LBNF Beam-line Radiological Protection Strategy

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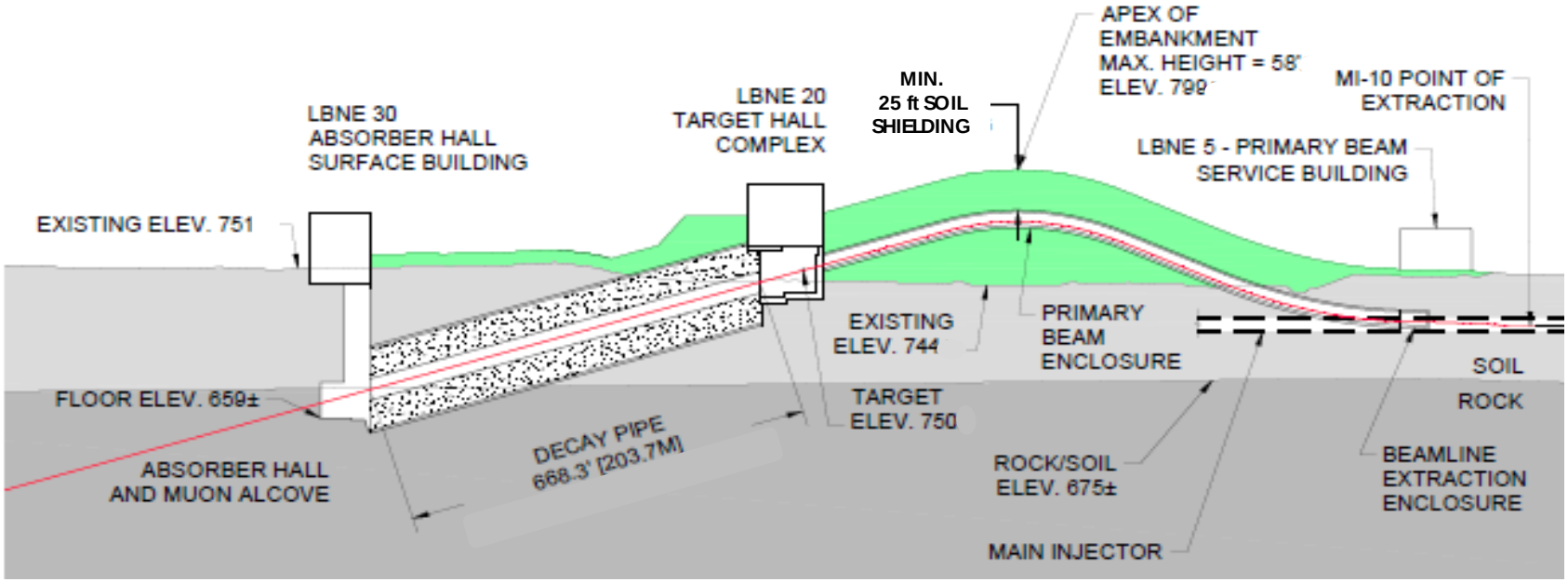
Outline

- Regulatory Requirements
- Radiological safety issues and strategy
  - Bulk soil shielding
  - Groundwater and surface water
  - Activated air emissions
  - Residual activation
  - RadioActive Water (RAW) systems
  - Material damage
- Direct and sky-shine dose offsite
- Summary and Status

Radiological Protection Strategy

- LBNE proton beam line will start by operating at 1.2 MW for 5 years and then at 2.4 MW for 15 years. A total of 20 years spread over 30 years.
- Radiological safety issues cover both off-site and on-site.



Regulatory Requirements

- Specified by federal, DOE and state regulations as given in Fermilab ES&H manual, which includes the Fermilab Radiological Controls Manual.

- Based on the above regulatory requirements a set of radiological requirements has been determined and documented for the LBNE beam line:
    - LBNE radiological design goal is to contribute to less than 25% of the limits of the radiological quantities specified by the Fermilab policies.

- Since the shielding of a beam line designed for 1.2 MW can not be easily upgraded to 2.4 MW, all shielding is designed for 2.4 MW. The only exception will be given later.

Regulatory Requirements

- FNAL has implemented a goal of limiting the dose at the site boundary to a maximum of 100 μSv in any given calendar year from all Fermilab sources. This is the total Fermilab offsite dose budget.

- Annual exposure of a member of public offsite, to the radioactive air emissions, from all Fermilab sources should be less than 1 μSv in a year.

- Maximum occupancy time in accelerator and beam line areas to allow a maximum of 1 mSv/week, with a maximum of 15 mSv/year.

Regulatory Requirements

- Ground and surface waters concentration limits, only for the significantly leachable and mobile radionuclides:
  - Groundwater: Tritium = 0.74 MBq/m^3, ^{22}Na = 14.8 kBq/m^3.
  - Surface water: Tritium = 70.3 MBq/m^3, ^{22}Na = 0.37 MBq/m^3

$$\sum_i \frac{C_i}{DCS_i} \leq 1$$

- State of Illinois requirement of "non-degradation of natural resources"
- Current regulatory standard detection limit for the above two radionuclides is
  - Tritium = 37 kBq/m^3, ^{22}Na = 1.1 kBq/m^3.

