Shielding Design for the LBNE Decay Pipe

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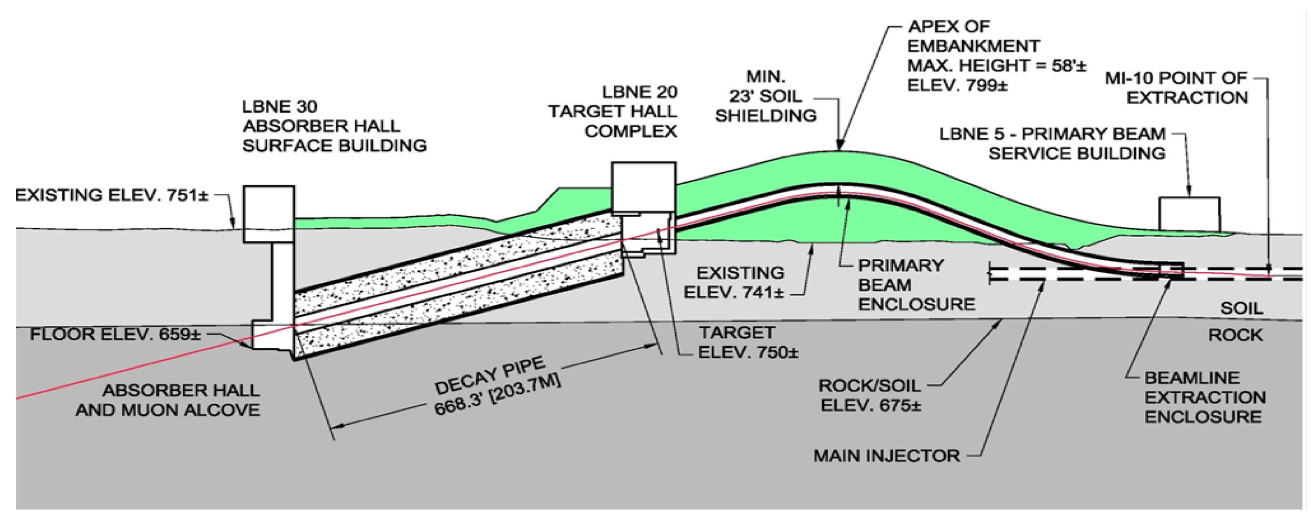
SATIF-12

Introduction

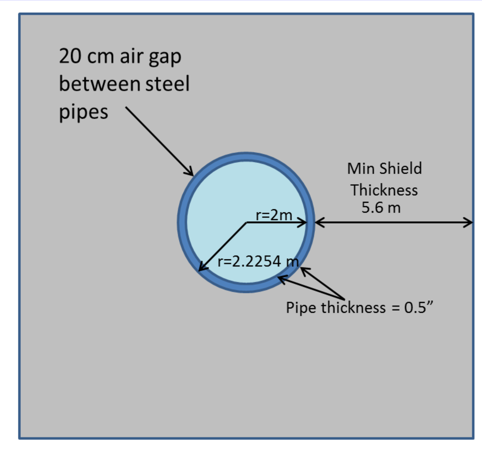
- The proposed Long Baseline Neutrino Experiment (LBNE) beamline is planned to deliver high intensity neutrino beam to a detector approximately 1300 km away in South Dakota.
- Operation of LBNE will generate radionuclides in the surrounding soil which can leach into the groundwater resources.
- Sufficient shielding on the decay pipe is needed to maintain the radionuclide concentration in the groundwater resources below State and Federal environmental regulatory limits on drinking water.
- Use MARS15 to calculate radionuclide concentrations in soil immediately outside of the decay pipe shield.
- Apply conservative assumptions in calculation to minimize risk of underestimating radionuclide concentrations in ground water.

LBNE Beamline Layout



Decay Pipe Shield Cross section

- 4m diameter decay pipe
- 20 cm air gap between inner an outer steel pipes for cooling purposes.
- Square cross section



Regulatory Limits on Radionuclide Concentration

- ^{3}H and ^{22}Na are the radionuclides of concern
- All other radionuclides generated are either too short lived, not mobile or are produced in significantly less quantities than ^{3}H and ^{22}Na to not warrant inclusion in the concentration calculation.

