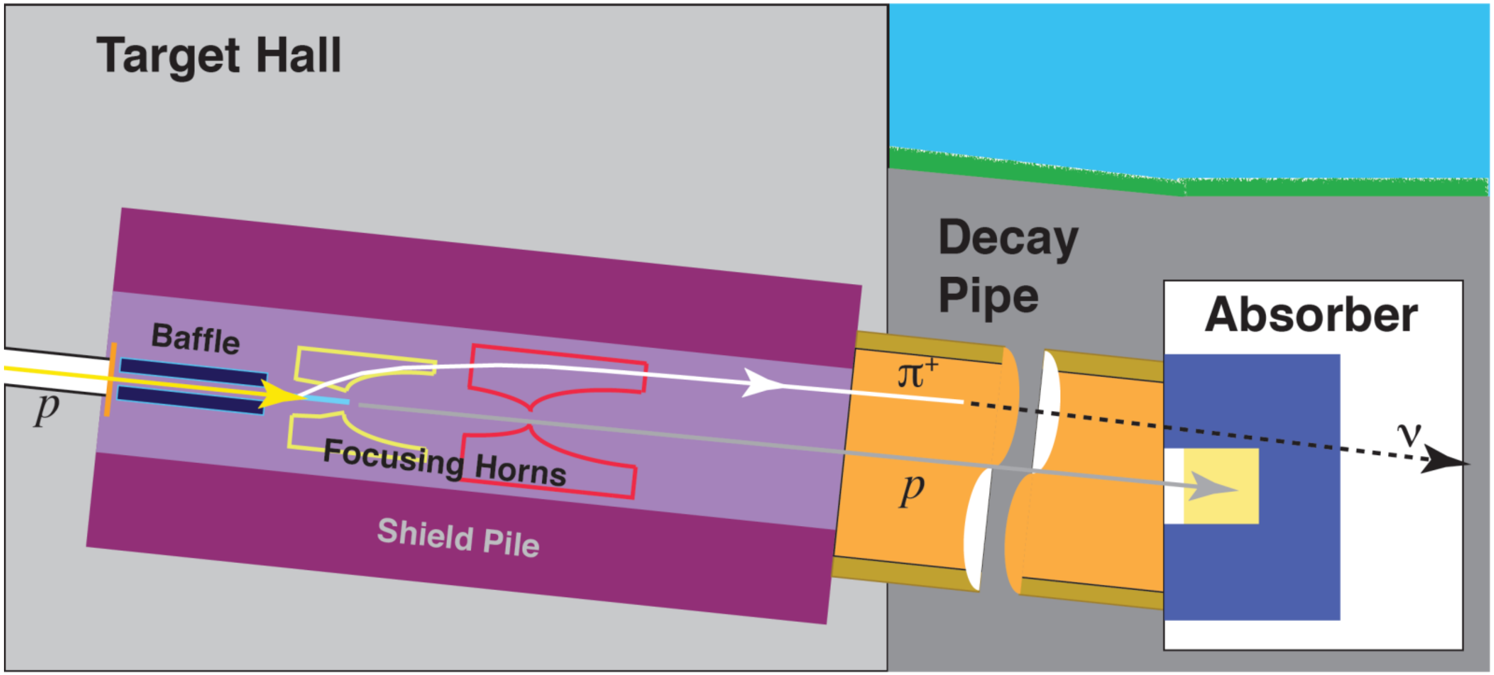
- **High beam-induced heat loads!**
- **LBNE cooling for target chase and decay pipe**
  - base design
    - 700 kW: air cooling only
    - 2.3 MW: add water cooling panels in target chase
- **LBNE cooling for absorber**
- **Final considerations**

Power Dissipation in Main Components



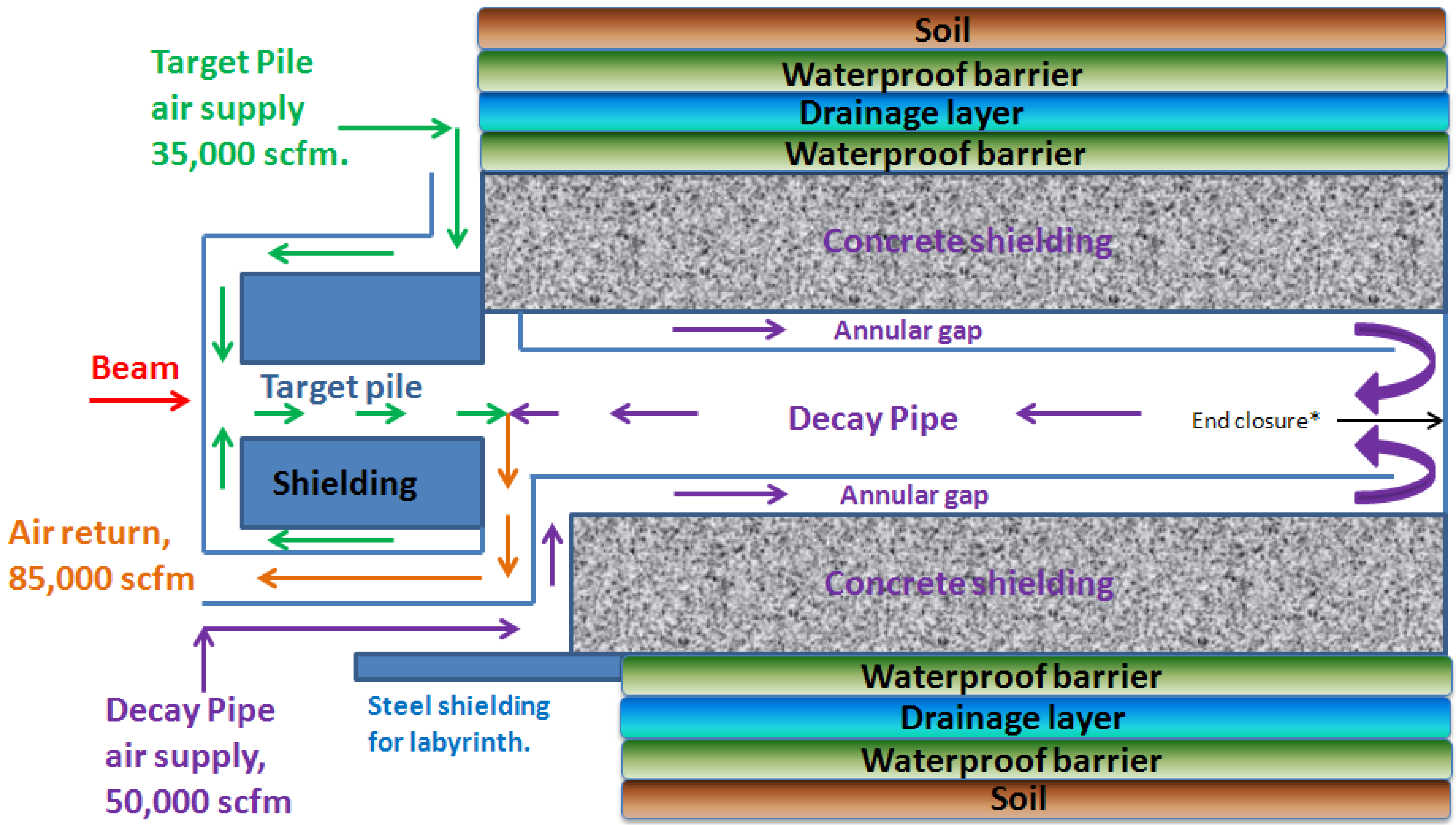
Name	Target	Horns	Target chase shield	Decay pipe	Decay channel shield	Absorb. systems
kW	47	154	629	287	244	540