Shielding the Primary Beam Transport-line Shielding

Two beam loss scenarios are considered, based on current technology used at NuMI beam line:

- Normal proton beam losses at the level of 1E-5
- Accidental loss of two full beam pulses per hour

		Full beam loss			1E-5 loss rate		
Dose Rate (DR) Under Normal Operating Conditions	**Controls**	Hadrons soil (m)	Transverse Muons soil (m)	Longitudinal Muons soil (m)	Hadrons soil (m)	Transverse Muons soil (m)	Longitudinal Muons soil (m)
DR < 0.5 μSv /hr	No precautions needed.	*12.4*	*9.6*	*208*	**6.9**	5.3	**84.7**

	Accident Scenario **2** full beam pulses lost	Hadrons	Muons	
Maximum Dose (D) Expected in One hour	**Controls**	**Transverse** soil (m)	**Transverse** soil (m)	Longitudinal soil (m)
D < 10 μSv	No precautions needed.	**7.6**	5.8	**104.3**

Ground and Surface Waters Contamination

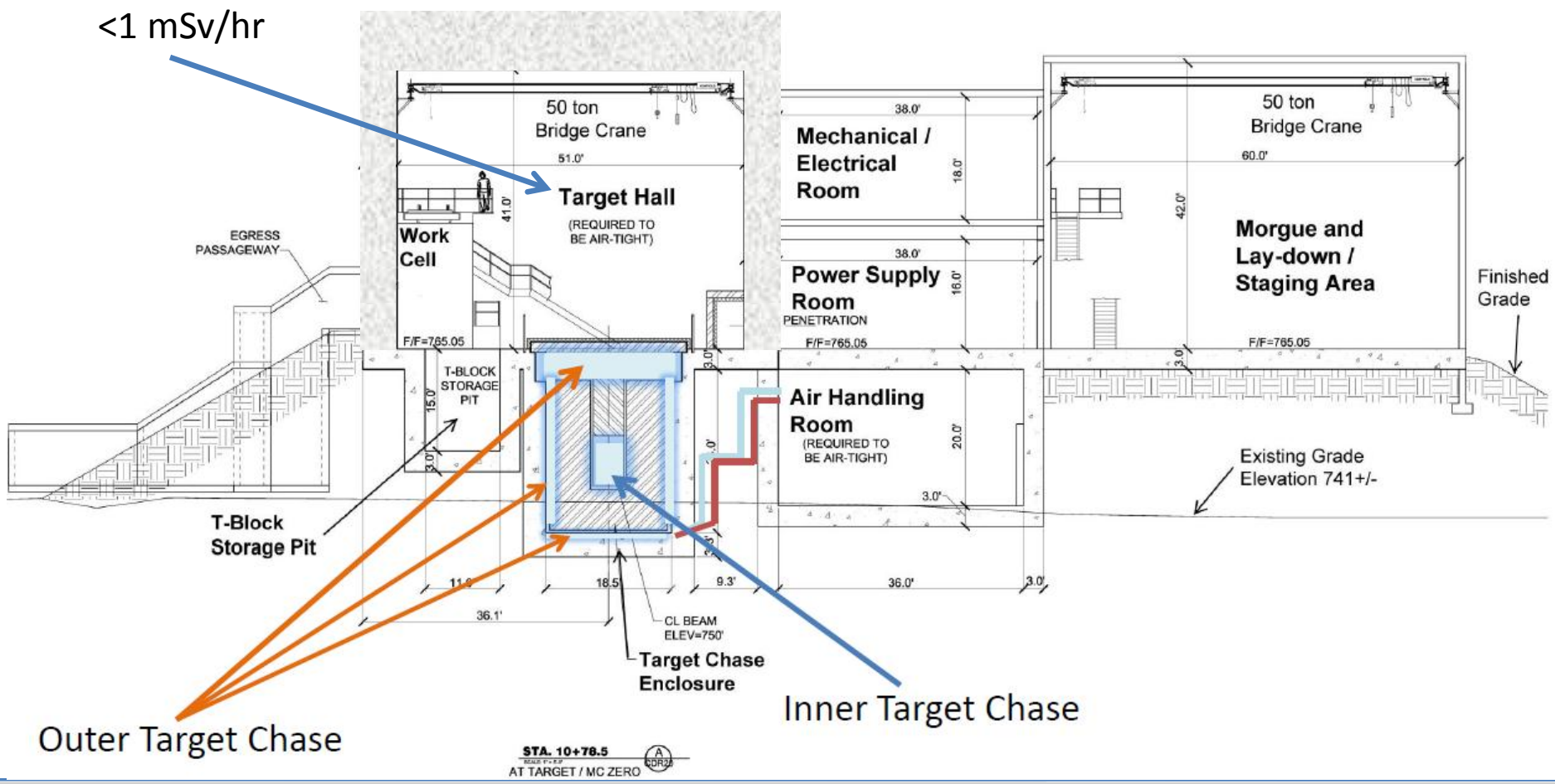
- Target Hall and Target Chase and the primary transport line are designed such that during 20 years of operation, radionuclide concentrations immediately outside the shielding stay well below the regulatory surface water limits.

- The seepage velocities, for the layers in the glacial till, are very small and the concentration of the radionuclides reaching the shallow aquifer are estimated to be reduced by 7 orders of magnitude to below the regulatory standard detection limits.
  - Additionally, a water impermeable geomembrane has been added to the outside of the Target Chase.