Federal Limits:

$$\sum_i \frac{C_i}{C_{i,\max}} \le 1$$

- C_i = Concentration of i^{th} nuclide
- $C_{i,max}$ = Derived Concentration Standard
- $C_{3H,max}$ = 20 pCi/cm^3
- $C_{22Na,max}$ = 0.4 pCi/cm^3

State of Illinois Standard:

- No degradation of the waters of the State
- To maintain radionuclide concentrations below detectable limits, use as target:

$$\sum_i C_i / C_{i,\max} \le 0.1$$

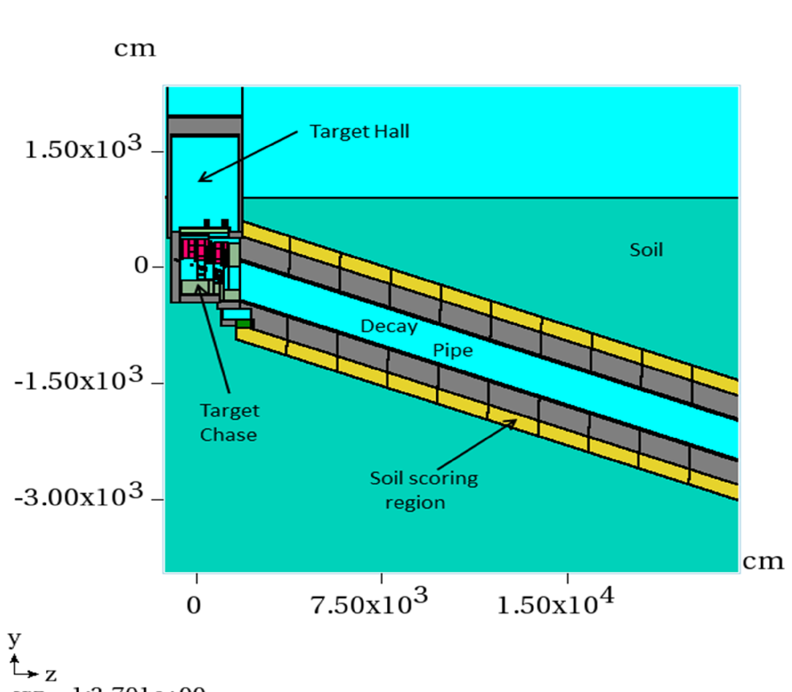
Detectable Limits:

^{3}H: 1 pCi/cm^3

^{22}Na: 0.04 pCi/cm^3

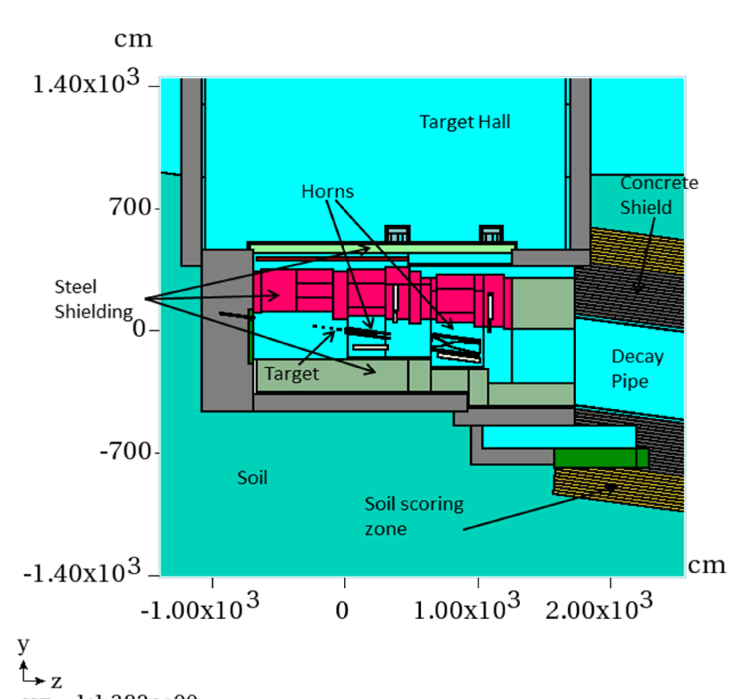
MARS Target Hall and Decay Pipe Model

Full Layout



- 200 m Decay pipe
- Detailed shielding in target hall
- Simplified focusing horns
- Air filled decay pipe
- Decay pipe cross section is circular instead of square for ease of calculation

