LBNE Target Pile & Decay Pipe Cooling

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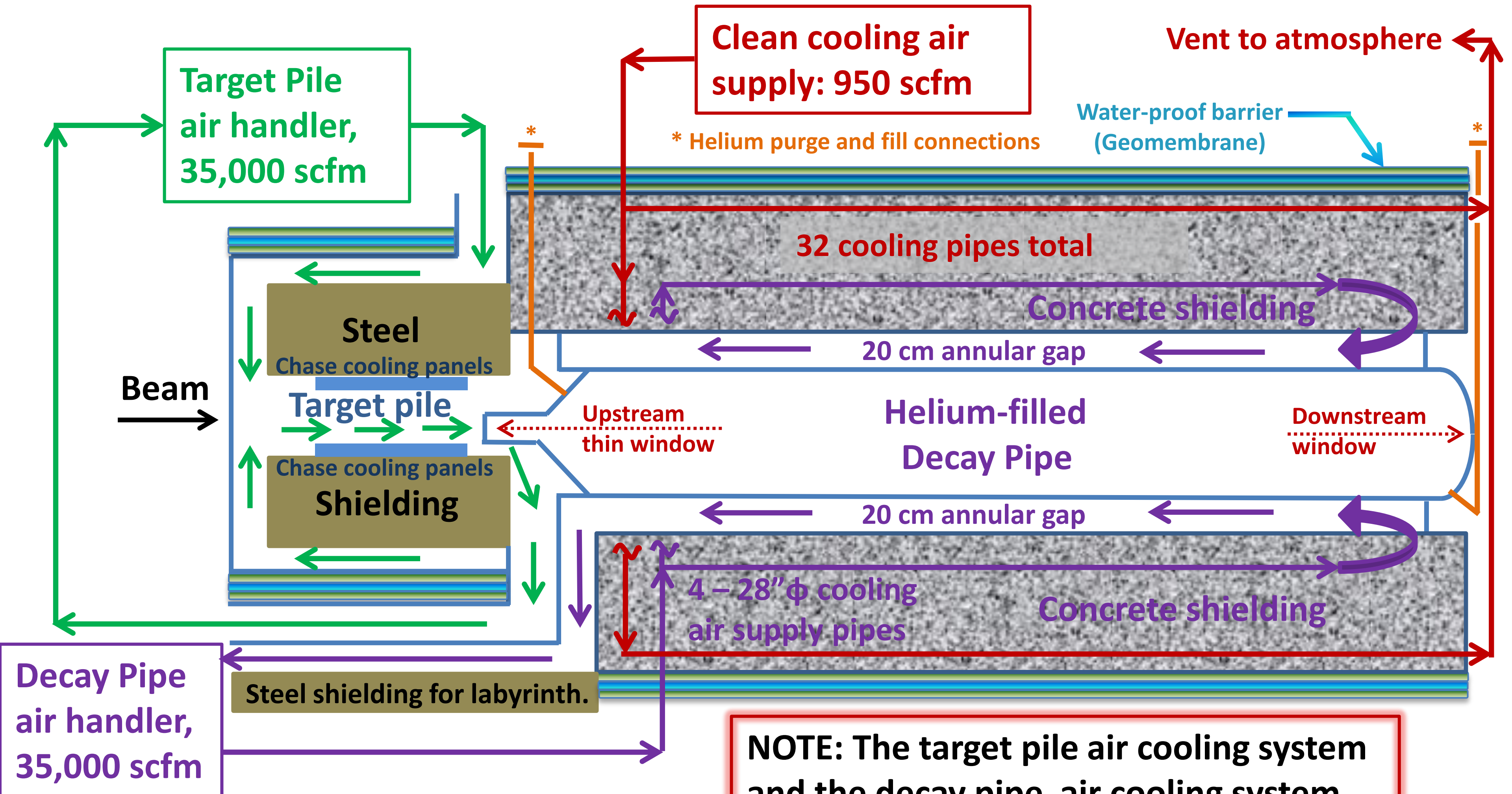
Outline

- Air cooling schematic
- Decay pipe airflow passages
- Target pile airflow passages
- Target pile chase cooling panels (water-cooled)
- Heat loads and cooling parameters
- LBNE Facility Lifetime
- Energy and temperature distributions
  - Decay pipe
  - Target pile chase cooling panels
  - Target pile bulk shielding (Not available)
- Air pressure drops
- Corrosion

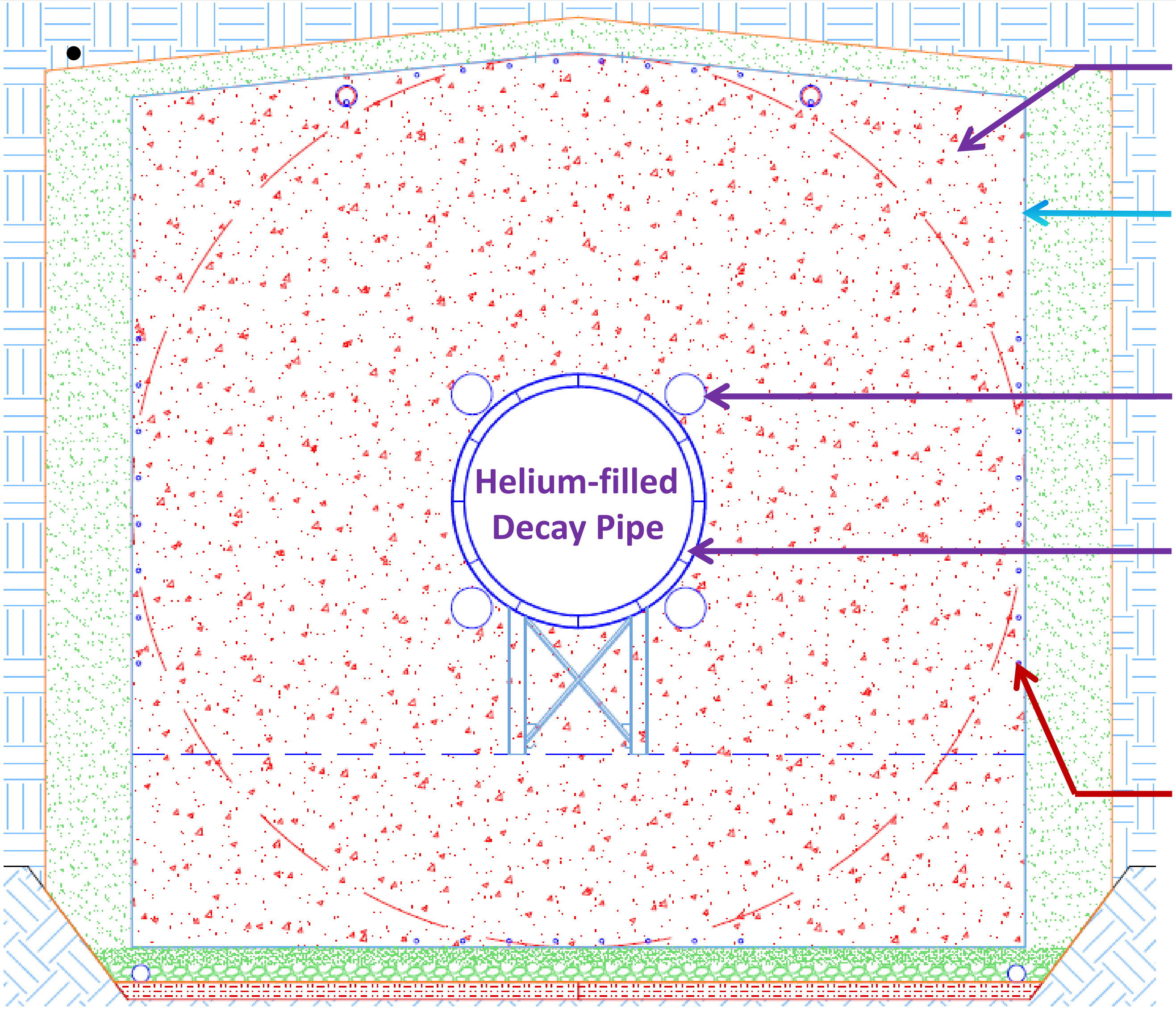
Target pile and decay pipe cooling air schematic

NOTE: The chase cooling panels are cooled with water.



NOTE: The target pile air cooling system and the decay pipe air cooling system are two separate systems.

Decay pipe airflow passages



Concrete shielding

Water-proof barrier (Geomembrane)

4 – 28”ϕ cooling air supply pipes

Cooling air returns in the annular gap of the double-wall decay pipe.

32 clean cooling air pipes. 950 scfm airflow total.