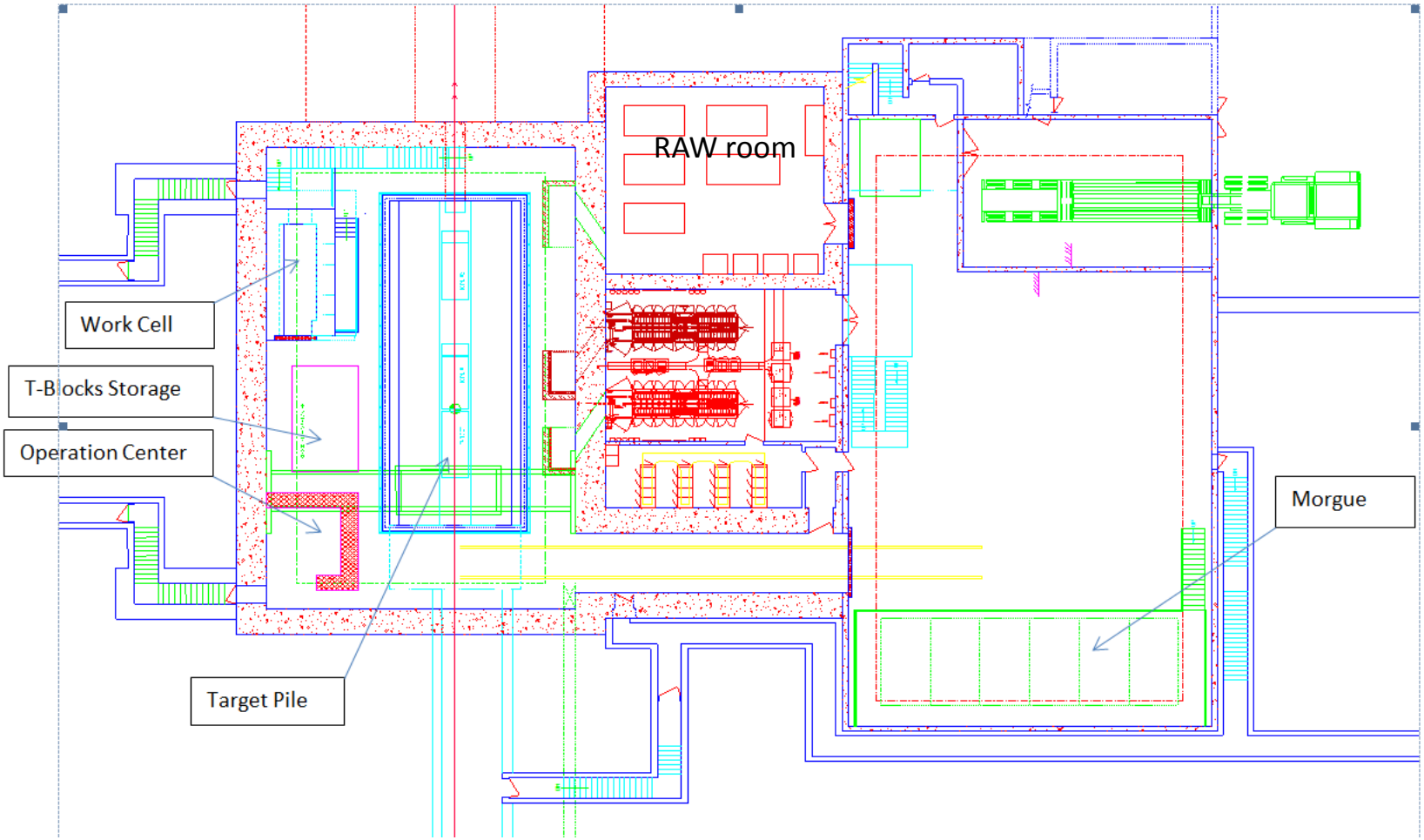
- For the rest of the beam line, from the start of the Decay pipe to the end of Absorber Hall, there will be sufficient shielding to render the concentration of the radionuclides of interest, accumulated over 20 years, to less than the current standard detection limits.

LBNF Target Hall Complex

Shielding of the target Chase: Bottom and sides are concrete and iron
Top has marble, borated poly and steel

