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Analysis of Radionuclide Activation in the NuMI Decay Pipe Shield

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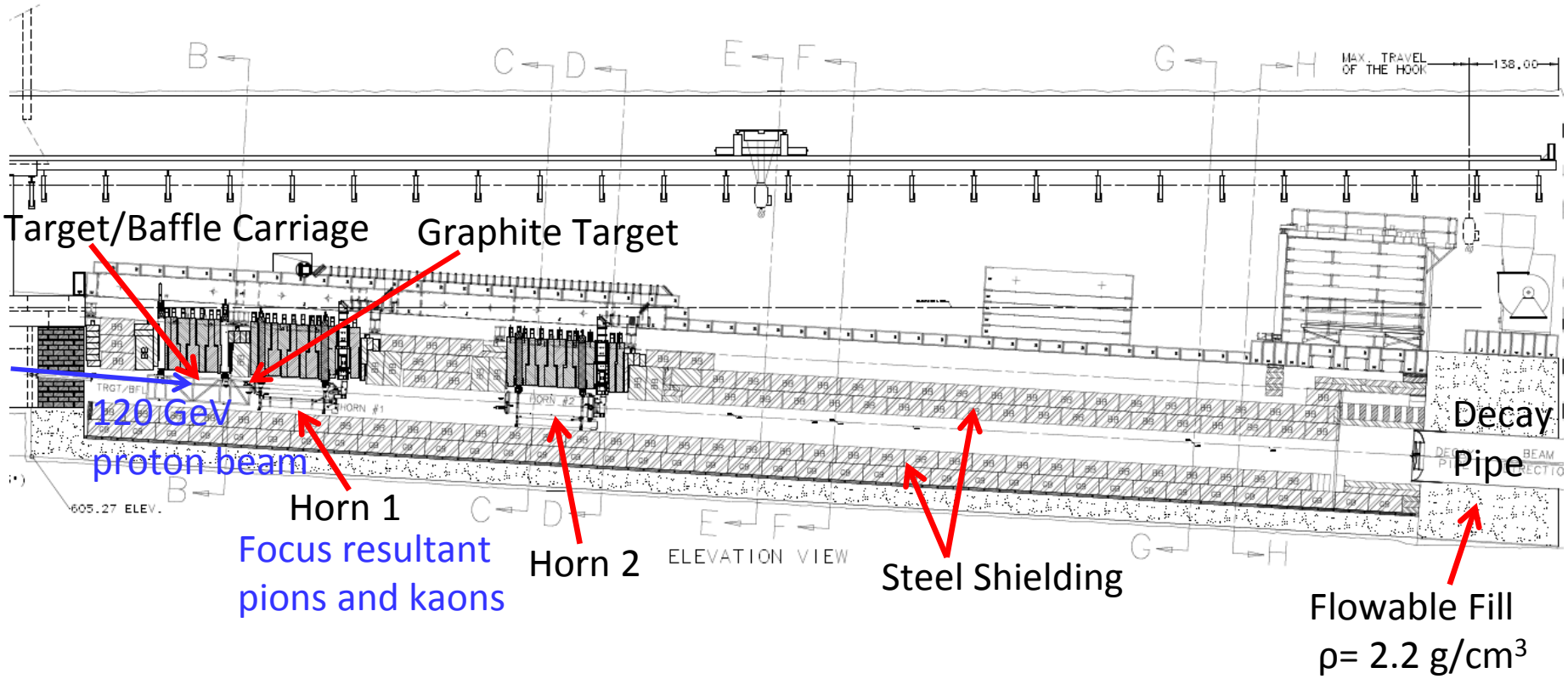
Outline

- Introduction
- NuMI beamline
- Activity found in the NuMI decay pipe shield
- Simple MARS model of NuMI for radionuclide production calculations
- Comparison of data to MARS
- Conclusion