Target pile airflow passages

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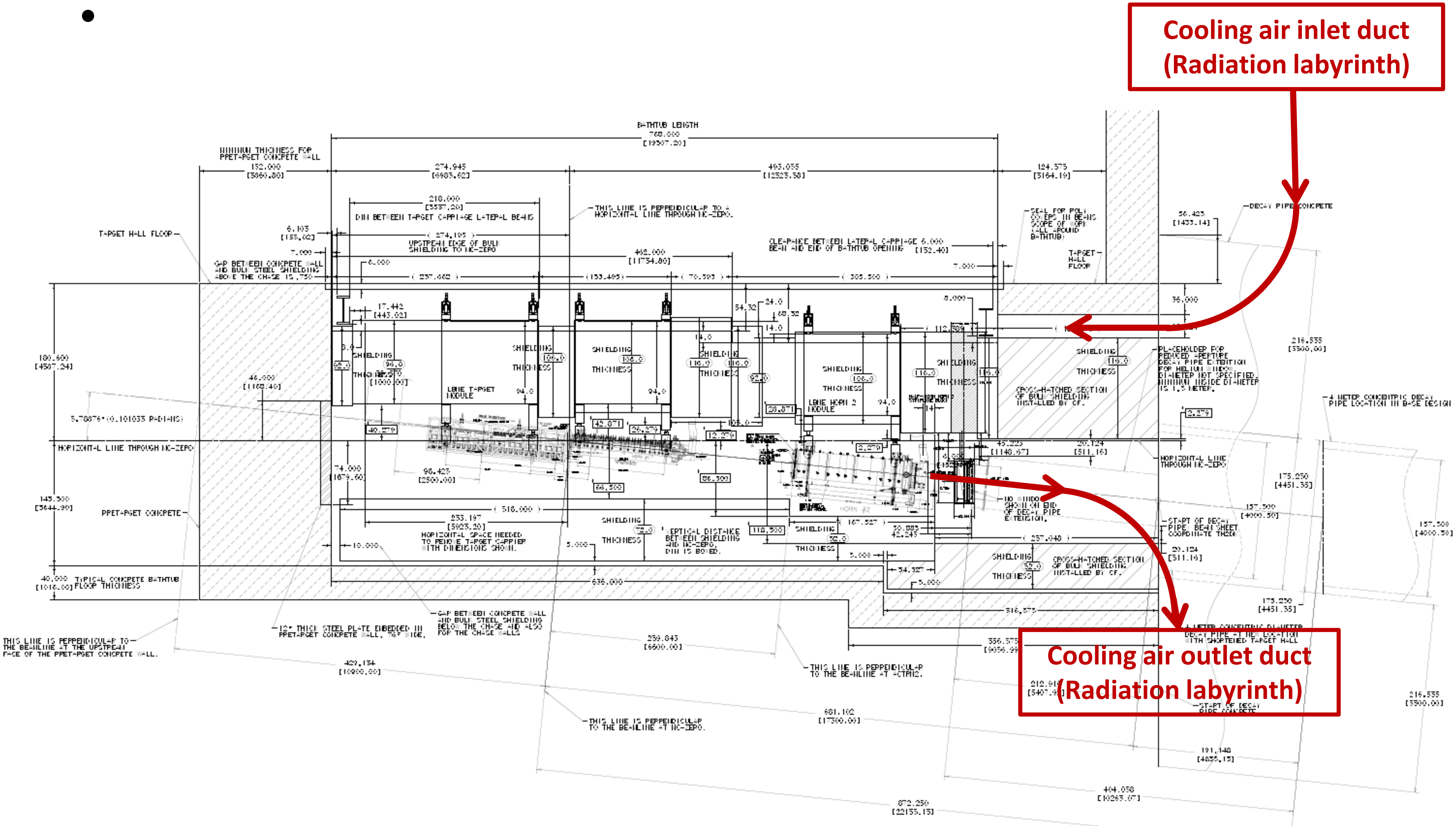
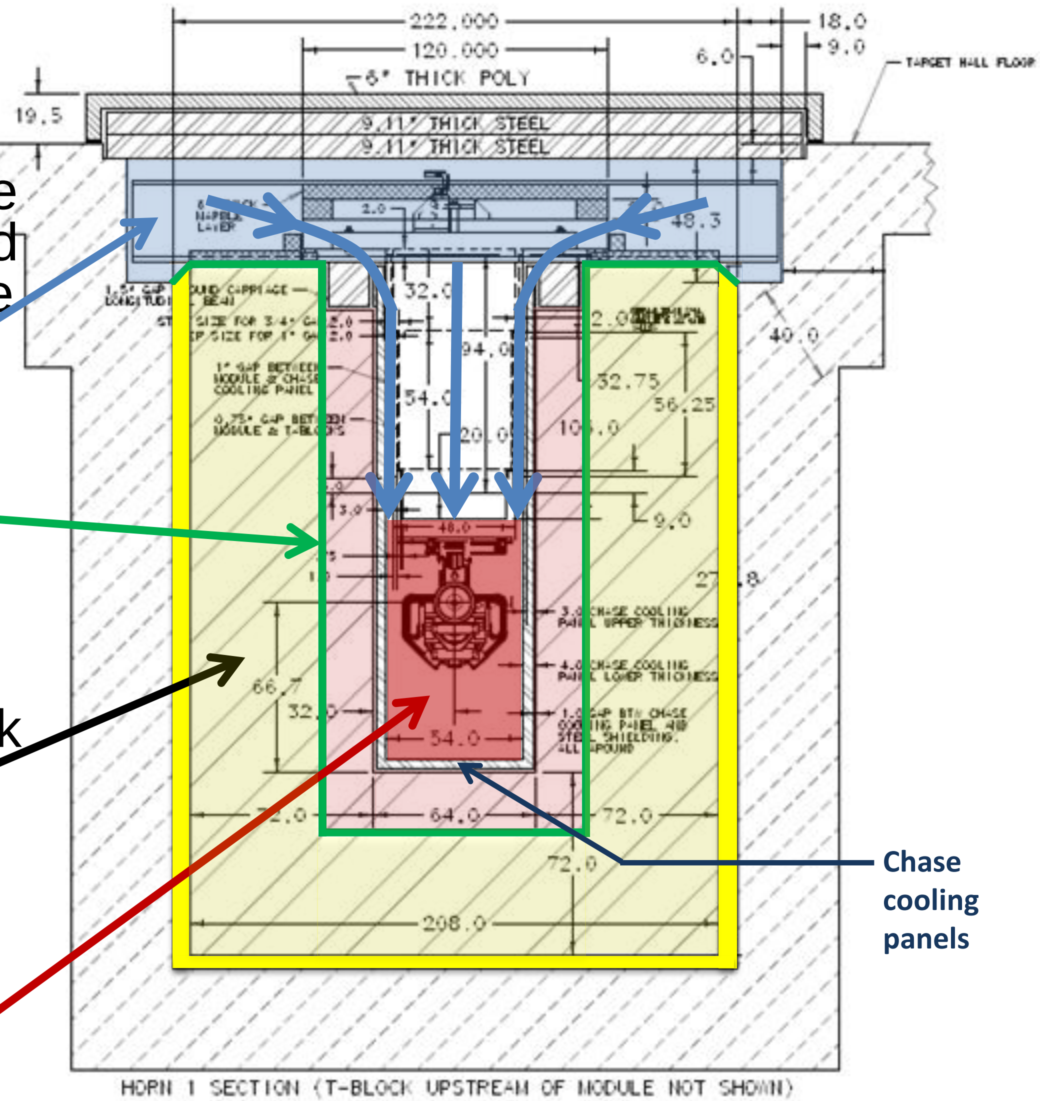


Target pile airflow passages

- Steel shielding is solid cross-hatching.
- Top supply airflow. Flow is downstream to upstream. The air flows through T-blocks and other shielding blocks into the chase.
- “Air block” sheet metal separates supply and return airflows.
- Side and bottom supply airflows. Flow is downstream to upstream. Some air flows through the spaces in the bulk steel shielding.
- Chase return airflow. Flow is upstream to downstream. Some air flows through the spaces in the bulk steel shielding.



NuMI Target Pile

- The air block sheet metal in the NuMI target pile is installed in the bulk shielding.
- Air block material is 304L stainless steel.
- The sheets are welded together with continuous welds.