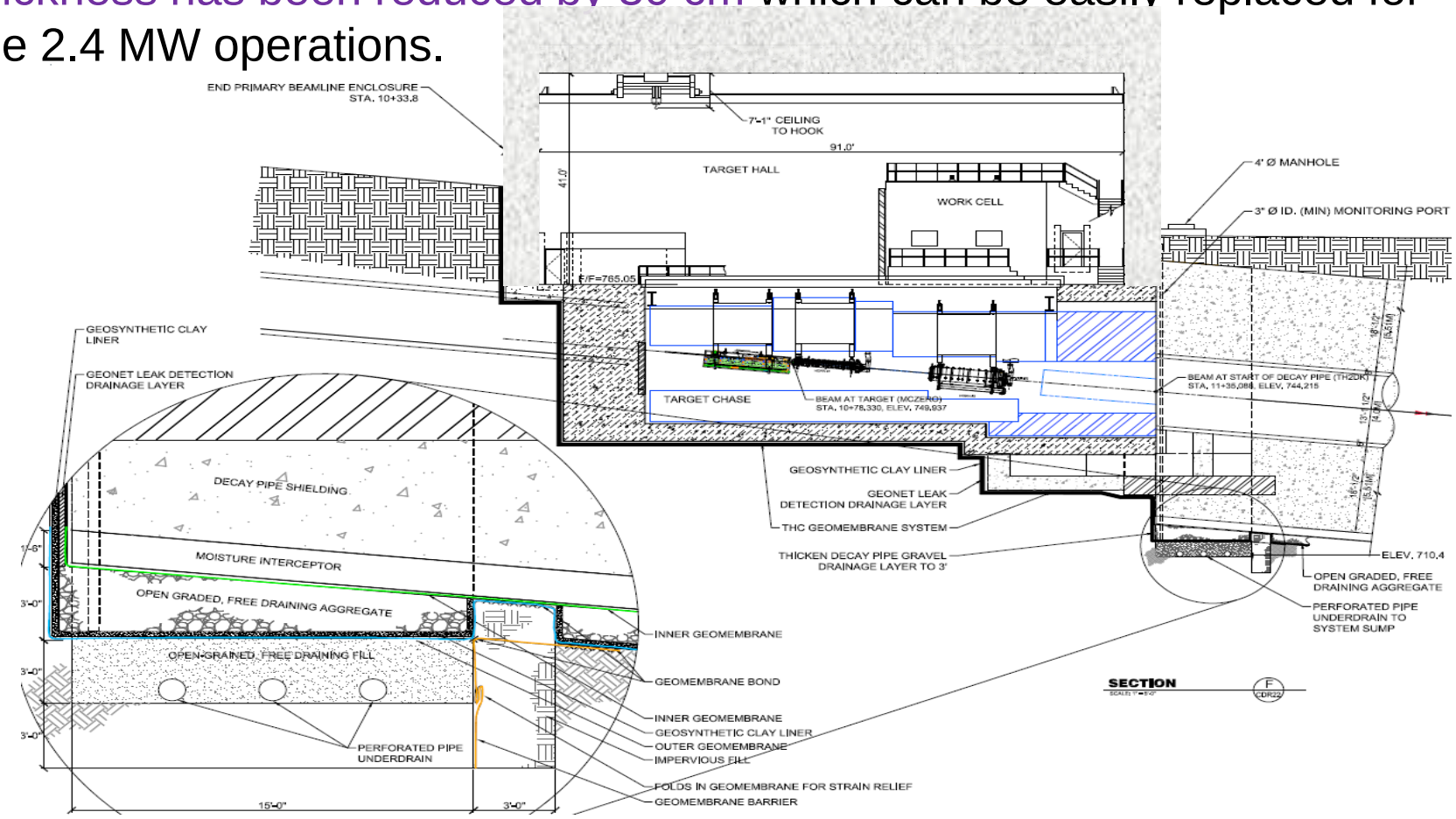


LBNF Target Hall Plan View

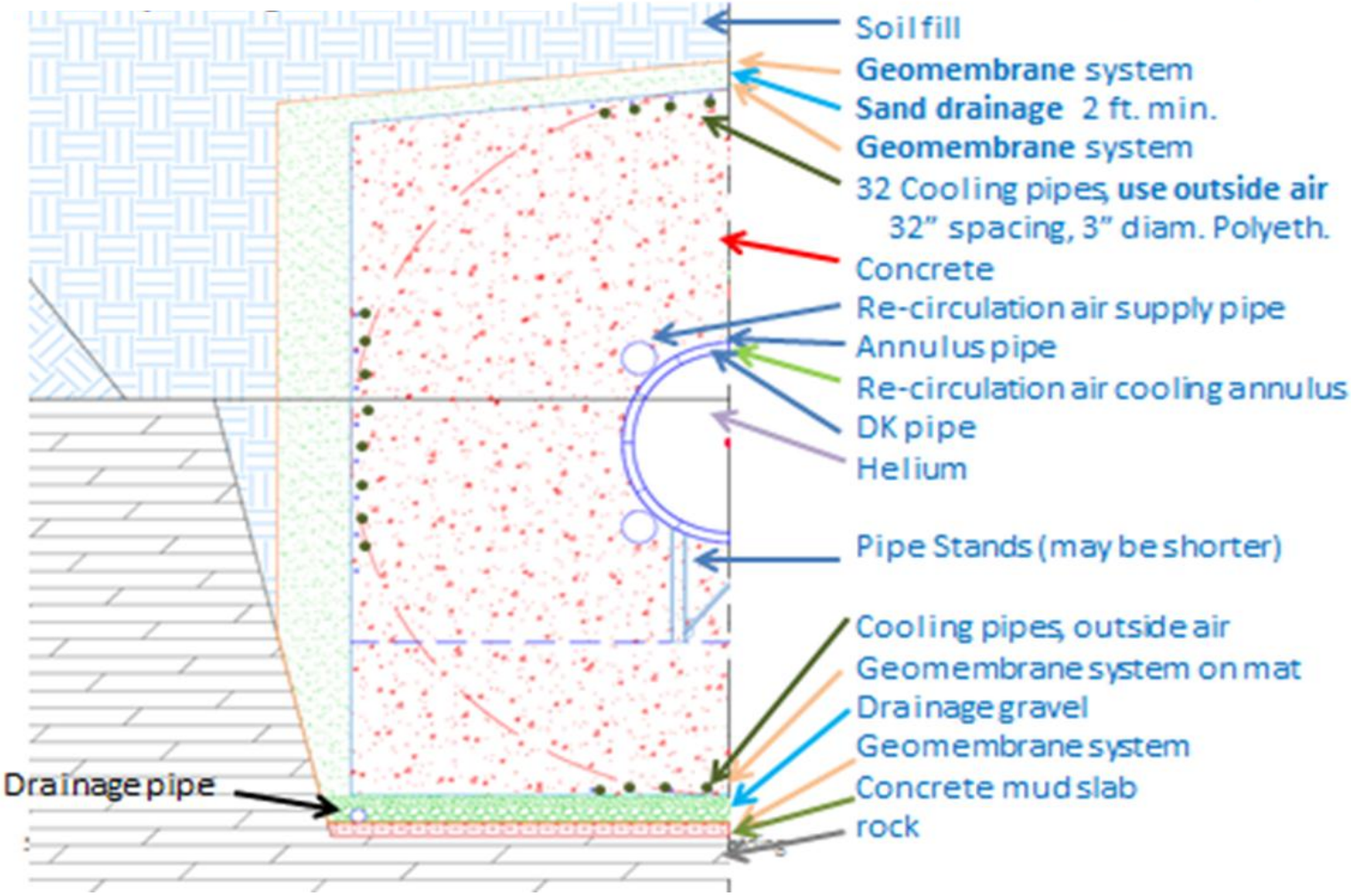


LBNF Target Chase and Decay Pipe Interface

Walls and the ceiling of the target hall are required to be 1.5m and 2.1m of concrete, respectively. However, for initial 1.2 kW operation the roof thickness has been reduced by 30 cm which can be easily replaced for the 2.4 MW operations.