Target Hall Detail

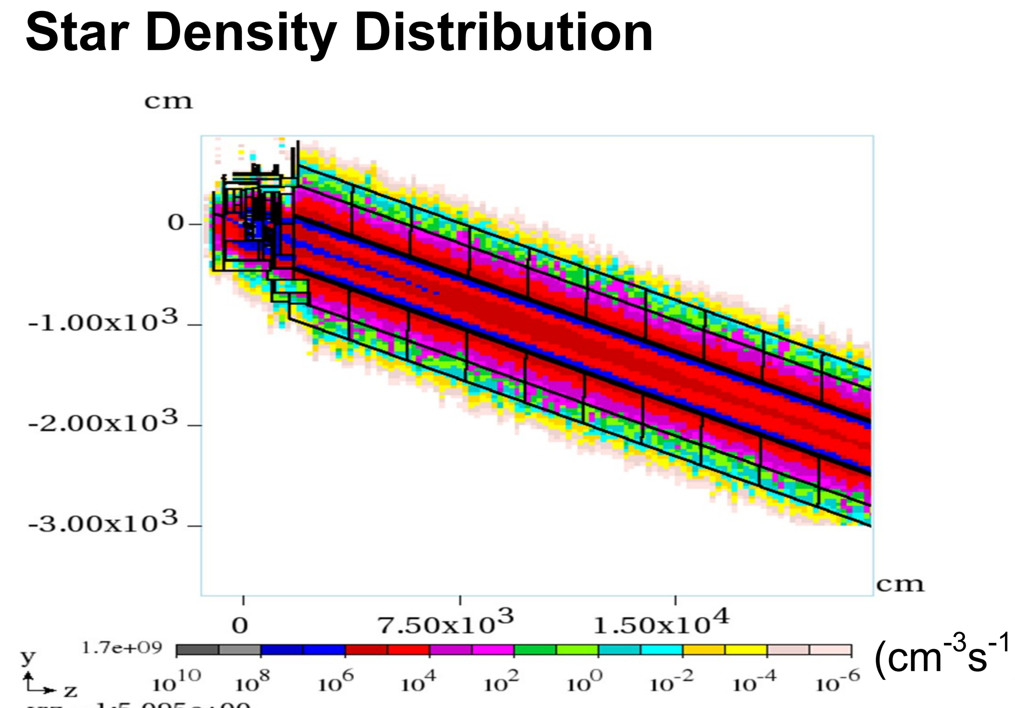


- Shield thickness fixed at 3 m
- Soil scoring region 2 m thick
- Decay pipe shield and soil scoring region subdivided into 10 longitudinal subsections

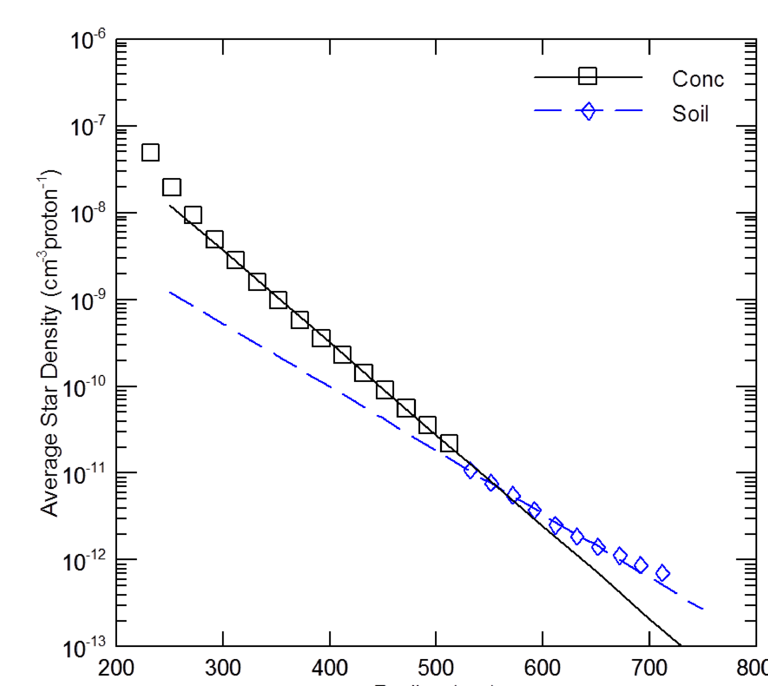
Star Density Calculation

- Extract out average star density (S_{av}) over a volume which contains 99.9% of the stars in the soil.
- Impractical to do multiple runs through very thick shielding to calculate the radionuclide concentrations.
- Use radial star density distributions to extract attenuation factor for concrete and soil.
- Extrapolate star density results for shielding thicker than 3m.