Target pile chase cooling panels (water-cooled)

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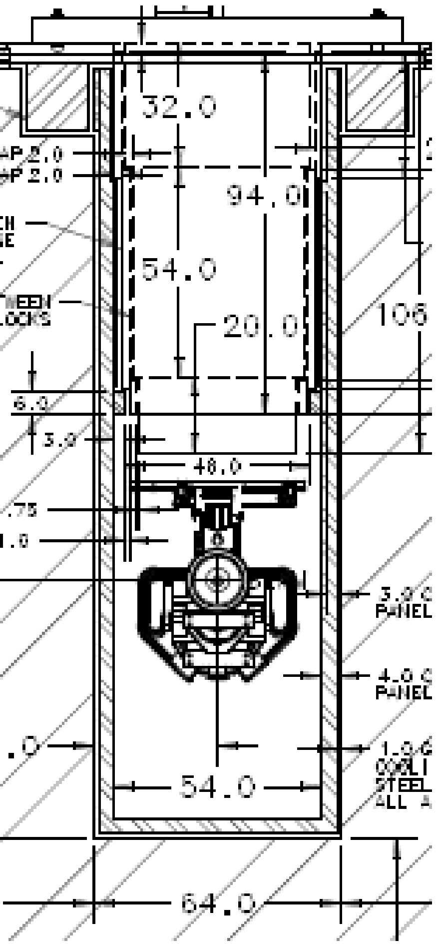
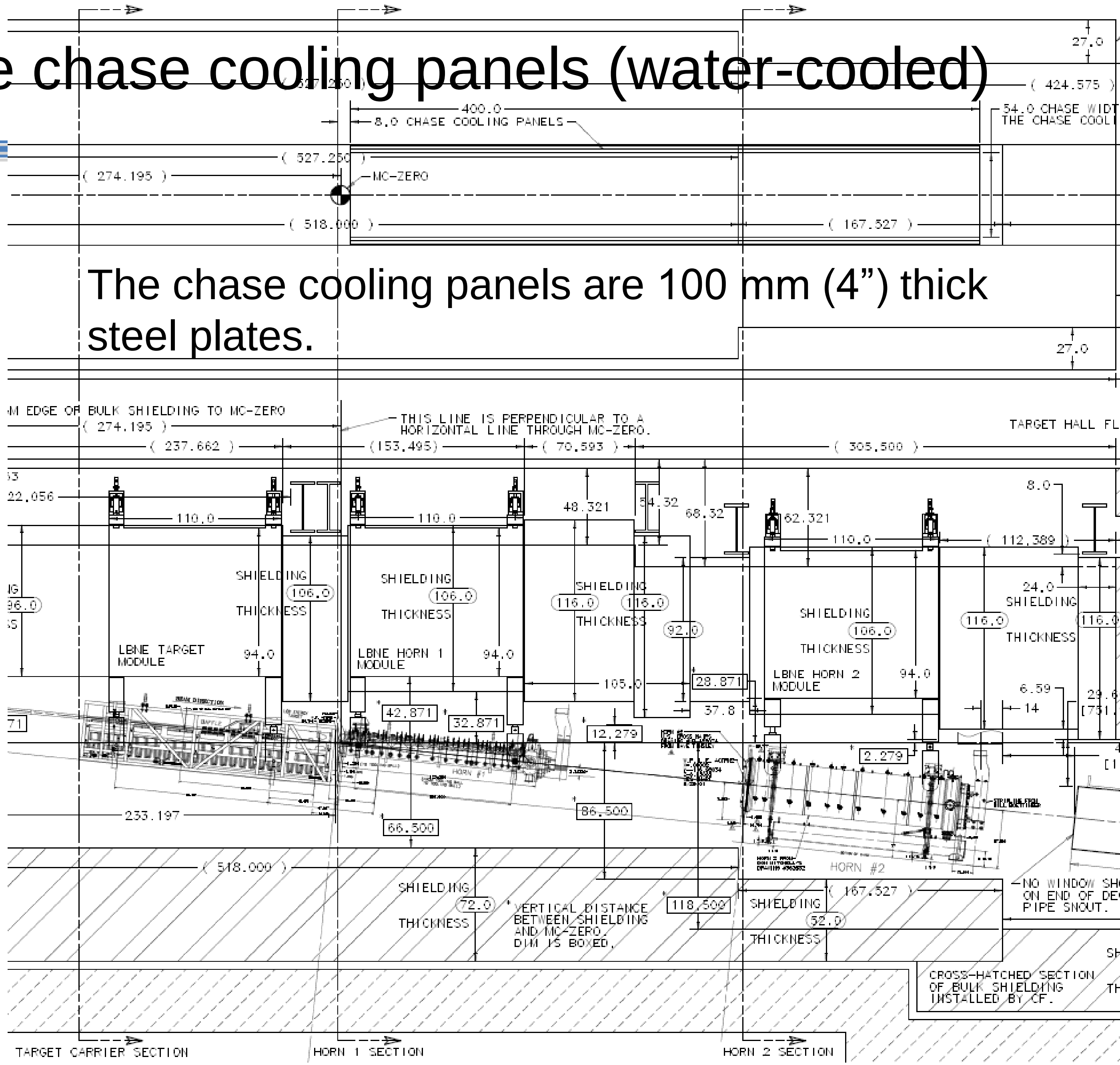


CROSS SECTION AT HORN 1

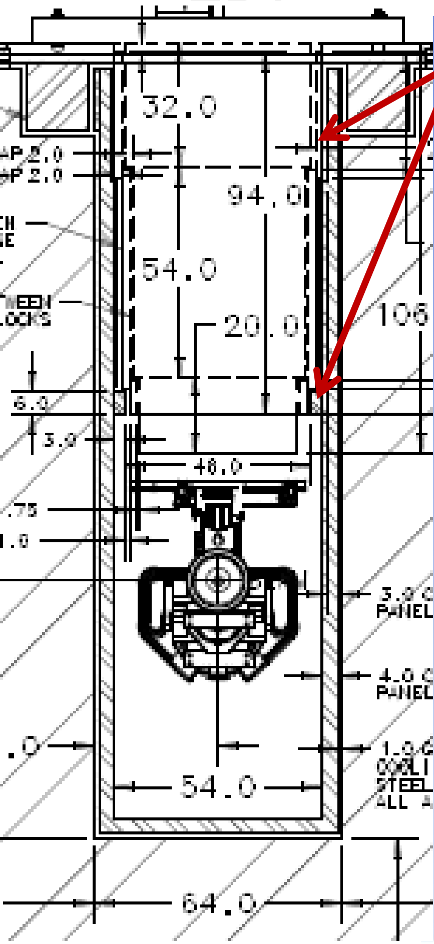
The chase cooling panels are 100 mm (4”) thick steel plates.