Target pile and decay pipe cooling

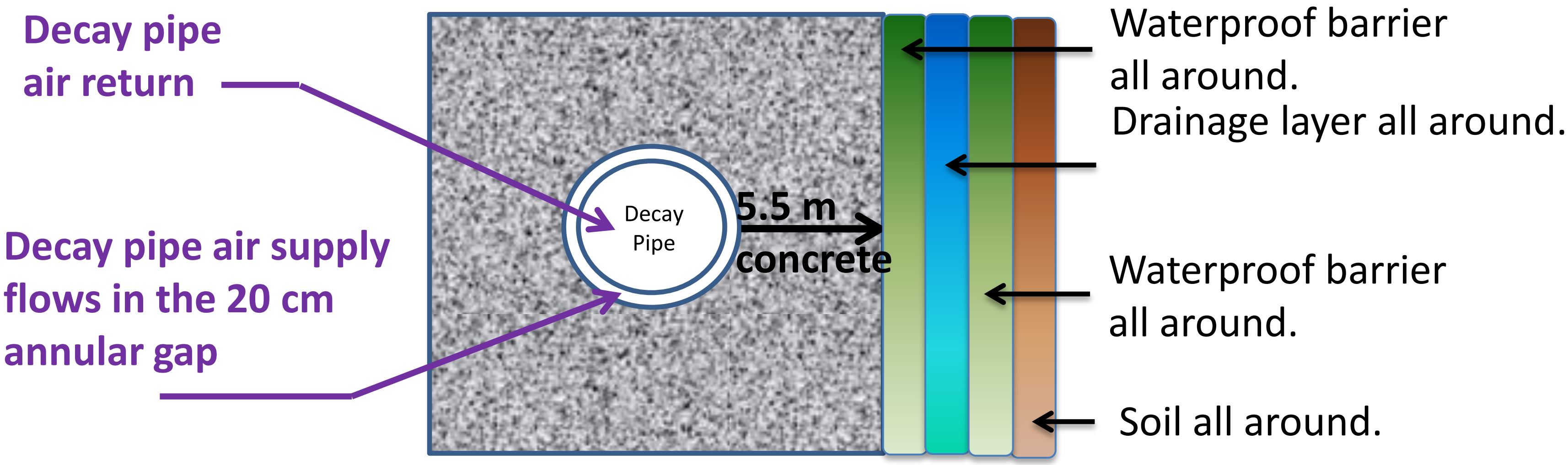
- **The base design is to have**
  - air cooled decay pipe, with air flowing at high velocity in the annular gap of two concentric decay pipes
  - air cooled target pile at 700 kW and a combination of air cooling and water cooling at 2.3 MW
  - common air supply for target pile and decay pipe at 15 °C.
- The reference design has an airflow rate of 50,000 scfm for the decay pipe
- The NuMI target pile has an airflow rate of 25,000 scfm at 700 kW
- Scaling from the 46” NuMI chase width to the 54” LBNE chase width, increases the LBNE target pile airflow rate to 35,000 scfm for 700 kW
  - for 700 kW, the 35,000 scfm airflow removes the energy deposited by the beam in the bulk steel shielding
  - for 2.3 MW, water cooling removes about 80% of the deposited energy and the balance is removed by the 35,000 scfm airflow

Target Chase and Decay Pipe airflow schematic

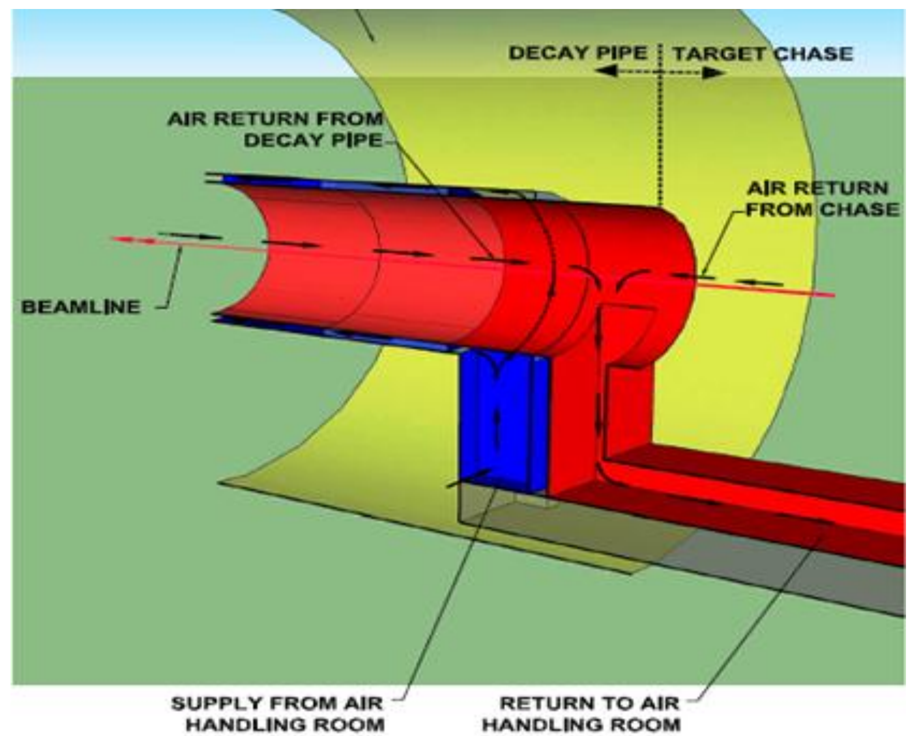
*End closure cooled by airflow.



Decay Pipe Design



- **Inner pipe**: **½" thick**, corrosion-protected mild carbon steel, supported on outer pipe with radial supports, **4 m inside diameter**.
- **Outer pipe**: **½" thick**, corrosion-protected mild carbon steel, embedded in shielding concrete, **4.4254 m inside diameter**.
- Annular airflow gap between the concentric pipes is 20 cm.



Decay Pipe Cooling

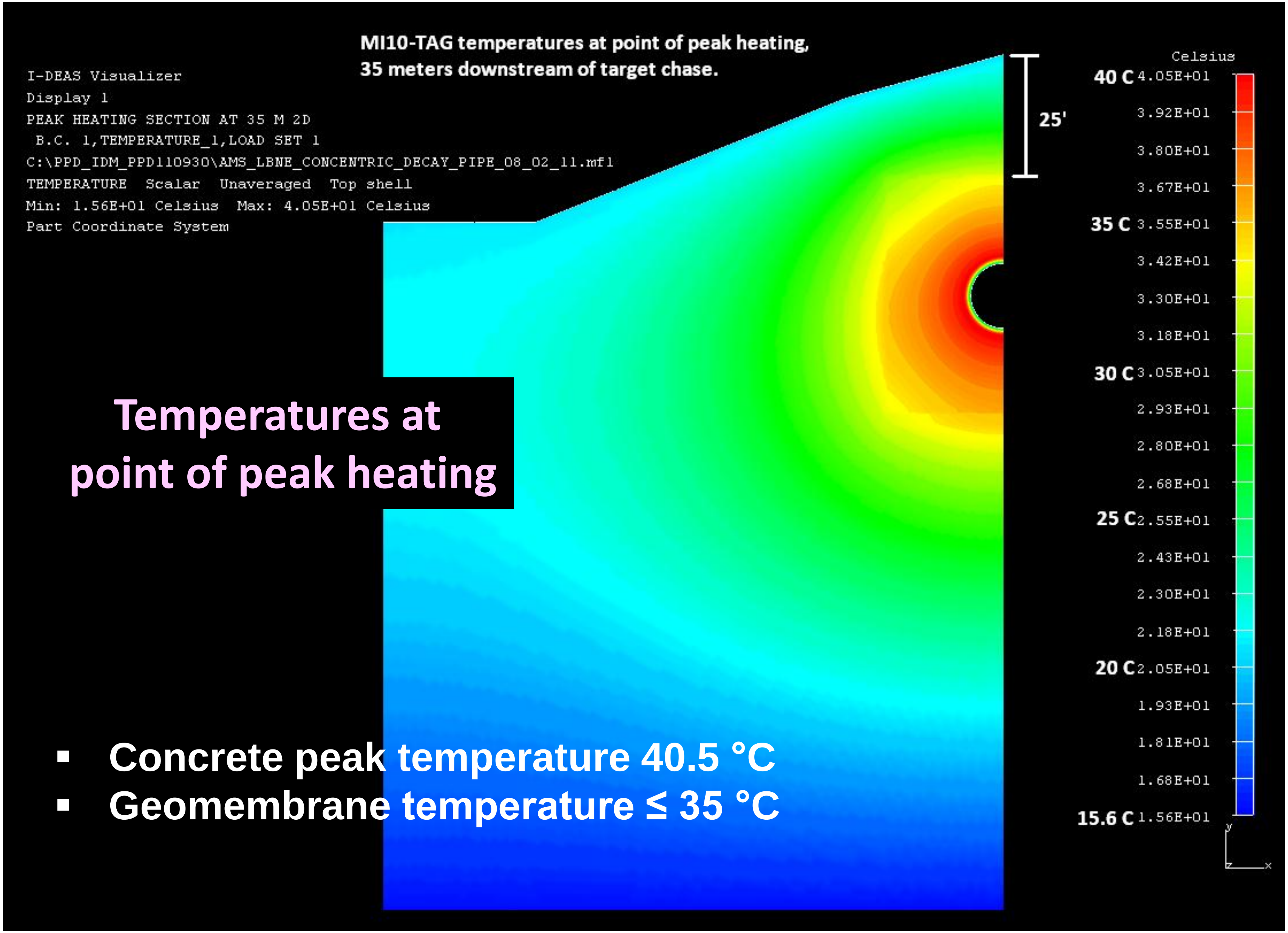
- **The inner ½" thick steel pipe absorbs 56% of the energy before it can reach the concrete, and the annular air gap prevents that heat from being conducted out to the concrete**
- Peak heating is 35 m from upstream end of decay pipe
- Closed air loop, 50,000 scfm flow rate, high velocity ➡ heat transfer coefficient 21 W/m^2K
- Air supply temperature = 15 °C (59 °F)
- Air exit temperature from decay pipe = 33 °C (91.4 °F)
- **All operating temperatures are a concern but geomembrane temperature is a major concern**
- Geomembrane service life is a function of temperature.
- Detailed information only available for HDPE
  - Geomembrane "strength half-life" from Rowe (2005)