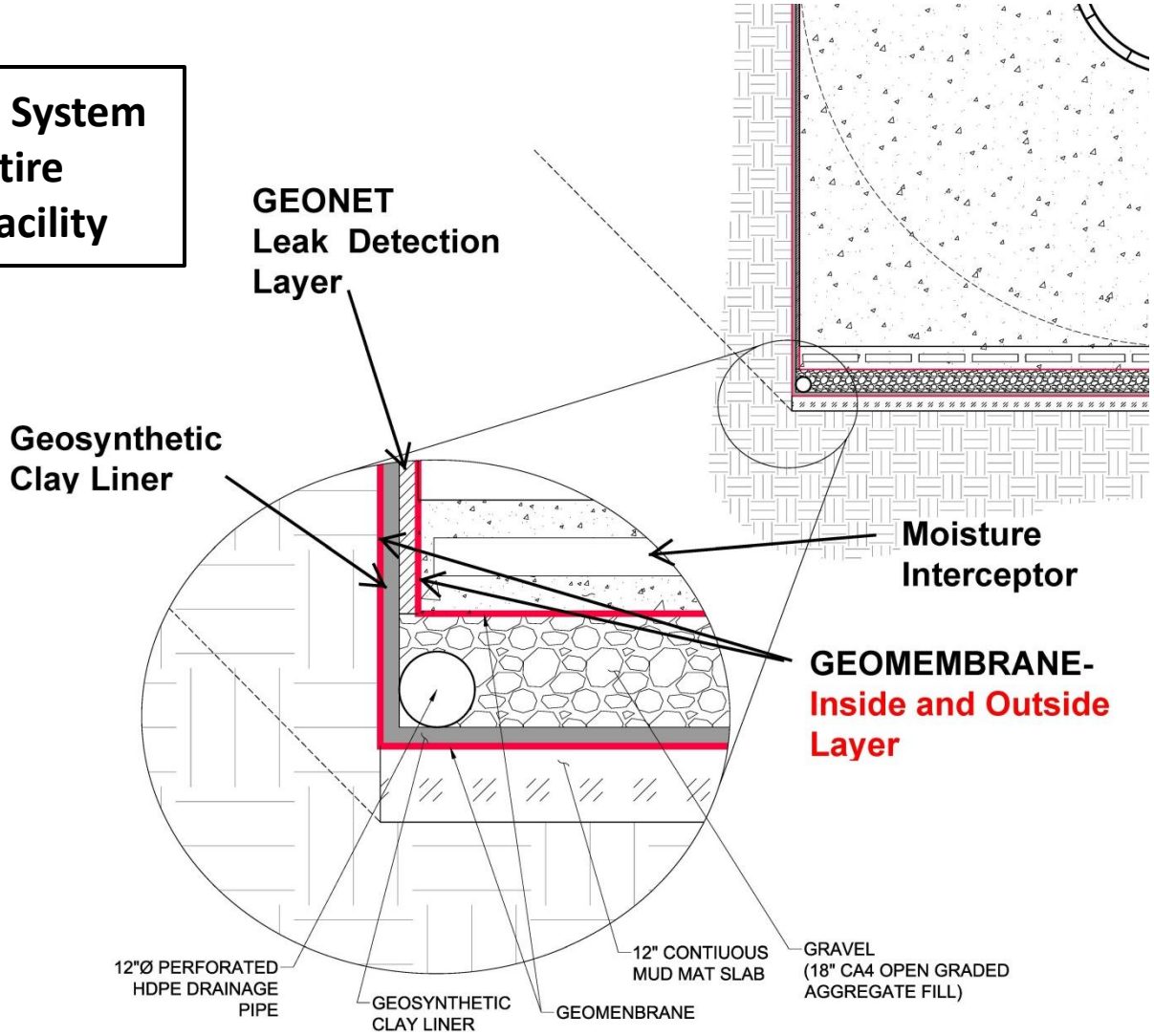


LBNF Decay Pipe Shielding

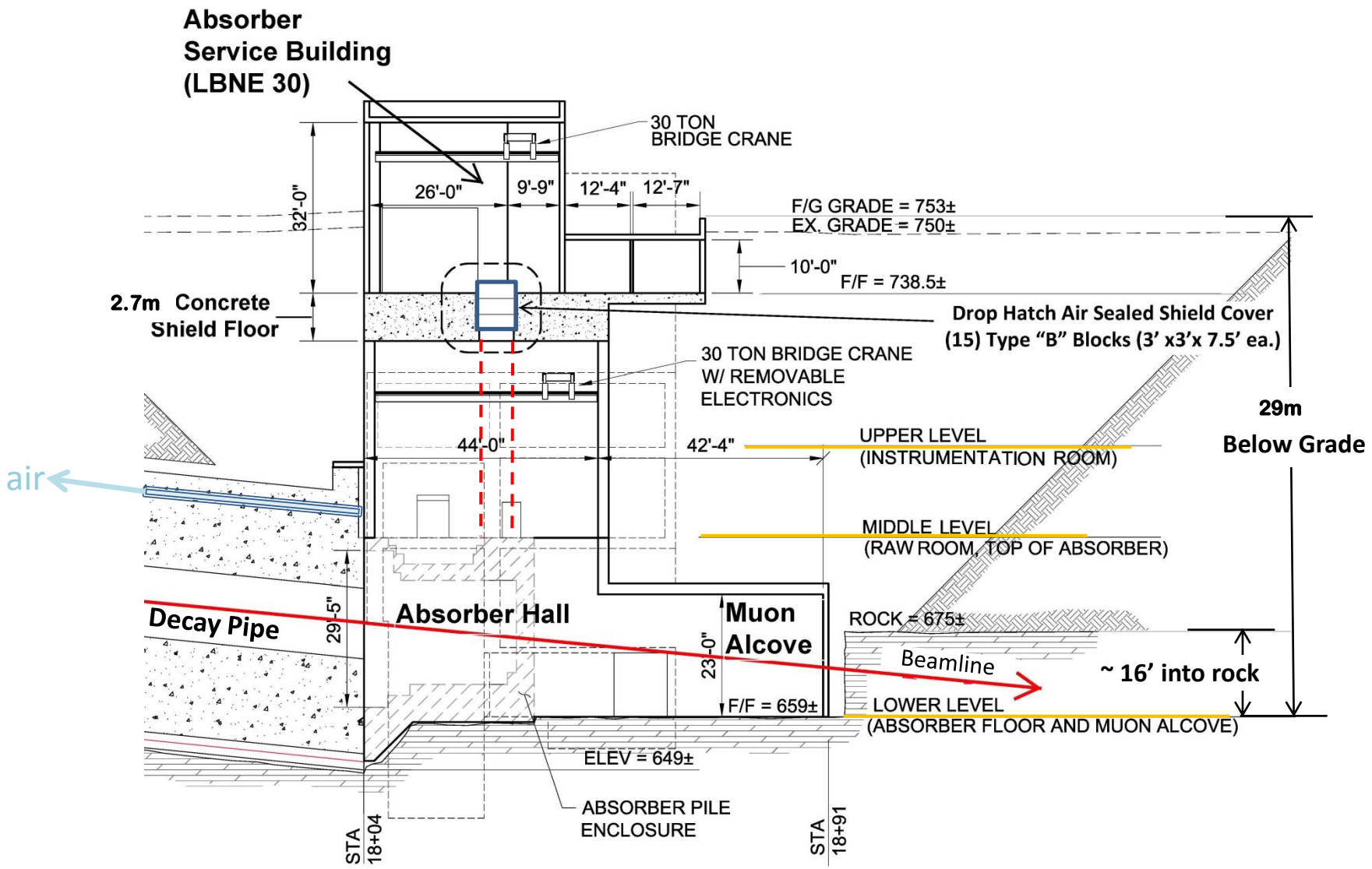