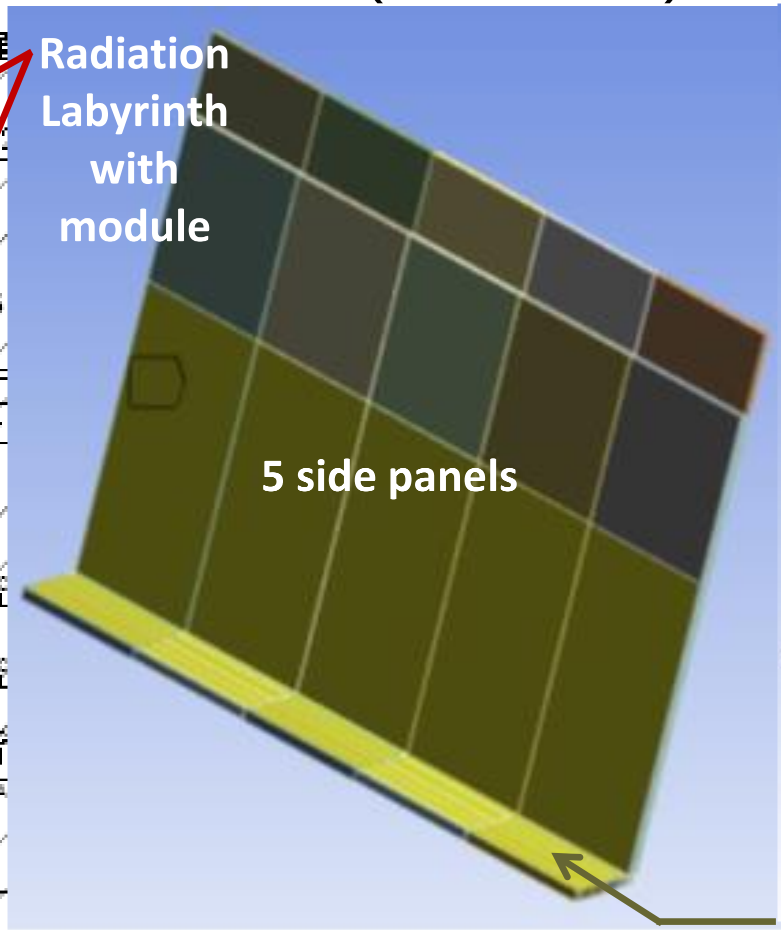


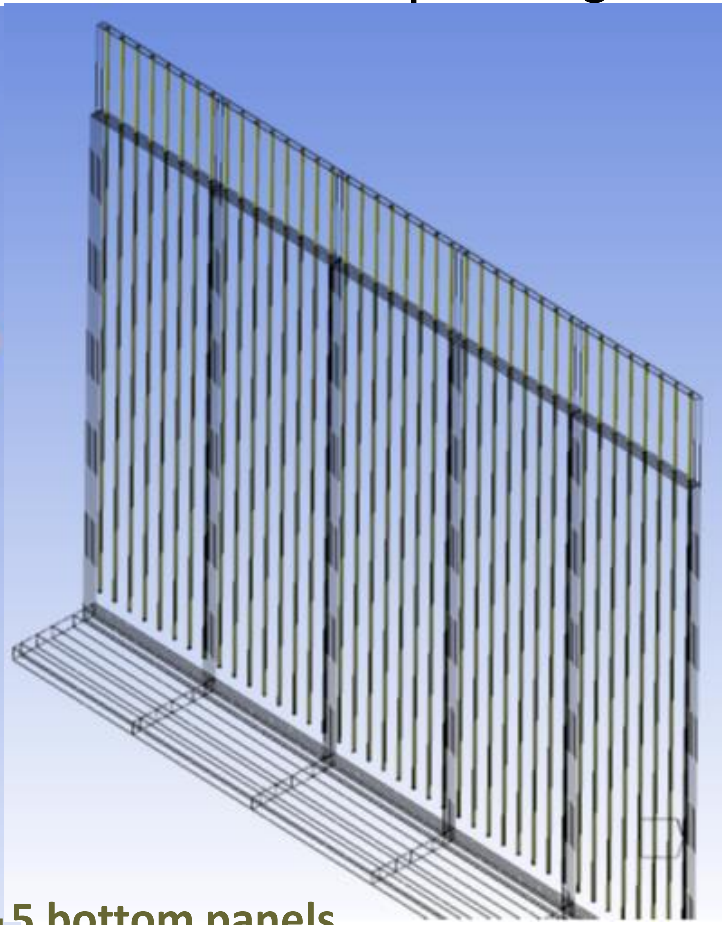
5 m high

Target pile chase cooling panels (water-cooled)

- 2D: Iso-view (1/2 model): Internal water passages:







Target pile chase cooling panels (water-cooled)

- Side panel dimensions: 1,219 mm length along the beamline x 5,050 mm height (48” length x 199” height); 100 mm (4”) thick.
- Bottom panel dimensions: 1,219 mm length along the beamline x 1,371 mm width (48” length x 54” width); 100 mm (4”) thick.
- The chase cooling panels are low carbon steel plates.

Heat loads and cooling parameters for 2.3 MW

- Annular decay pipe: MARS energy deposition is 700 kW.
  - Inner pipe: 360 kW MARS energy deposition
  - Outer pipe: 100 kW MARS energy deposition
  - Shielding concrete: 240 kW MARS energy deposition

  - Air flow rate: 35,000 scfm (71,440 kg/hour) in decay pipe
  - Heat load: 834 kW (1.2 multiplier on MARS energy deposition)
  - Air supply temperature: 15 °C (59 °F)
  - Air return temperature: 57 °C (135 °F)

  - Air flow rate: 950 scfm (1,940 kg /hour) by geomembranes
  - Heat load: 6 kW (1.2 multiplier on MARS energy deposition)
  - Air supply temperature: 15 °C (59 °F)
  - Air return temperature: 26 °C (79 °F)

Heat loads and cooling parameters for 2.3 MW

- Target pile: MARS energy deposition is 525 kW.
  - Chase cooling panels: 317 kW MARS energy deposition
  - Bulk steel shielding: 208 kW MARS energy deposition

  - Air flow rate: 35,000 scfm (71,440 kg/hour)
  - Heat load: 250 kW (1.2 multiplier on MARS energy deposition)
  - Air supply temperature: 15 °C (59 °F)
  - Air return temperature: 27.5 °C (81.5 °F)

  - Water flow rate: 290 gpm (66 m^3/hour)
  - Heat load: 380 kW (1.2 multiplier on MARS energy deposition)
  - Water supply temperature: 38 °C (100 °F)
  - Water return temperature: 43 °C (109 °F)

LBNE Facility Lifetime

- Lifetime required for the facility and the waterproof barrier is 50 years:
  - 5 years operating at 1.2 MW
  - 15 years operating at 2.4 MW
  - 10 years for construction, upgrades and maintenance
    - Sub-total = 30 years for the Operating Lifetime
  - 10 years for activation cool-down
    - The facility is ready for demolition after the cool-down period.
  - Allow 10 years to plan and complete demolition.
  - Facility Lifetime requirement is 30 + 10 + 10 = 50 years.
  - NOTE: The waterproof barrier must have a lifetime of at least 50 years so it is intact when concrete demolition starts. The concrete will have a sizable tritium inventory 20 years after the 30-year operating lifetime is over and the waterproof barriers will still be needed to prevent water from wetting undisturbed concrete during demolition.

LBNE Facility Lifetime

- Waterproof barrier (geomembrane) strength half-life is a function of operating temperature:
  - Detailed information only available for HDPE (Courtesy of Ed Kavazanjian - Consultant):
    - Geomembrane “strength half-life” from Rowe (2005)

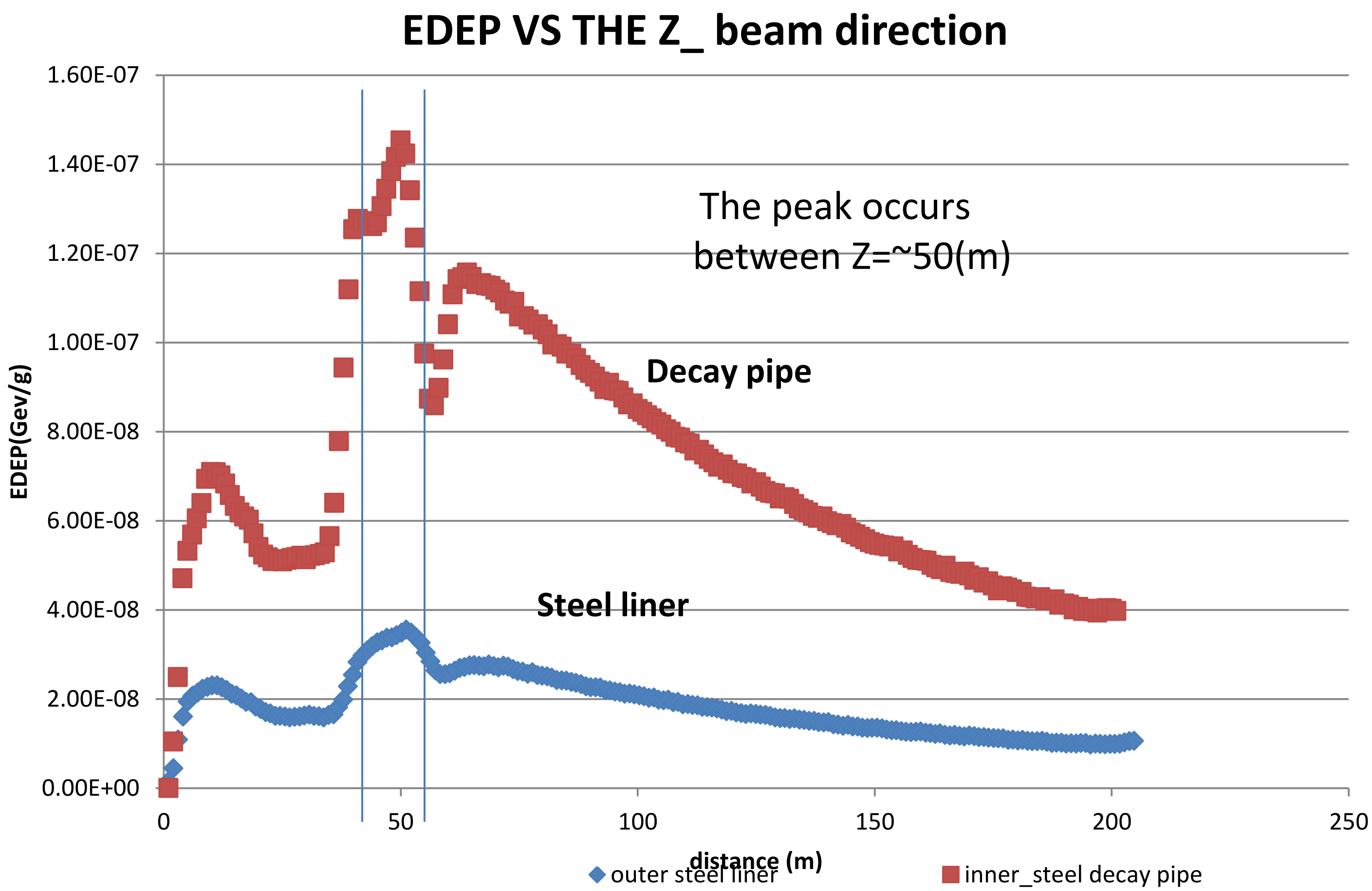
      130 yrs @ 35^{o}C continuous

      80 yrs @ 40^{o}C continuous

      35 yrs @ 50^{o}C continuous
- Based on the facility lifetime requirement of 50 years, we select a geomembrane strength half-life of 80 years and specify 40 to 45 °C as the maximum operating temperature range for the waterproof barrier. Waterproof barrier temperature will slightly exceed 40 °C during the 15 years of 2.4 MW operation but will be much less than 40 °C when the particle beam is off so we believe we will be very close to achieving the 80-year strength half-life.