    130 yrs @ 35^o C

    80 yrs @ 40^o C

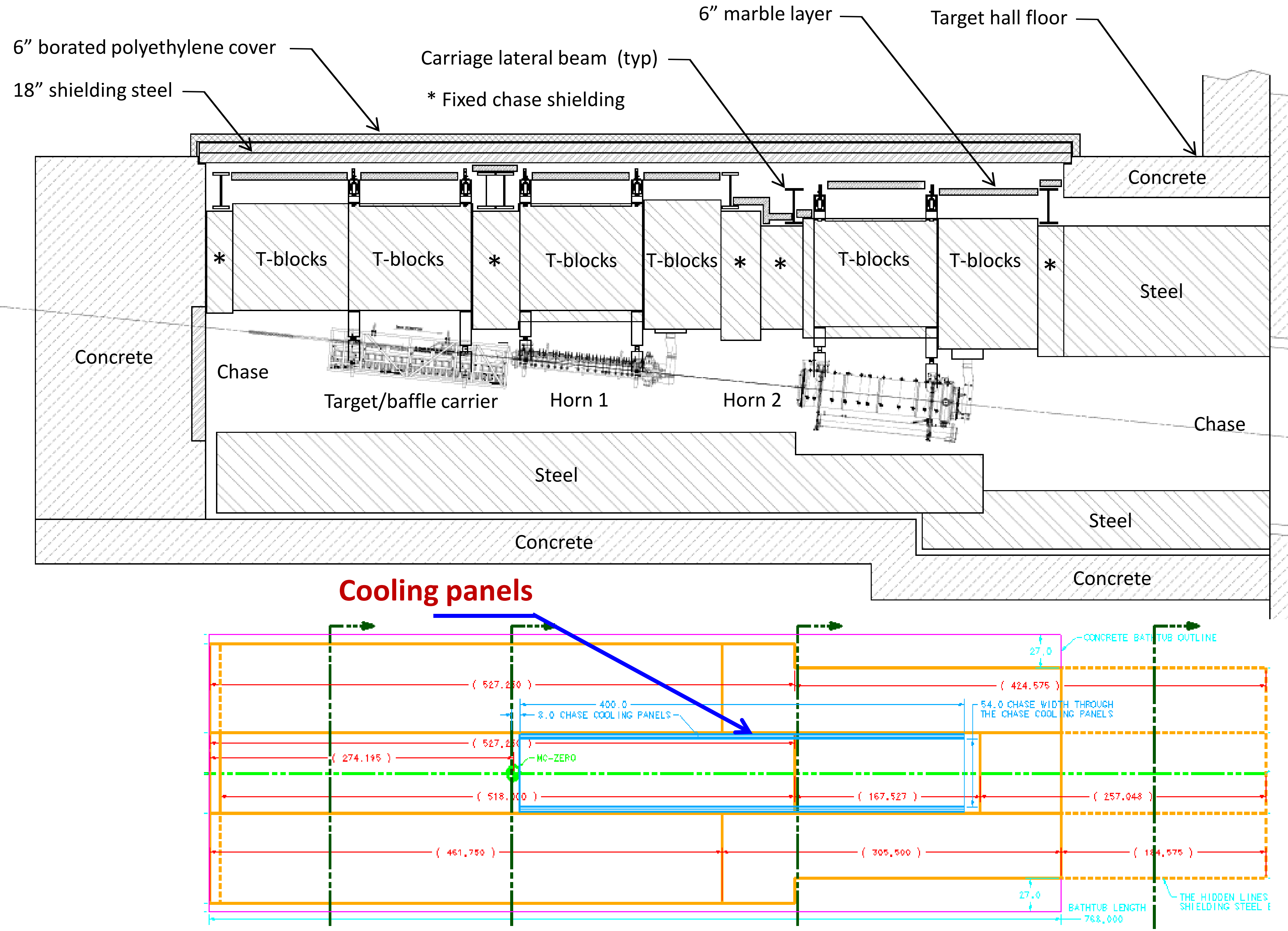
    35 yrs @ 50^o C

Decay Pipe Cooling Analysis



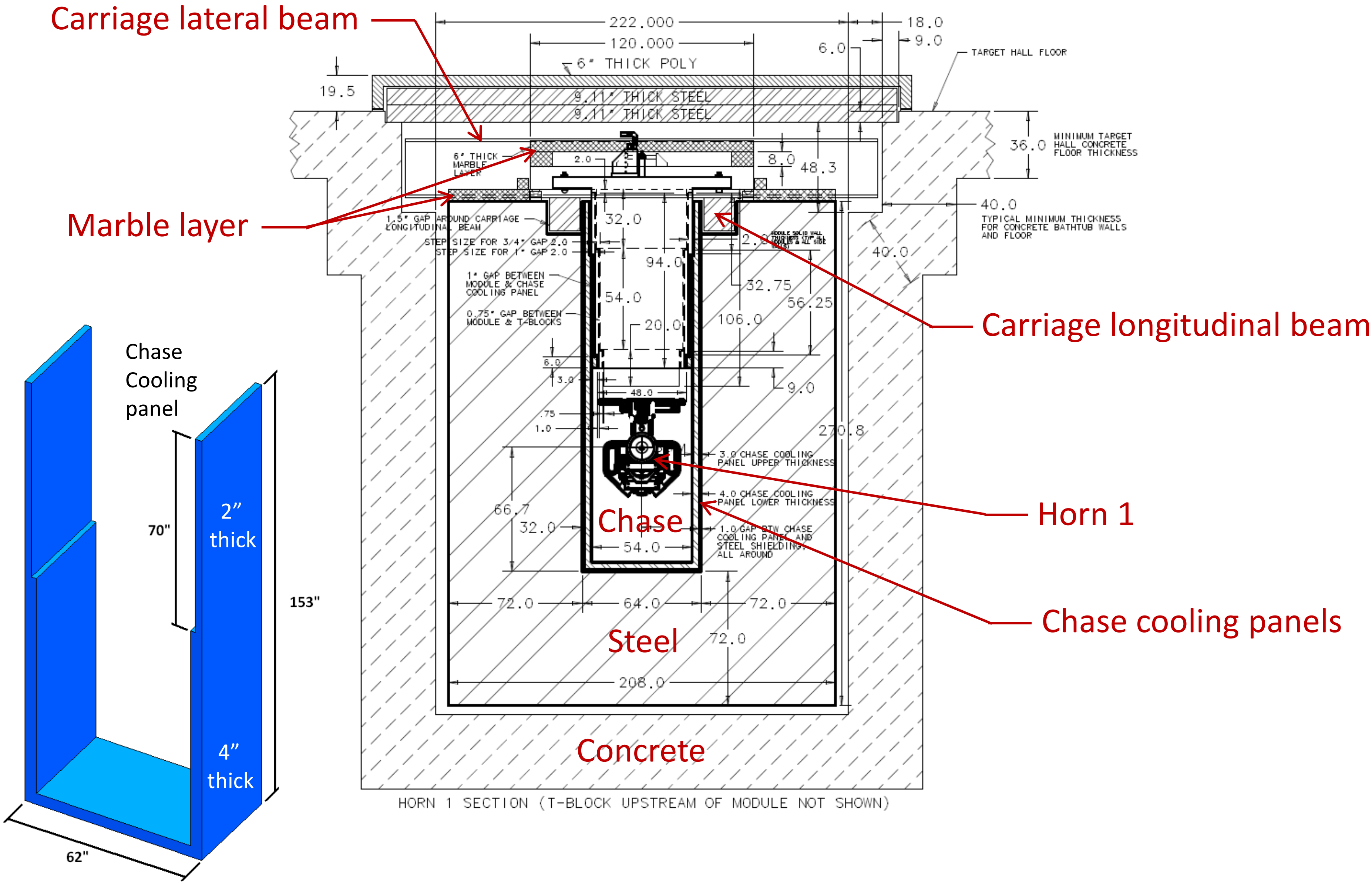
Temperatures at point of peak heating

- Concrete peak temperature 40.5 °C
- Geomembrane temperature ≤ 35 °C

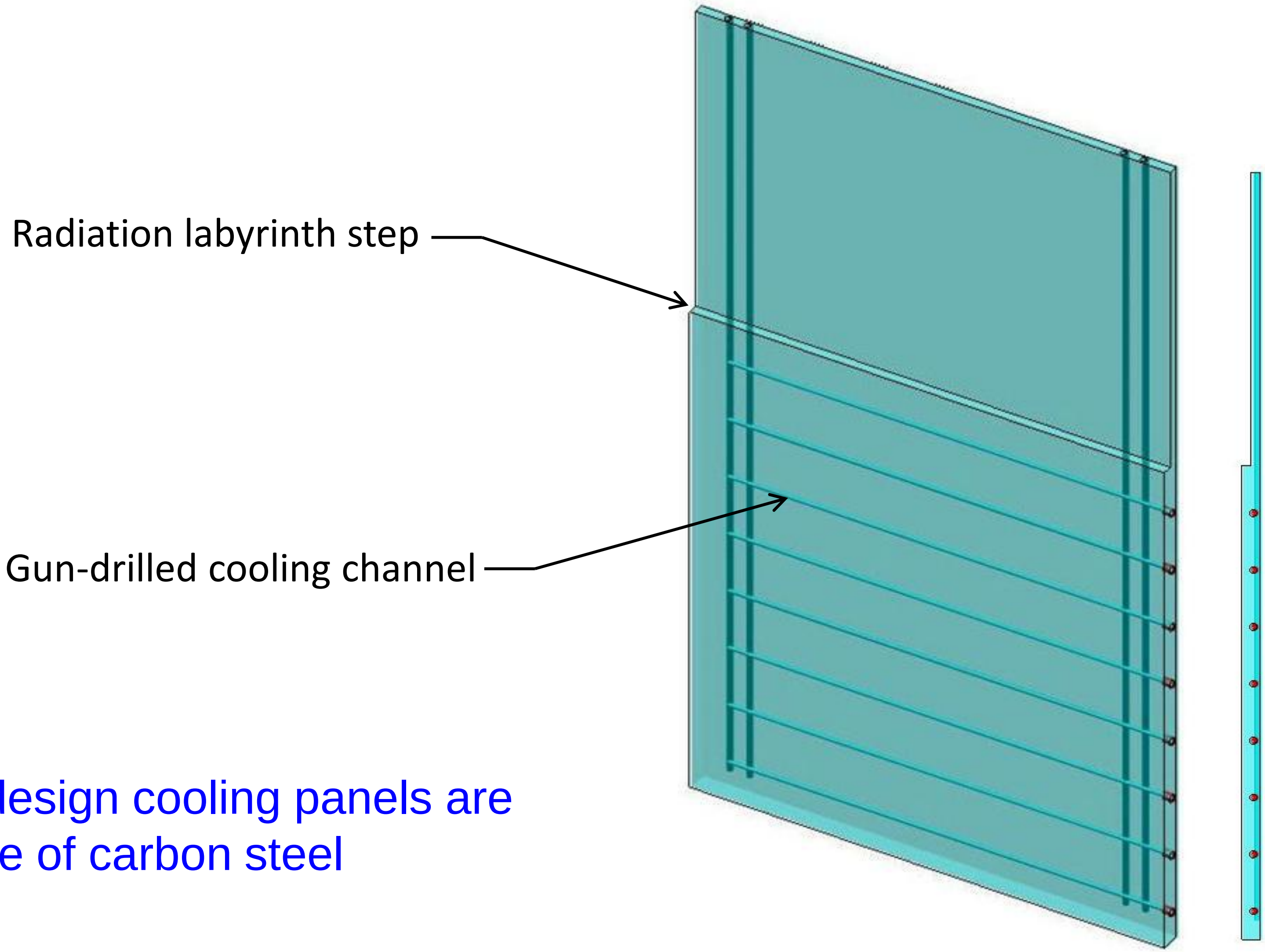


6” borated polyethylene cover
18” shielding steel
Carriage lateral beam (typ)
* Fixed chase shielding
6” marble layer
Target hall floor
Concrete
T-blocks
*
Steel
Chase
Target/baffle carrier
Horn 1
Horn 2
Cooling panels
CONCRETE BATHTUB OUTLINE
27.0
(424.575)
400.0
8.0 CHASE COOLING PANELS
54.0 CHASE WIDTH THROUGH THE CHASE COOLING PANELS
(274.195)
MC-ZERO
(167.527)
(257.048)
(461.750)
(305.500)
BATHTUB LENGTH
768.000