Geo-membrane System

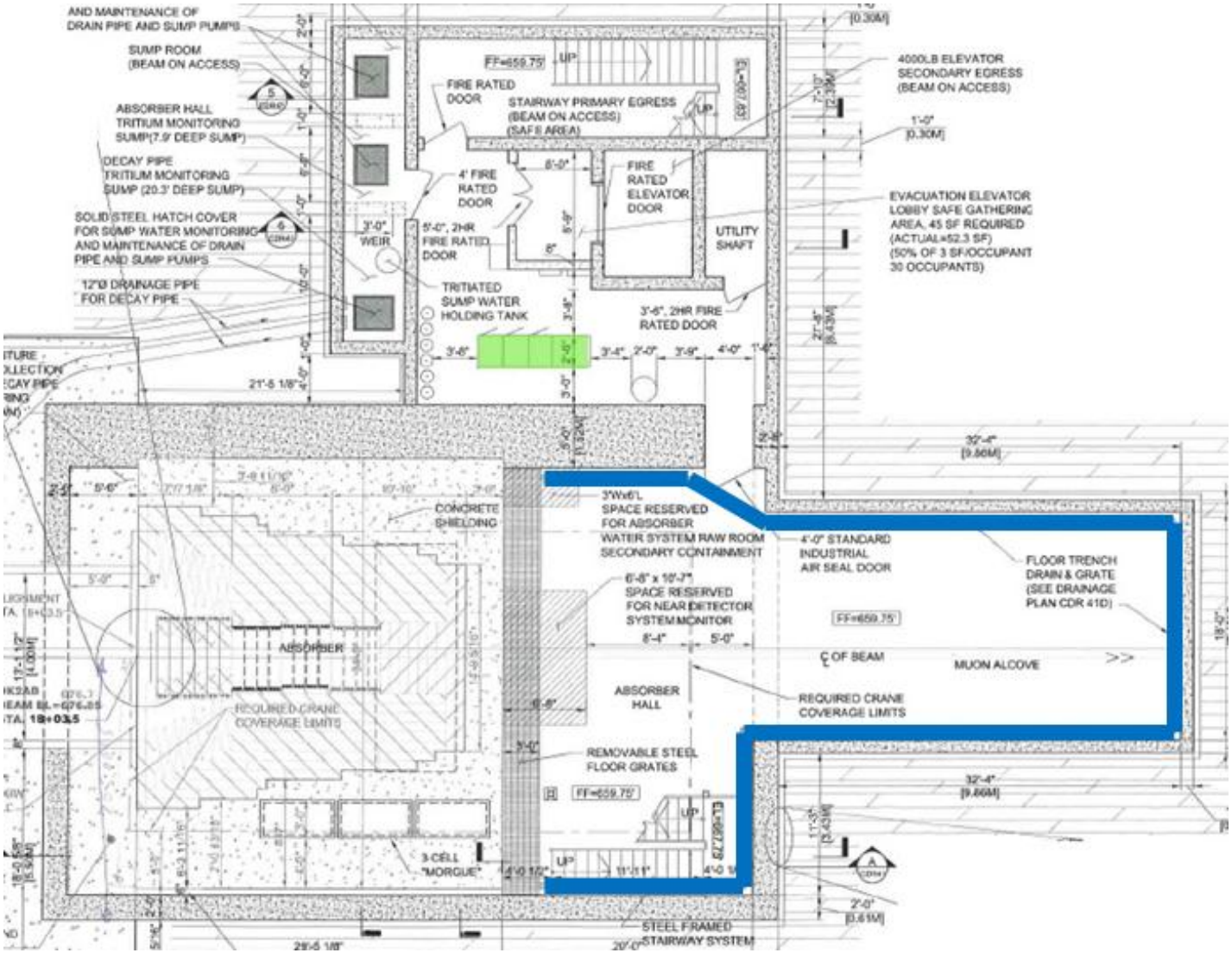
Geomembrane System Around Entire Decay Pipe Facility