Star Density Distribution



Radial Star Density Distribution

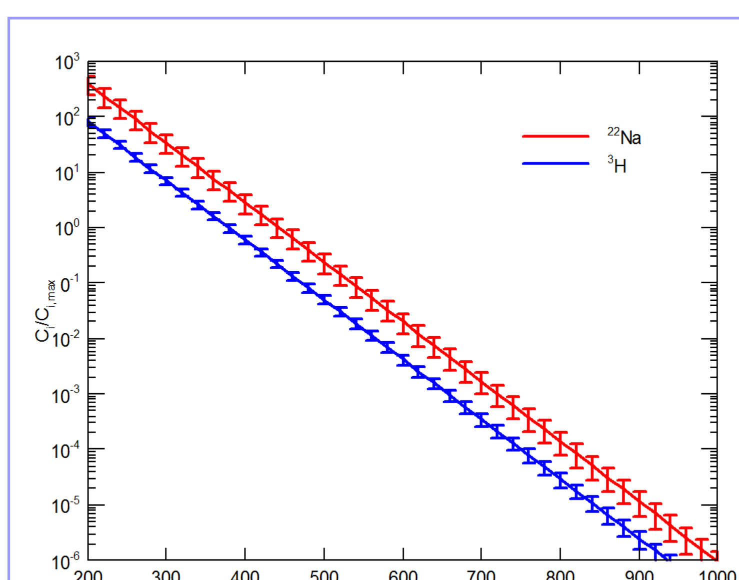


Nuclide Production

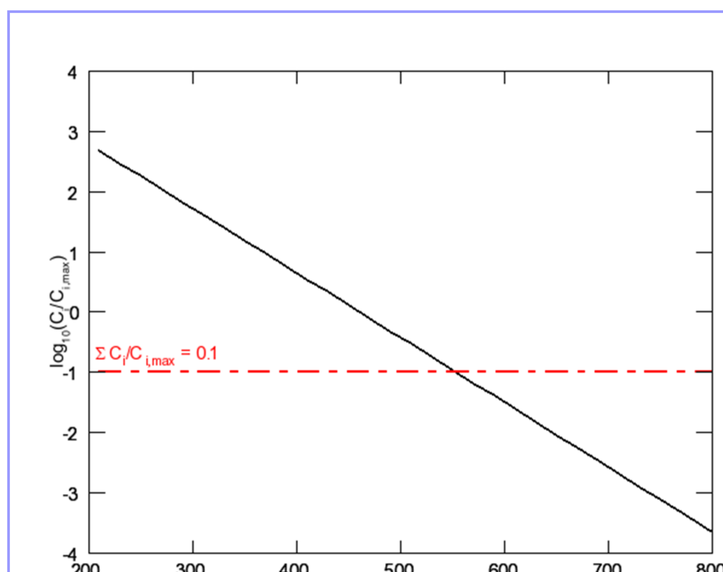
- Calculate the fraction of ^{3}H and ^{22}Na produced per star in soil (K_i).
- K_{3H} = (2.9±0.3)×10^{-2}
- K_{22Na} = (2.6±0.2)×10^{-2}

Radionuclide Concentrations

- Use average star density in the volume containing 99.9% of the stars and the nuclide production per star as calculated from MARS to estimate the radionuclide concentrations.
- Total integration time is 30 years for a 2.3MW 120GeV proton beam at a 65% duty factor.



The concentration ratio ($C_i/C_{i,max}$) for ^{22}Na and ^{3}H as a function of shield thickness. ^{22}Na dominates due to the smaller value for the Derived Concentration Standard. These results are extrapolations from the results for 3m of concrete shielding.