Target Hall Shield Pile Design



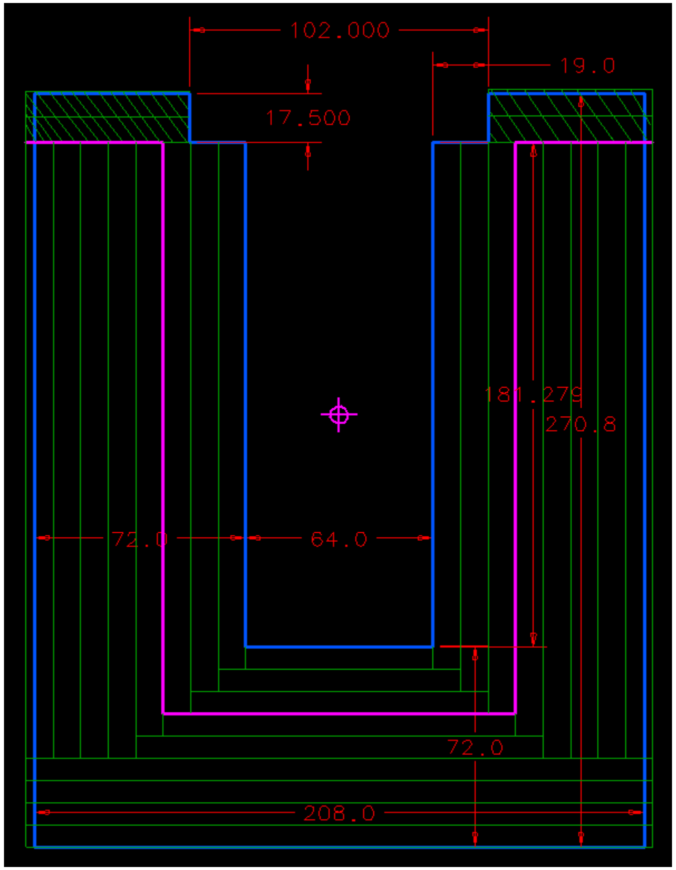
Target Hall cooling panels



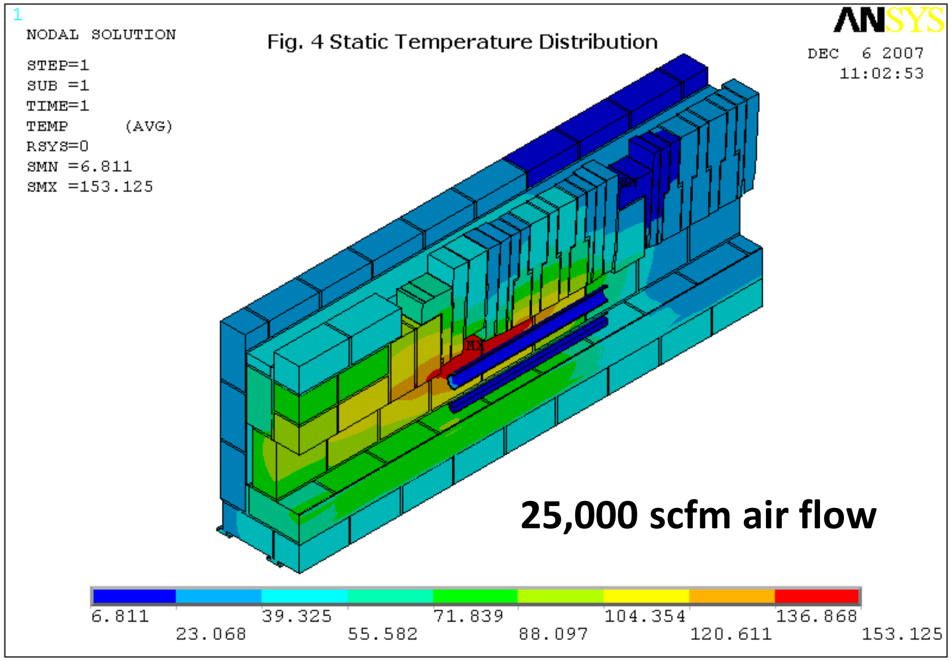
In the base design cooling panels are made of carbon steel

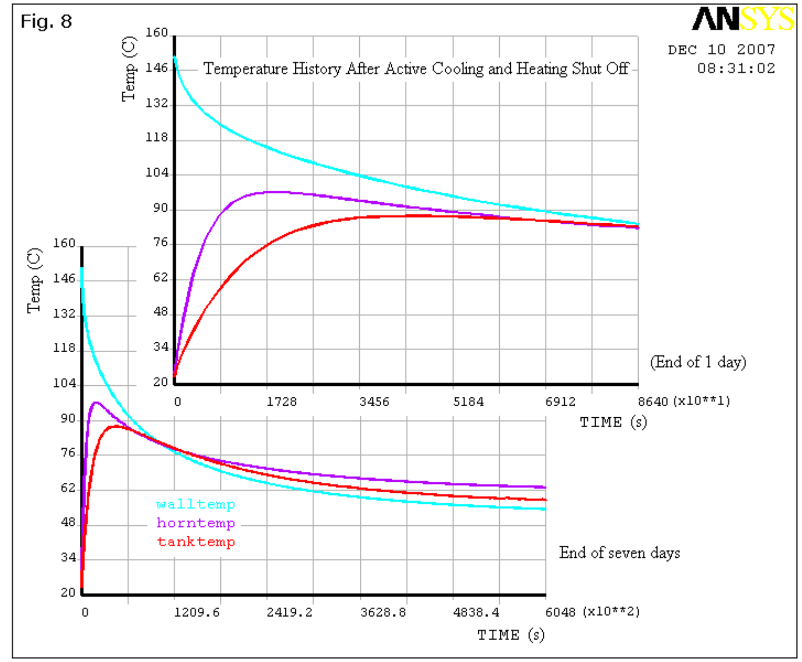
Target Hall Shield Pile "Air Block"

- NuMI target pile air block sheet. It is placed between bulk shielding layers.
- LBNE target pile air block sheet:



FEM 3-D Thermal Analysis of NuMI @ 700 kW

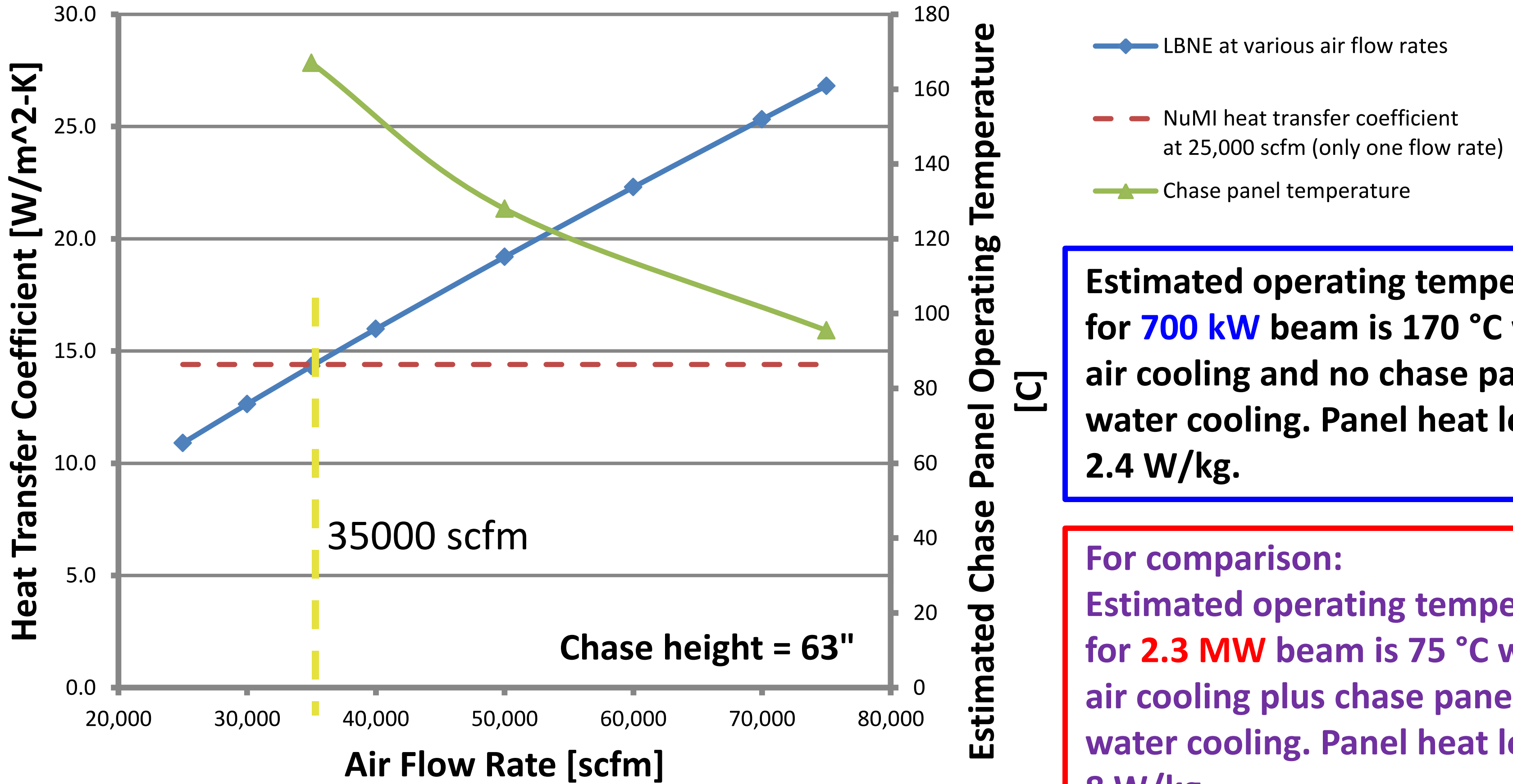




- A 3D thermal finite element model has been developed for NuMI target hall shielding blocks.
- For the 700 kW ME configuration, the **maximum static temperature is 153C** on the chase side wall (“blue-block”), and it is towards the downstream end of Horn 1.
- The radiation heat to horn and water tank is 4,290 watts. **After all active cooling and heat are shut off, the horn temperature will not exceed 100 C.**