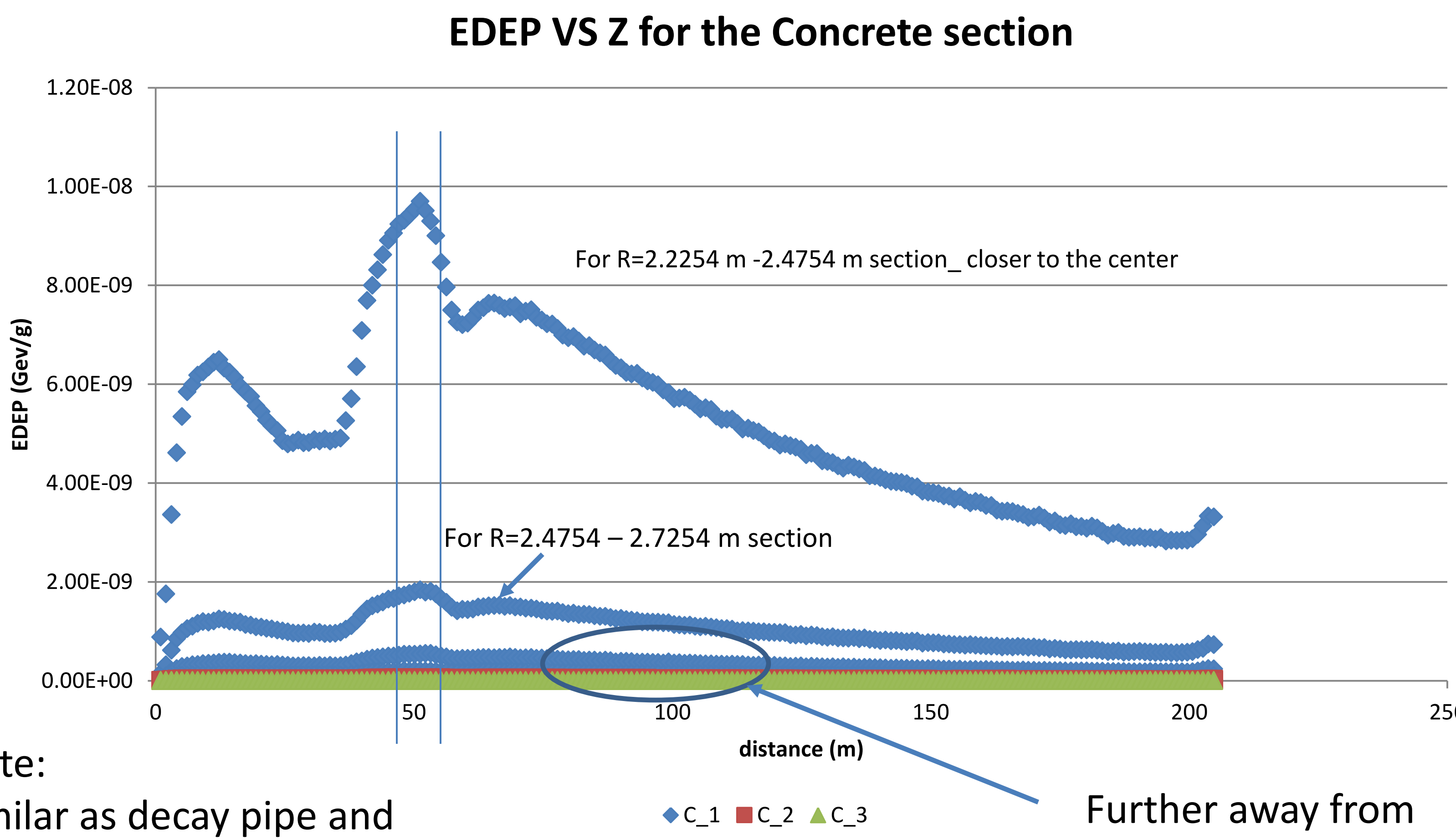
Energy distribution – Decay pipe

- Energy distribution at 2.3 MW



Energy distribution – Decay pipe

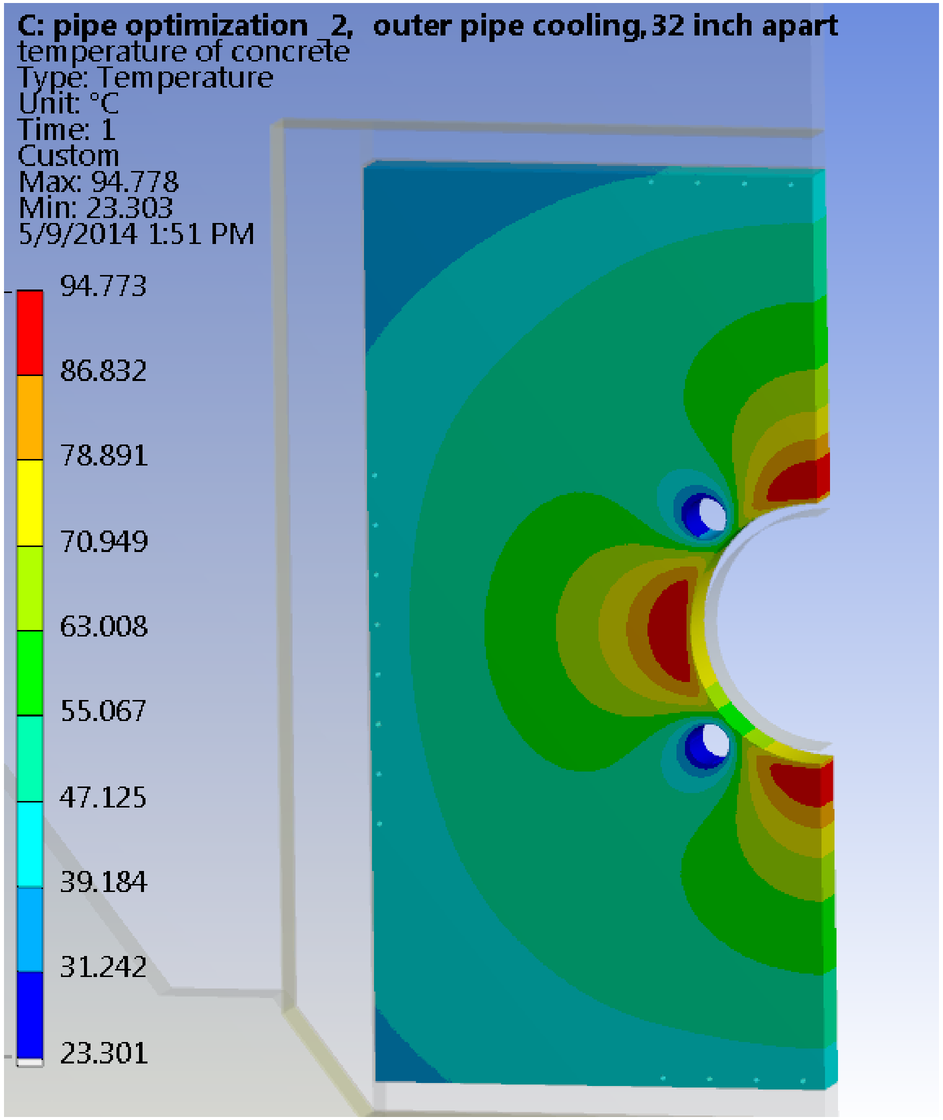
- Energy distribution at 2.3 MW



Note:
Similar as decay pipe and steel liner, the maximum occurs at Z=~50 m

Further away from center, EDEP decays quickly

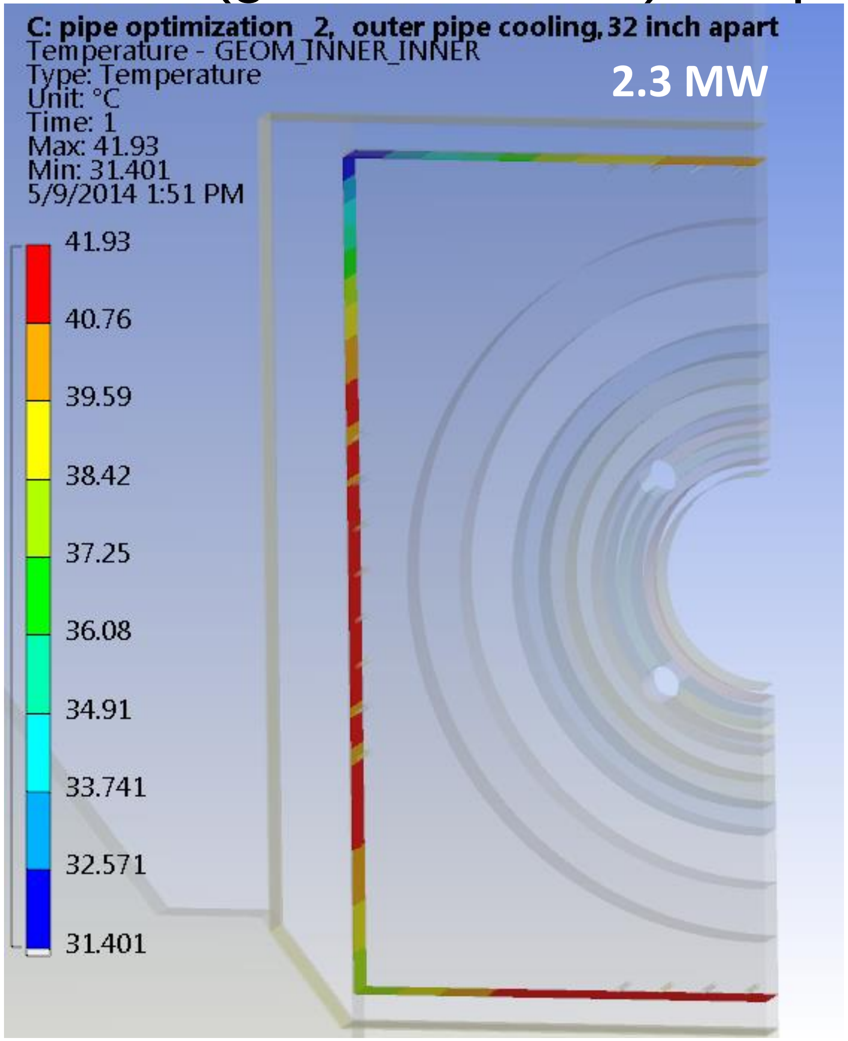
Temperature distributions – Decay pipe