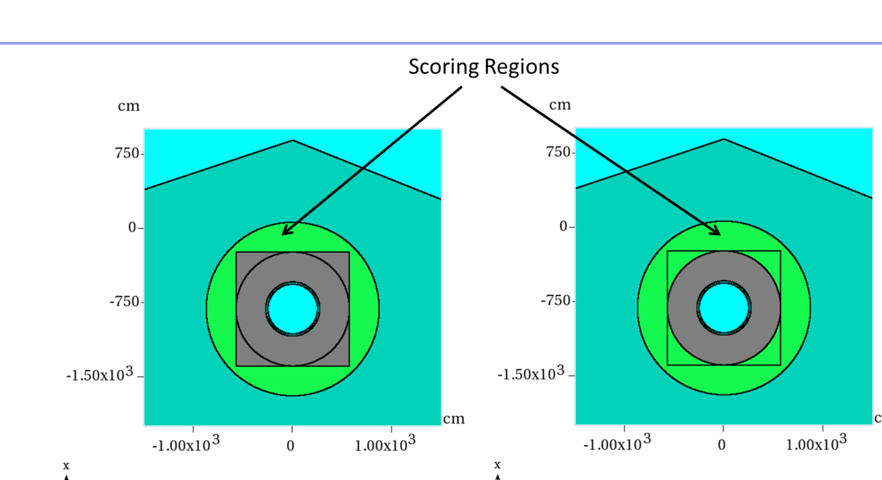


The sum of concentration ratios as a function of decay pipe shield thickness. The minimum shield thickness is located where the sum of the concentration ratios matches the condition:

$$\sum_i C_i / C_{i,\max} \le 0.1$$

Minimum Shield Thickness Definition

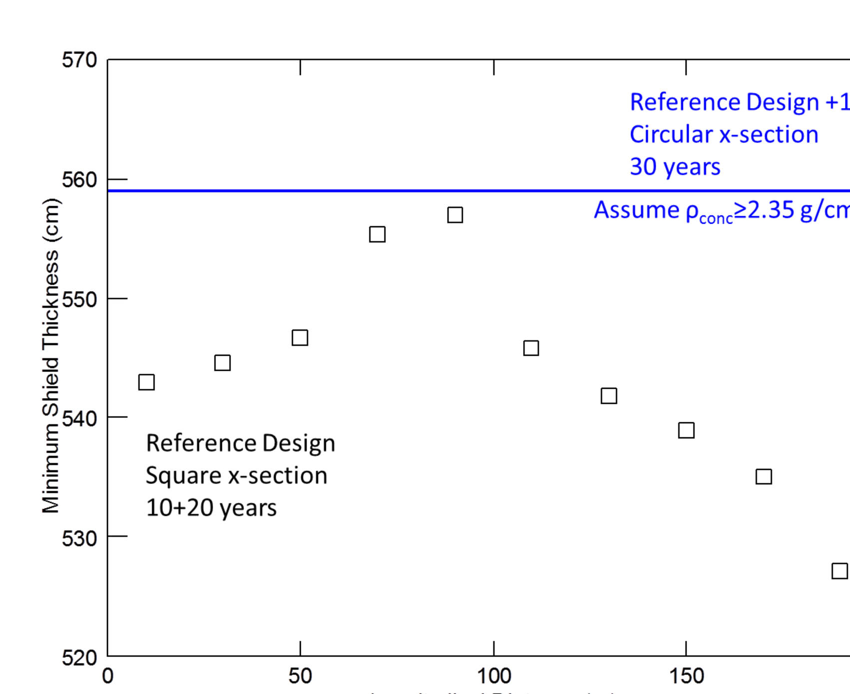
- Need to minimize the chance of detecting radionuclides in the ground water during the lifetime of the LBNE beamline while remaining within the project's budget.
- Uncertainties in operation and input parameters may underestimate the amount of radionuclides produced during operation.
- Add the 1σ error to the final result to accommodate the uncertainties in the input parameters.
- Assume operation at the maximum possible beam power for the maximum lifetime of the facility even though the beamline will be initially operated at a lower beam power.
- The circular shield cross section in the MARS model will overestimate the star densities compared to the planned square cross section. The square shielding cross section will reduce the average star density in by 88%.



The correction factor shielding cross section was determined by using MARS to calculate the star density in a cylindrical scoring region surrounding the decay pipe but excluding the area that would lie inside the square decay pipe shield. The ratio of the star densities in the scoring region for the circular shield and that for the square shield was found to be 0.88

Results

- Minimum shield thickness is 559±10 cm
- Corrected minimum shield thickness for all 20 m long subsections are less than the conservative average minimum shield thickness.



The minimum shield thickness as a function of z-position in the decay pipe. The black boxes are the results scaled by the shield cross section correction and the integration time correction for 10 years at 700kW followed by 20 years at 2.3MW. The blue line shows the average minimum shield thickness plus 1σ with no correction factors applied.