LBNE Target Hall Shield Pile Cooling

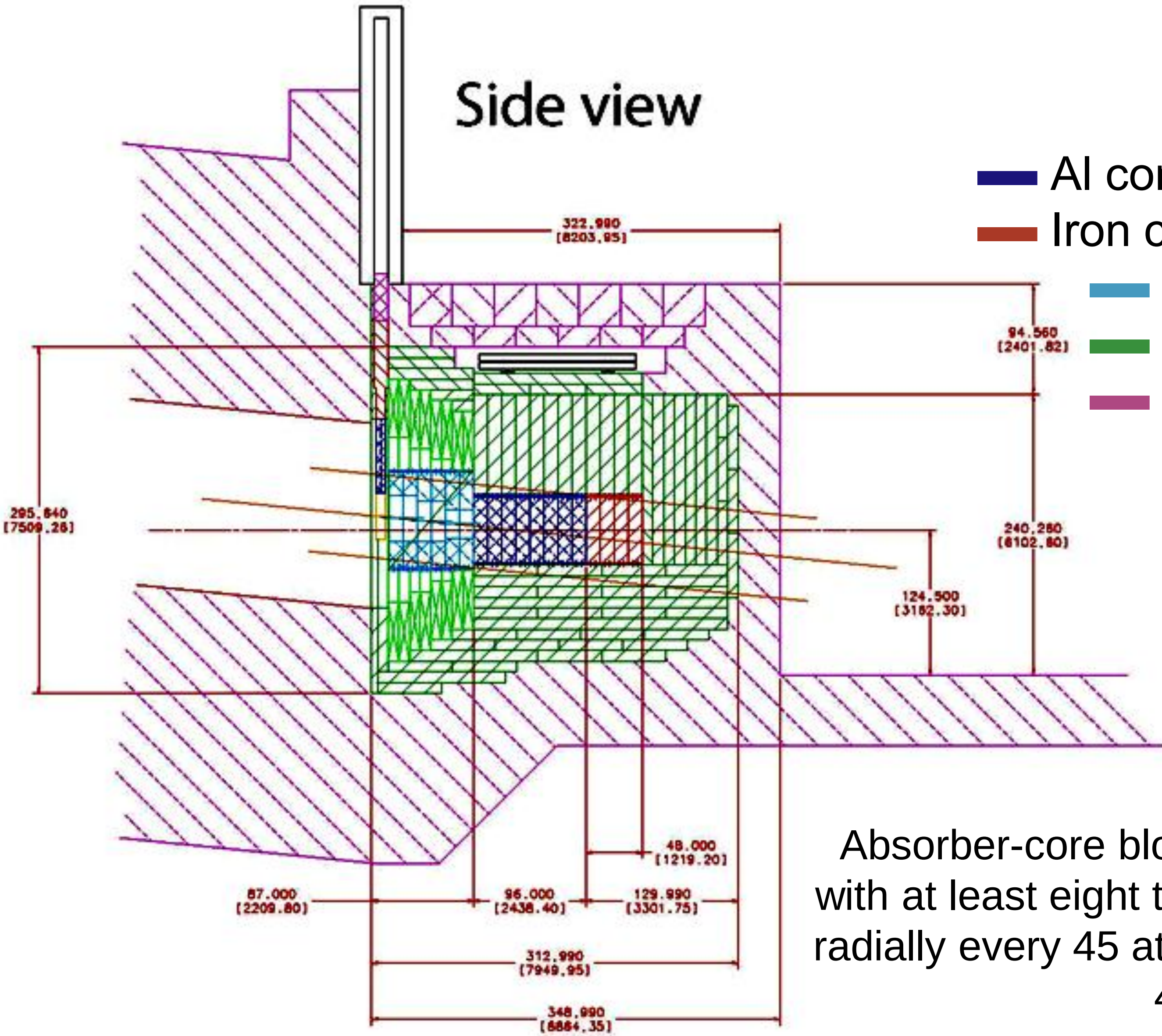
Heat Transfer Coefficient vs Air Flow Rate For LBNE Chase: 700 kW beam, air cooling, chase cooling panels installed but no cooling water, at Largest Empty Cross Sectional Flow Area



Estimated operating temperature for 700 kW beam is 170 °C with air cooling and no chase panel water cooling. Panel heat load is 2.4 W/kg.

For comparison: Estimated operating temperature for 2.3 MW beam is 75 °C with air cooling plus chase panel water cooling. Panel heat load is 8 W/kg.

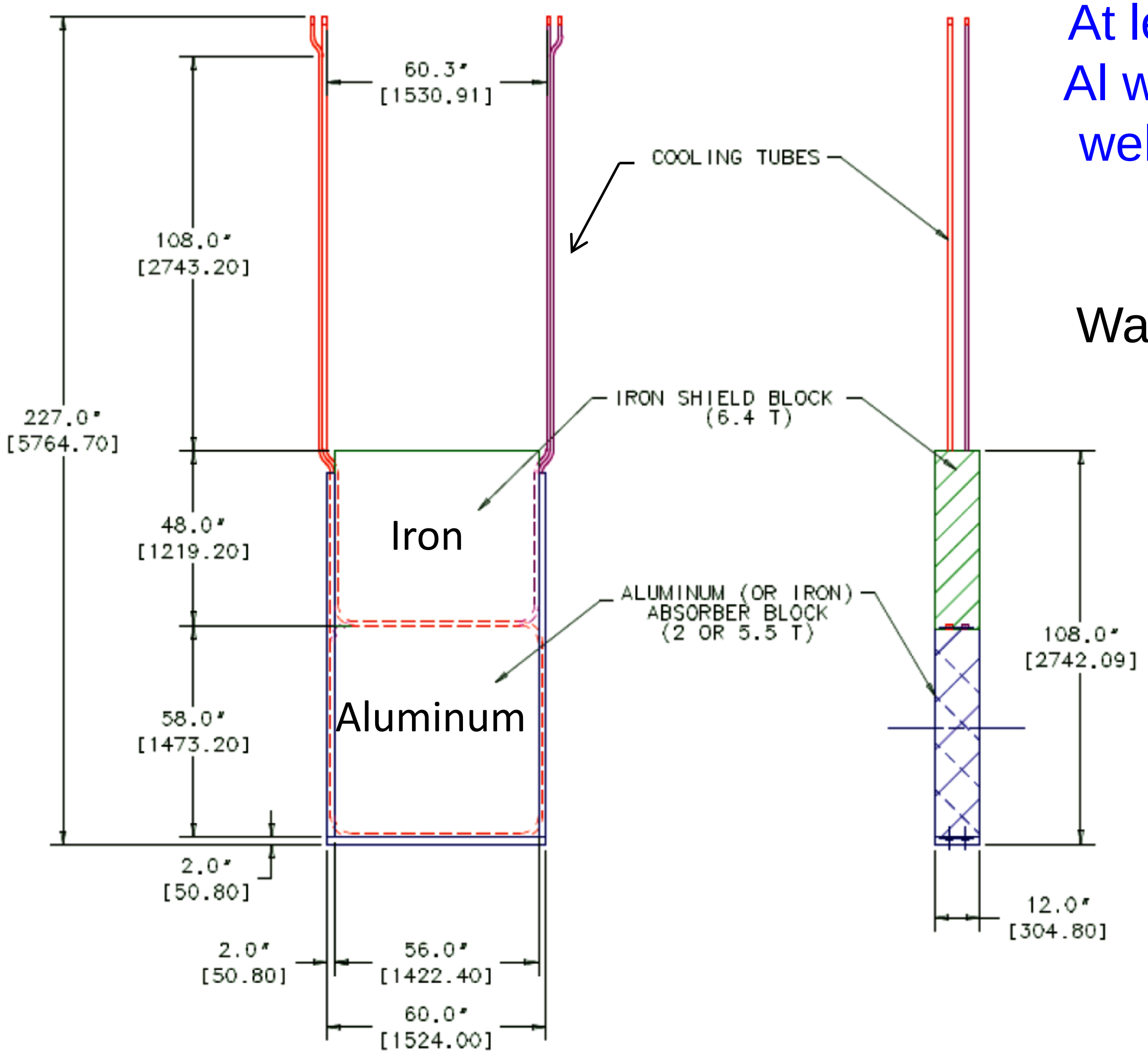
Absorber design



- Al core blocks (60”x60”x12”)
- Iron core blocks (60’x60”x12”)
- Al pre-mask
- Iron shielding blocks
- Concrete

Absorber-core blocks will be instrumented with at least eight thermocouples, distributed radially every 45 at a radius of approximately 400 mm