2.3 MW Case	74 pipes (base line) Case_1	32 pipes Case_1a
Maximum steel decay pipe temperature (C)	89.118	89.118
Maximum annulus steel liner temperature (C)	76.623	76.803
Maximum Concrete Temperature C	94.164	94.778
Maximum temperature (Geomembrane _ inboard)	41.795	41.93

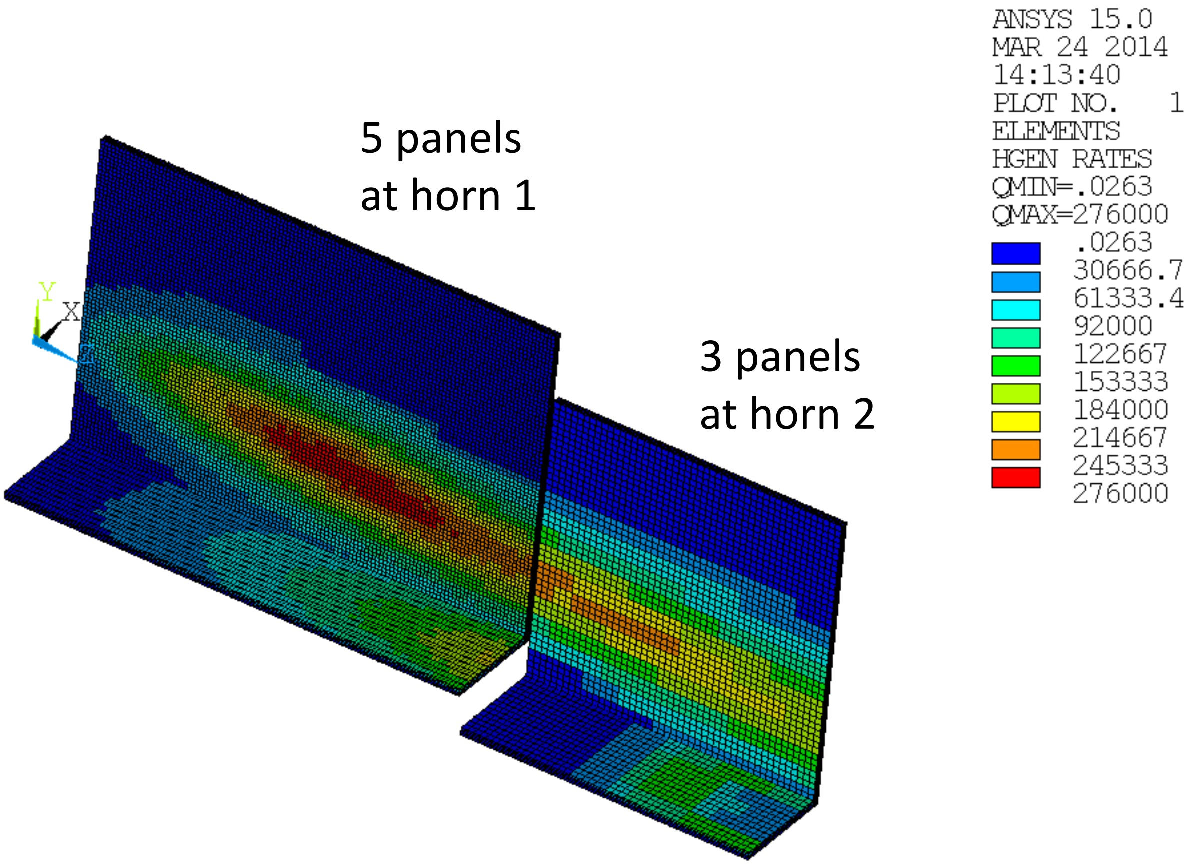
Temperature distributions – Decay pipe

- Water-proof barrier (geomembrane) temperatures:



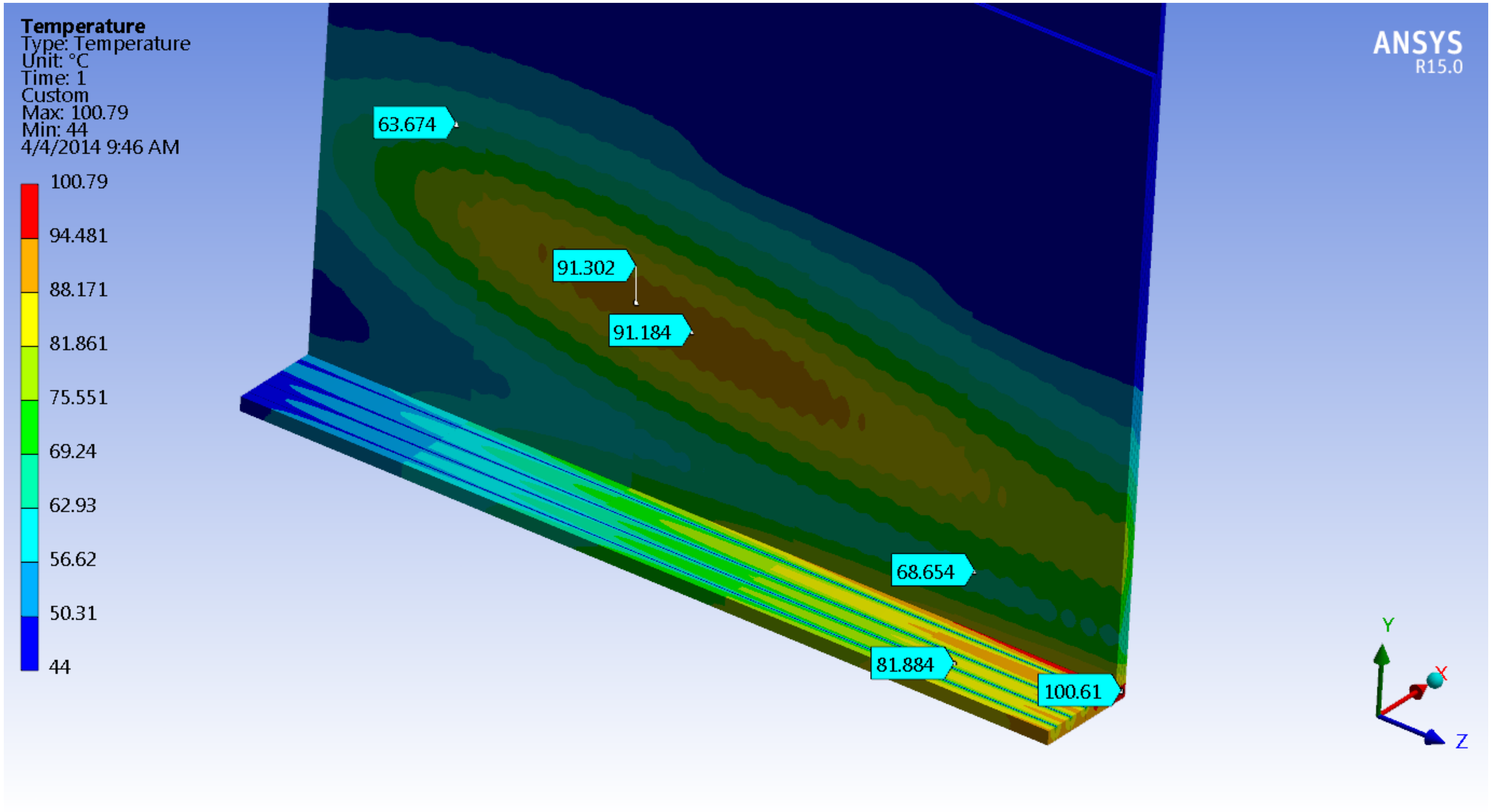
Energy distribution – Target pile chase cooling panels

- Energy distribution at 2.3 MW



Temperature distributions – Target pile chase cooling panels

- Eight cooling passages in each side panel, 8 tube passes on each bottom panel, 38 °C (100 °F) cooling water supply temperature, 2.3 MW:

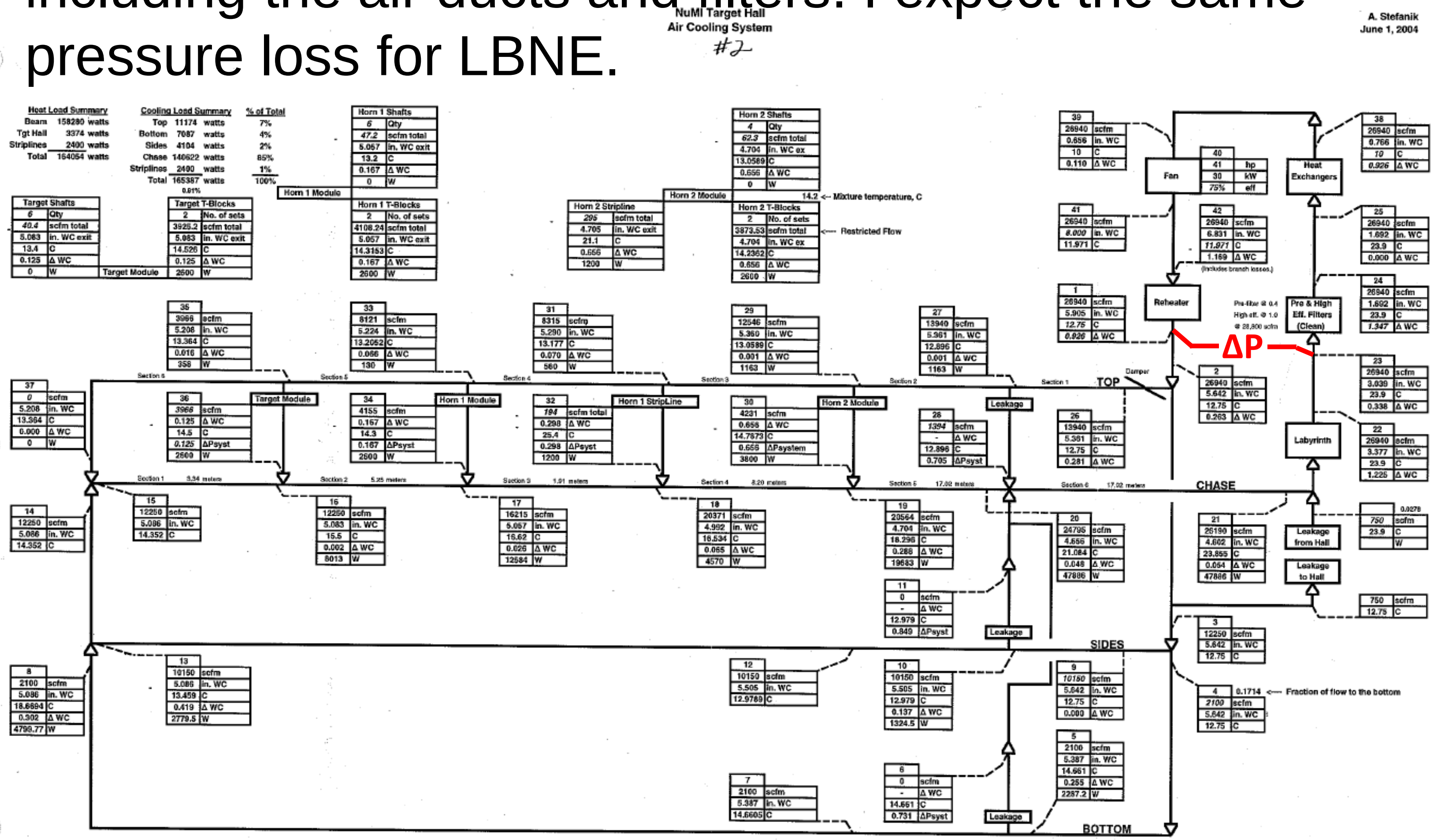


Air pressure loss – Decay pipe

- Air flow rate for the decay pipe: 35,000 scfm (71,440 kg/hour)
  - ΔP = 2,500 Pa (10 "WC) for the 4 supply lines and the decay pipe annulus.
- Air flow rate out by the geomembranes: 950 scfm (16,330 kg /hour)
  - ΔP = 625 Pa (2.5 "WC) for the 32, 76.2 mm (3") inside diameter pipes.

Air pressure loss example – NuMI target pile

- NuMI: **ΔP** = 746 Pa (3” WC) for only the target pile, not including the air ducts and filters. I expect the same pressure loss for LBNE.



Corrosion

- Design life for beam related corrosion is 20 years. (5 years at 1.2 MW plus 15 years at 2.4 MW.)
- LBNE will receive 27.3 MW-years in its operating lifetime.
- NuMI has received 1 MW-year so far.
- If moist air is used to cool the LBNE target pile and decay pipe, the primary corrosive issues are:
  - Moisture (non-beam related corrosion)
  - Nitric acid, HNO_3 (beam related corrosion)
  - Ozone, O_3 (beam related corrosion)
  - Stress corrosion cracking/hydrogen embrittlement of high strength low alloy steel (beam related corrosion)
- We will eliminate the last issue by not using high strength low alloy steels.

Corrosion

- We will control some corrosion by drying the air. Relative humidity for the cooling air supply is currently required to be less than or equal to 10%.
- For comparison, the relative humidity in the NuMI target pile for the cooling air supply is 20%. The cooling air return is in the 30% to 50% range.
- With dry cooling air the primary corrosive agents in the LBNE target pile and decay pipe are:
  - Ozone, O_3 (beam related corrosion).
  - N_xO_x (beam related corrosion)
- Of these two, ozone is the dominate corrosive agent.