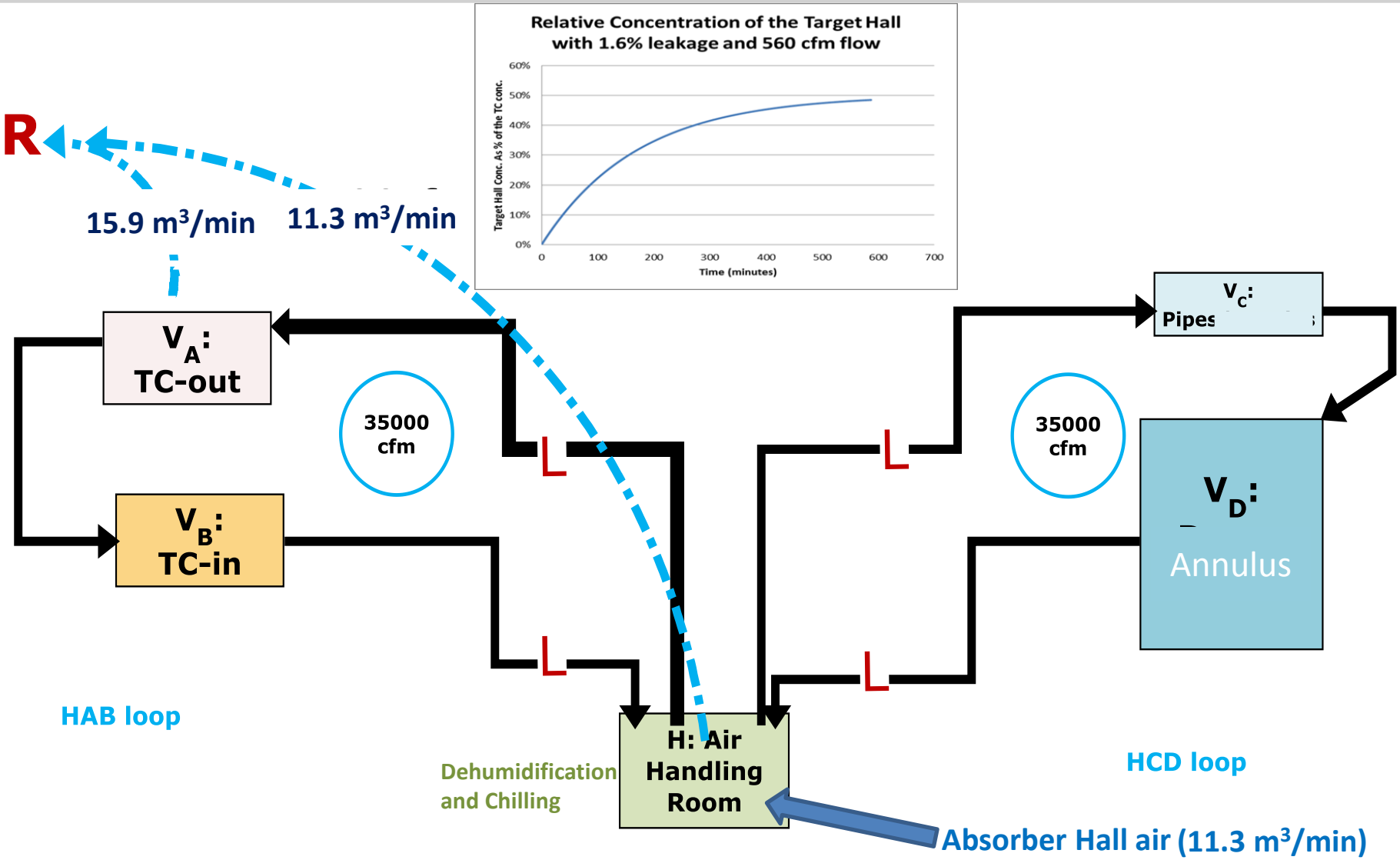
Absorber Complex -1



Absorber Complex -2



Simplified Air Flow Diagram



Activated Air Emissions

Txcool (hrs)	Total Annual (Ci)	Ar-41 (Ci)	Fraction of FNAL total budget
0	**304**	83	101%
0.5	**148**	68	49%
1	**85**	56	28%

- The activated air in the Target Hall will be sent to the NuMI beam line to take advantage of NuMI beam line's long air transit times. This transit provides much more than 1 hour of decay time for the air, before release to outside.

Residual Activation

- Primary transport line designed to keep losses to less than 1E-5 rate. With the steep grades of the LBNF primary beam enclosures, the beam loss and beam control devices will be employed to keep the residual radiation inside the beam line to less than **0.5 mSv/hr, on contact**.

- Neutrino beam line devices in the target chase could reach dose rates of a few tens of Grays per hour.

Average Dose Rates On Contact (Gy/hr)											
Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Target module	0.17	0.28	0.36	0.42	0.47	0.52	0.56	0.59	0.62	0.65	0.67
Target	0.38	0.62	0.80	0.93	1.05	1.15	1.23	1.31	1.38	1.44	1.50
Horn-1 module	*6.02*	*9.79*	*12.56*	*14.74*	*16.56*	*18.10*	*19.45*	*20.65*	*21.73*	*22.70*	*23.60*
Horn-1	5.33	8.66	11.11	13.05	14.65	16.02	17.21	18.27	19.23	20.09	20.88
Horn-2 module	*0.13*	*0.21*	*0.27*	*0.32*	*0.36*	*0.39*	*0.42*	*0.45*	*0.47*	*0.49*	*0.51*
Horn-2	0.65	1.05	1.35	1.58	1.78	1.94	2.09	2.21	2.33	2.43	2.53

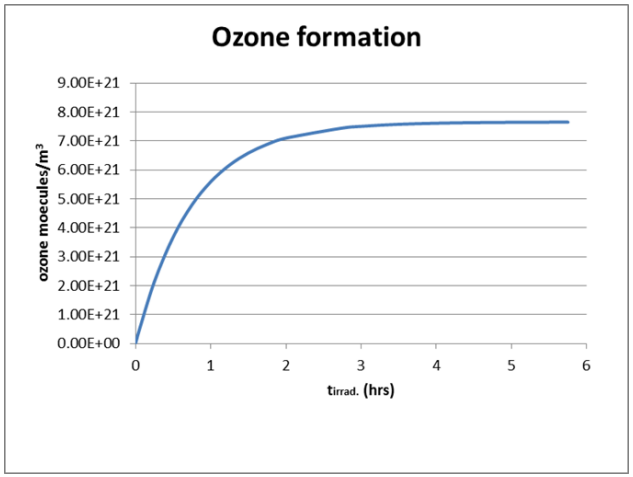
- Based on the predicted maximum activation levels after 10 years of operation, the shielding of the work/repair cell for these devices is designed such that for a 20 Gy/hr. object, the dose rate outside is less than 2.5 μSV/hr.

RadioActive Water systems

- Beam-on dose rates are high due to the high concentrations of short lived radio-isotopes in the RAW systems.