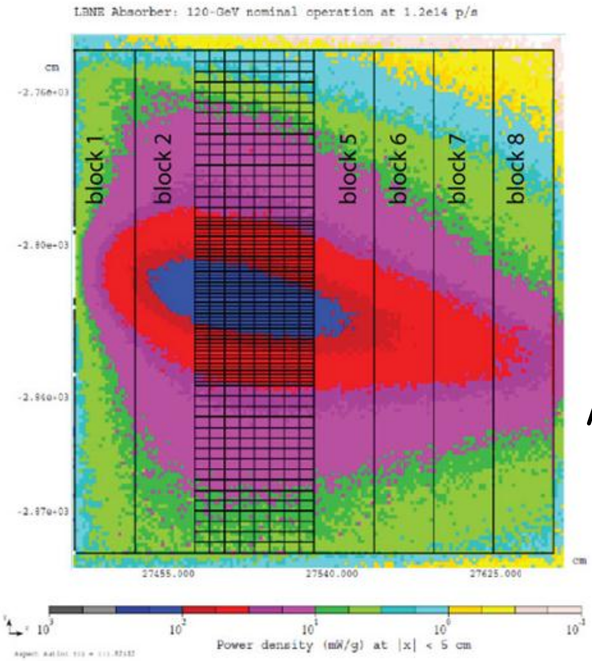
Absorber cooling



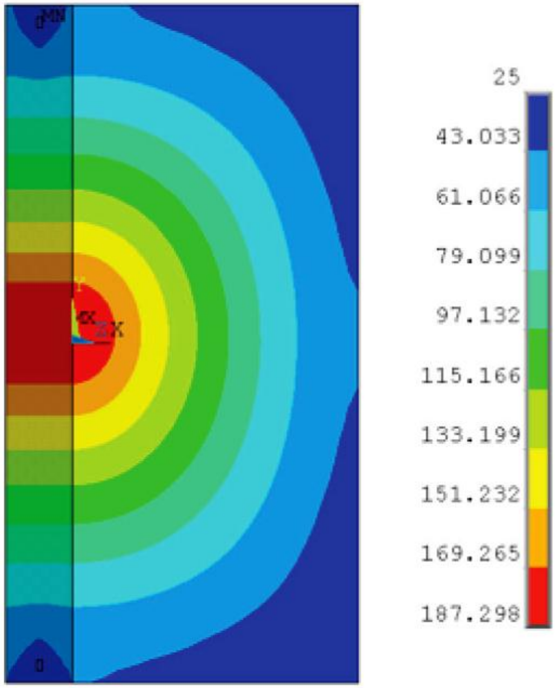
At least three continuous Al water-cooling lines are welded to the four sides of the core blocks

Water temperature 25 °C

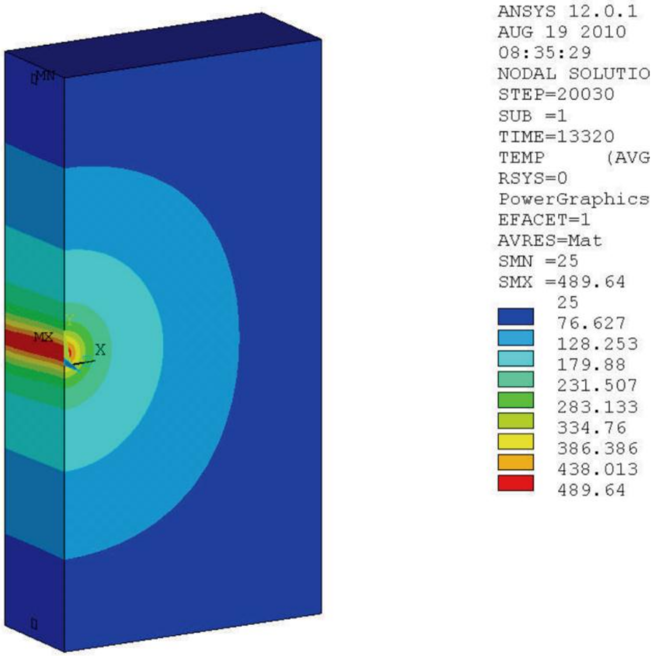
Absorber temperature analysis



Longitudinal energy deposition in the Al core, normal operation



Steady state temperature for the 3rd Al core block, normal operation



Accident condition, 15 direct beam pulses superimposed to steady conditions

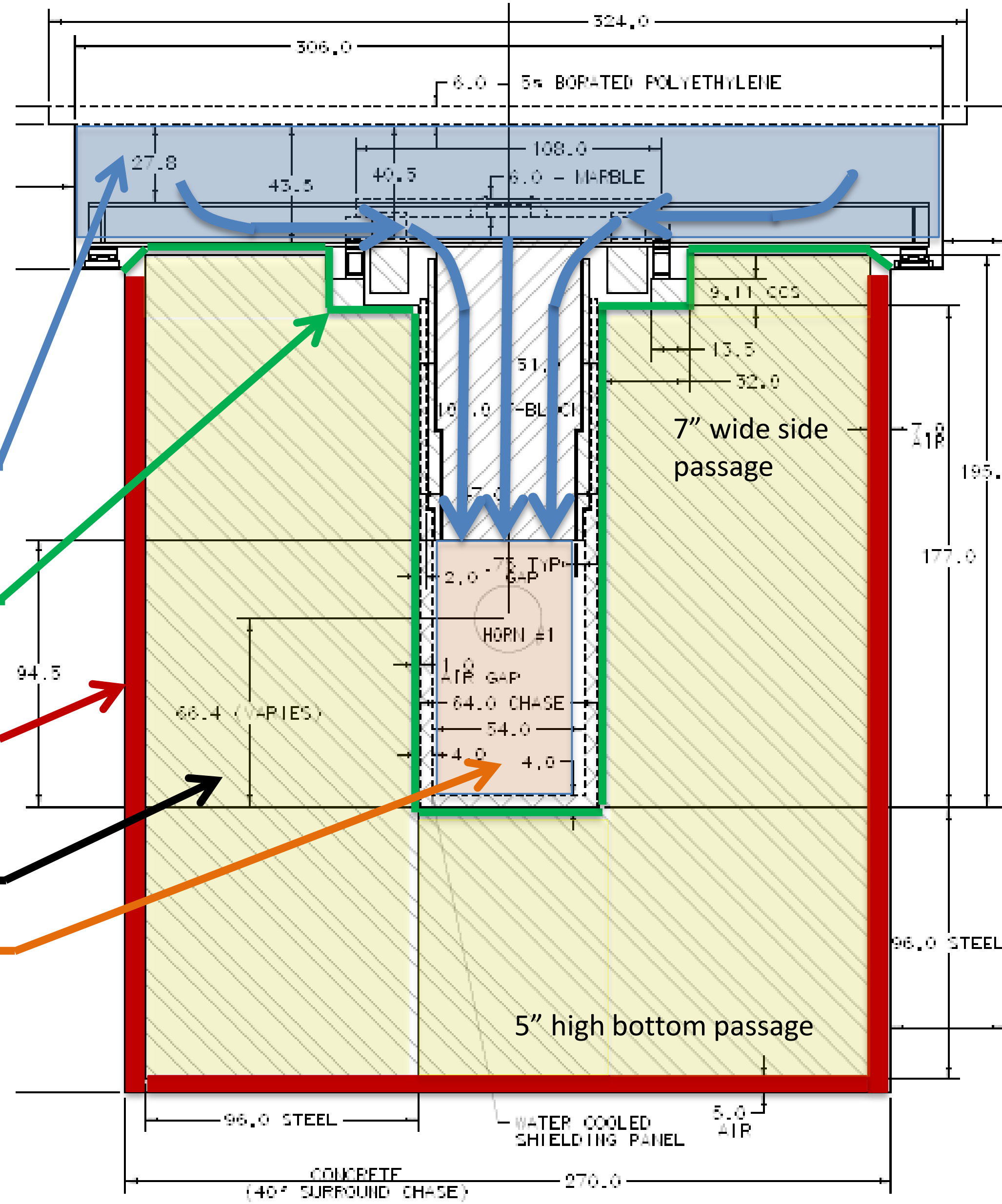
Final considerations

- Base design for cooling of target chase, decay pipe and absorber has been presented, still at the conceptual phase
  - radiological issues have been taken into account
- Experience with NuMI shows that tritium release and NOx induced corrosion can be minimized by dehumidification of air
- Still, need to consider the alternative of a He filled decay pipe (water cooled?)
  - increase in ν flux by 5-10%
  - presence of air limited to target chase, no transport of target chase air in decay pipe region
- Utilization of carbon steel for water cooling needs careful consideration
  - many thanks for sharing T2K experience