Corrosion

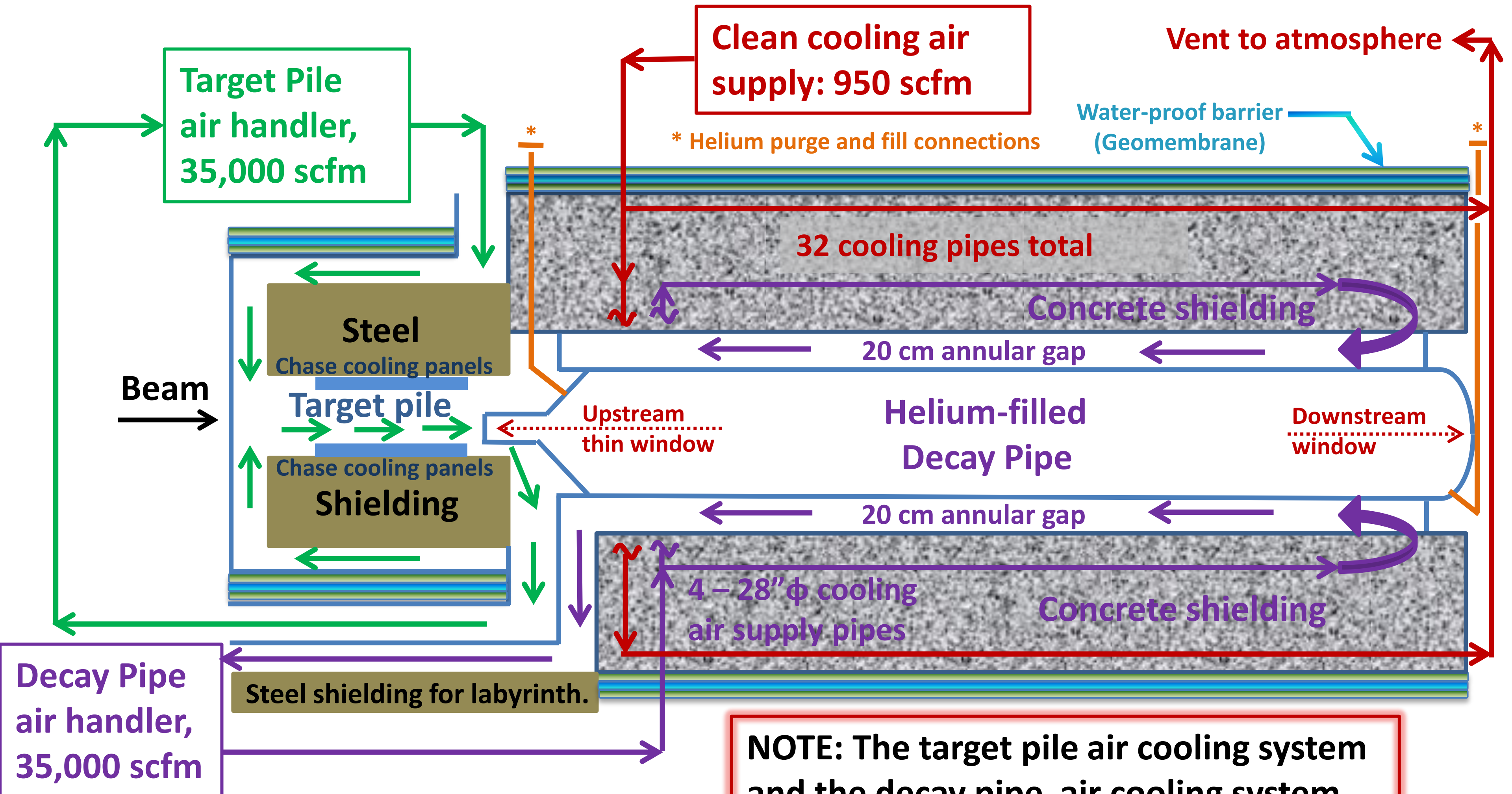
- Our plan to study ozone and N_xO_x corrosion:
  - Consult with HEP facilities.
  - Conduct literature search.
  - Work with corrosion consultants. We are working with a consultant now and might do so again in the future.
  - Develop a mathematical model to predict the formation of corrosive agents when the beam interacts with the cooling airflow.
  - Test the mathematical model by measuring concentrations of corrosive agents in the NuMI target pile. We have started installing sample tubing in the target pile and will be purchasing instruments in the near future.
  - Expose metal samples to the high radiation and the corrosive environment in the NuMI target pile. The material samples include: aluminum, carbon steel, stainless steel, anodized aluminum, the heat affected zone (HAZ) of welded joints, and weld material.

Corrosion

- Our plan to study ozone and N_xO_x corrosion (continued):
  - If necessary, run tests to determine quantitative ozone corrosion rates (uniform and pitting) at concentrations and temperatures expected in the LBNE target pile for base metals, the heat affected zone (HAZ) of welded joints, and the weld material.
- Corrosion is most critical for components made with thin materials because function can be lost or impaired when the material corrodes through. An important example is the decay pipe.
- We can eliminate oxygen related corrosion in most of the decay pipe by cooling it with dry nitrogen gas instead air.

Target pile and decay pipe cooling air schematic

NOTE: The chase cooling panels are cooled with water.



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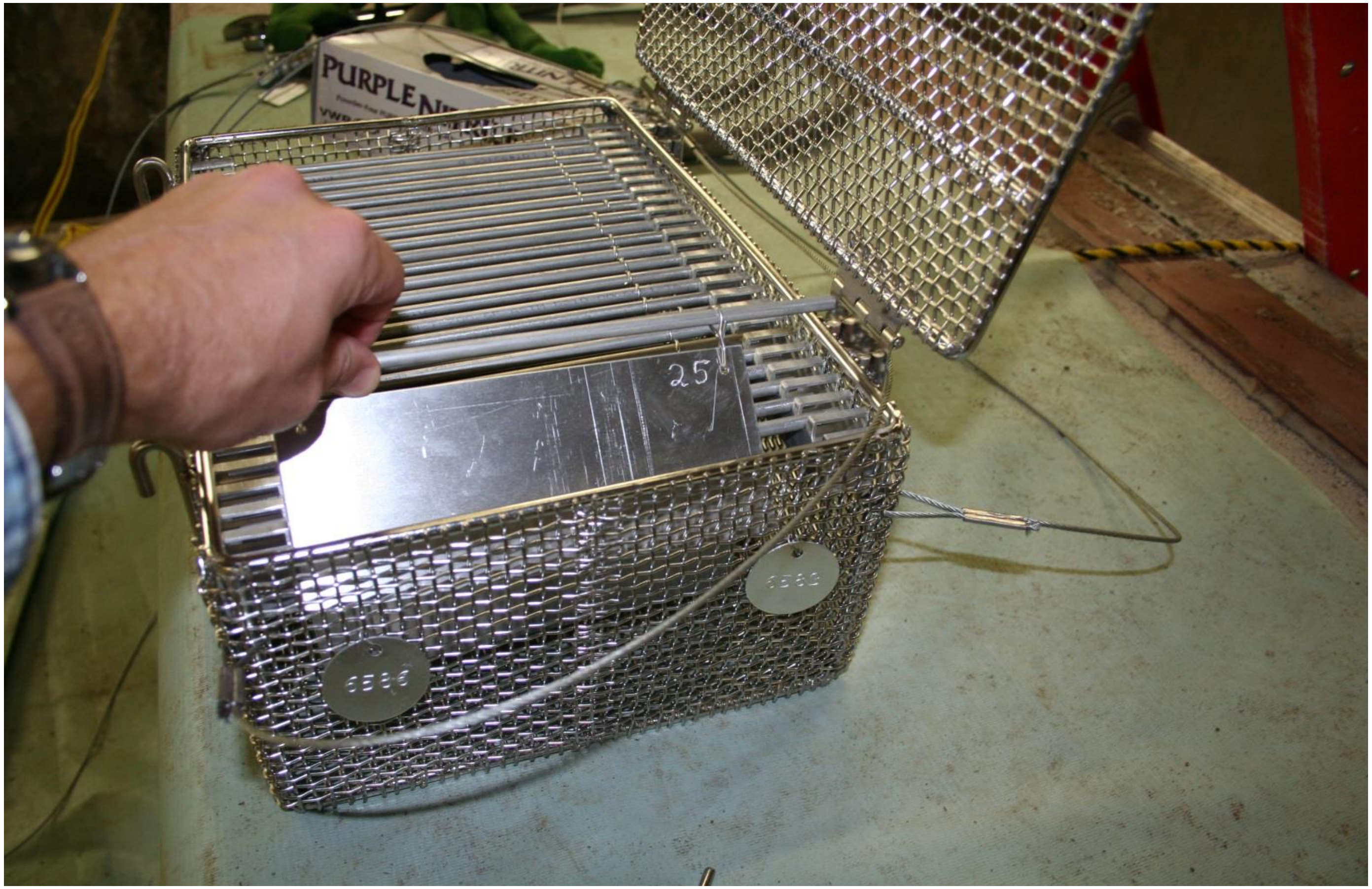
Corrosion

- Sample basket in the NuMI target pile. It gets installed in the chase by the horns.



Conclusion

- We have reviewed the preliminary decay pipe design.
- We have more work to do to finalize the design.
- Thank you for attending my presentation.
- Comments?
- Questions?