- RAW room is shielded.
- De-Ionization bottles have their own shielding.
- Several levels of **spill control** is built in the design of the RAW room and water systems.
- Radiolytically produce hydrogen gas will be vented.
- A predetermined cooling time is required before access to RAW room is allowed.
- RAW tanks will be sampled regularly.
- RAW is disposed of as low level radioactive waste.

Material Damage

- Ozone and Nitric Acid in target chase air are sources of corrosion
  - Reduce humidity
  - Remove acidic condensate during the chilling of air
  - Neutralize acid using Sodium Hydroxide
  - allow room for corrosion
- Radiation damage
  - Radiation damage knowledge
  - Radiation damage testing
  - Time/Distance/Shielding
  - Selection of material and placement
  - Inspection of equipment
  - Life expectancy



Radiological issues: Prompt sky-shine and direct doses

The combined annual direct and skyshine doses are calculated at the site boundary and at Wilson Hall. The doses are lower at other locations.

For a 2.4_MW_beam	Site Boundary (μSv/year)	Wilson Hall (μSv/year)
Primary transport line Skyshine	0.066	0.004
Transport line muons direct	0.333	0.000
Target hall with concrete roof skyshine	5.844	0.375
Target hall walls direct	1.835	0.006
Target hall roof direct	0.037	0.070
Decay pipe above ground section skyshine	2.155	0.138
Decay pipe above ground section direct	0.100	0.000
Absorber hall service building roof skyshine	2.800	0.017
Absorber hall service building roof direct	0.007	0.001
Total skyshine	***10.9***	***0.5***
Total annual dose, direct and skyshine	**13.2**	**0.6**

Summary

- LBNF beam line base design meets the radiological goals.

- **Refinements of the** base design continues as more detailed MARS simulations become available.