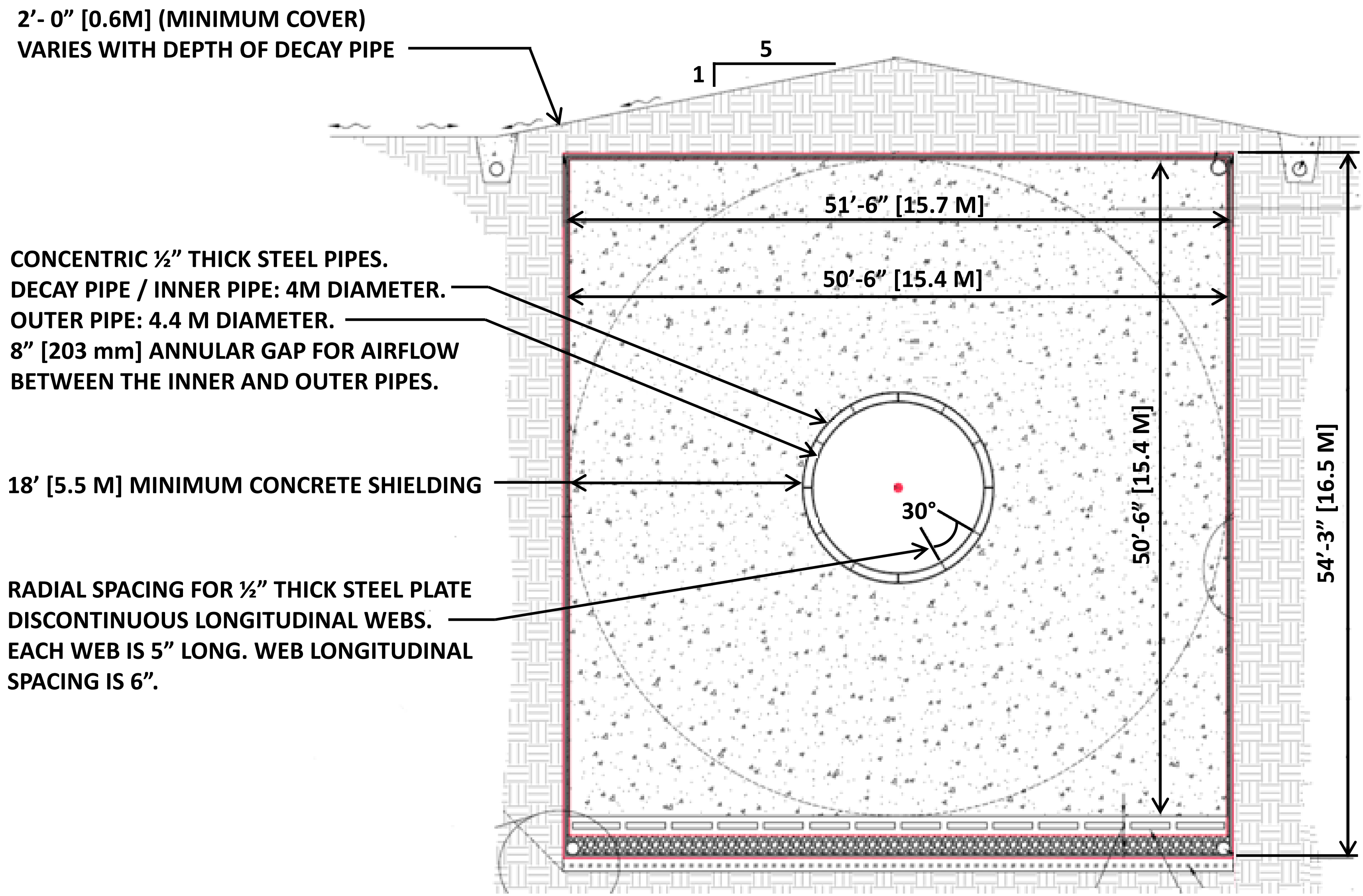
Backup

Target Hall Shield Pile Air Flow

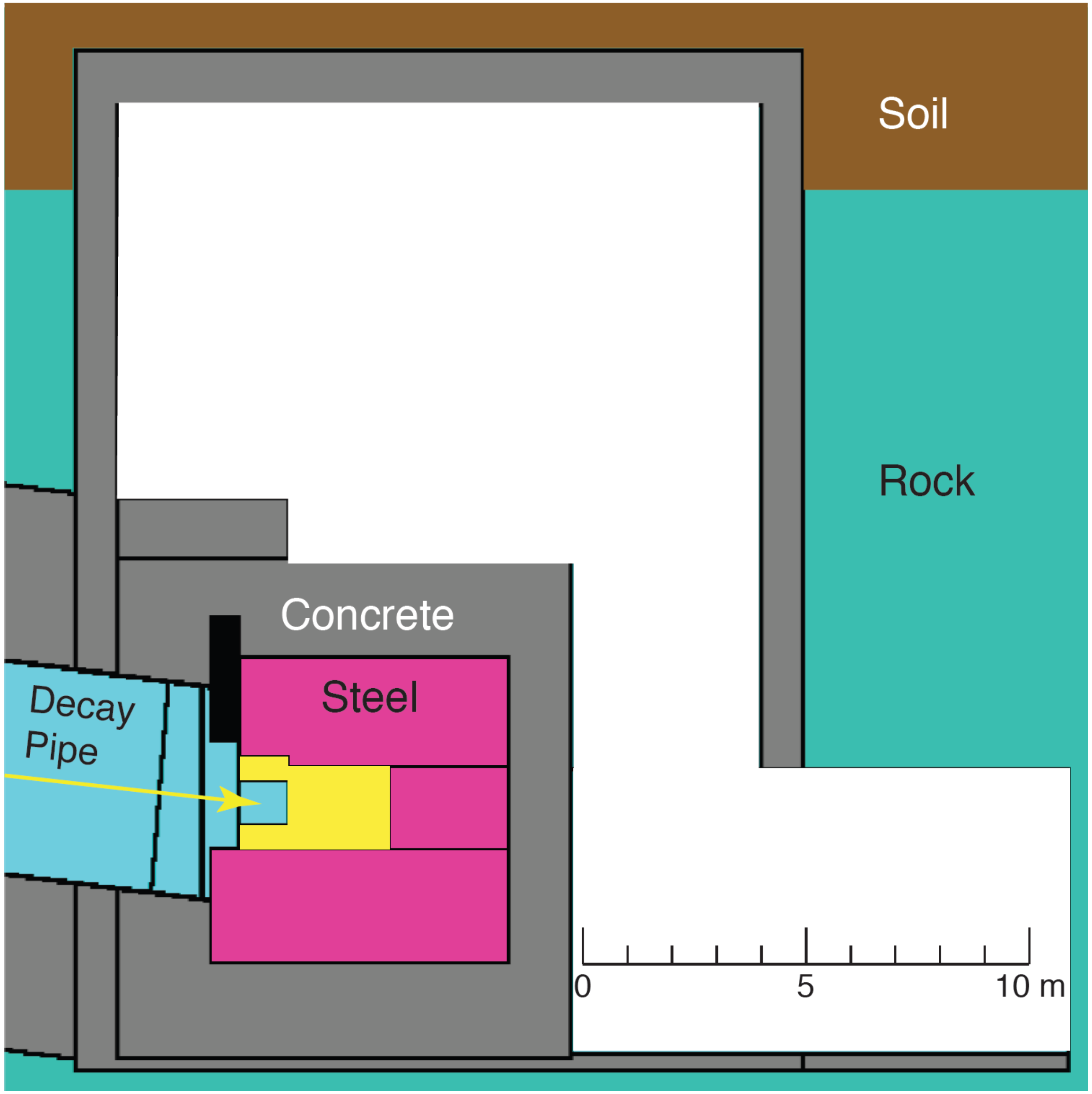
- Cross section through horn 1 at beam sheet point MC-ZERO.
- Steel shielding is cross-hatched.
- Top supply airflow. Flows downstream to upstream. Flows through T-blocks and other shielding blocks into the chase.
- “Air block” sheet metal separates the supply and return airflows.
- Side and bottom supply airflows. Flows downstream to upstream.
- Some air flows through the gaps in the bulk shielding.
- Chase return airflow.



Neutrino Beam Decay Pipe



Neutrino Beam Absorber



Absorber Complex – Longitudinal Section

The Absorber is conceptually designed for 2.3 MW

A specially designed pile of aluminum, steel and concrete blocks, some of them water cooled which must contain the energy of the particles that exit the Decay Pipe.