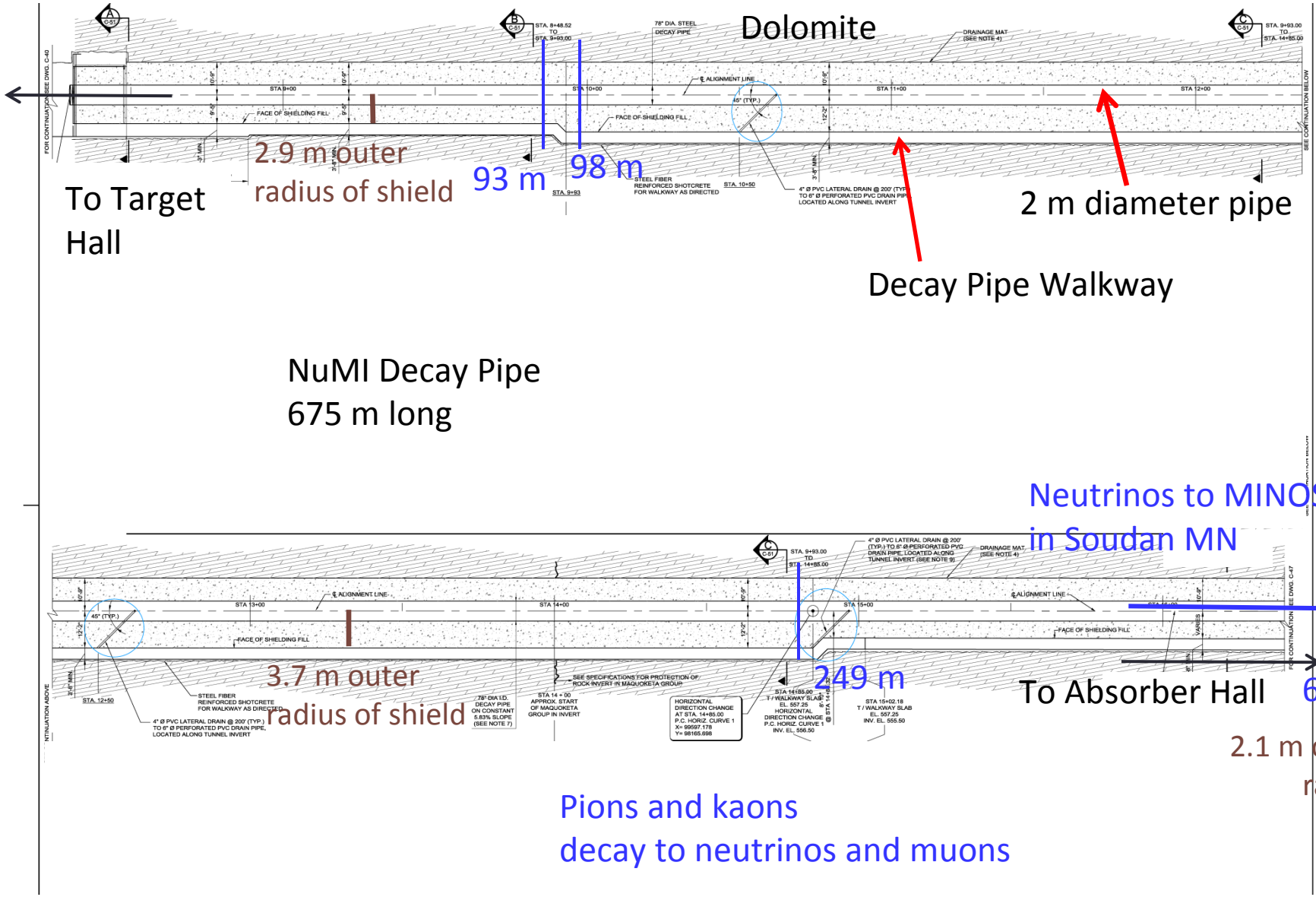
Introduction

- Tritium is highly mobile.
  - Can transmit as gaseous hydrogen (HT) or as water (HTO)
  - Able to transfers from one medium to another.
  - Is difficult to contain.
- Important to understand tritium production and behaviour in beamline shielding.
  - Use core samples collected in 2006 and 2010 from the NuMI decay pipe shield for tritium studies.
- Test MC method to predict tritium production.
  - Use non-tritium radionuclides as benchmark.

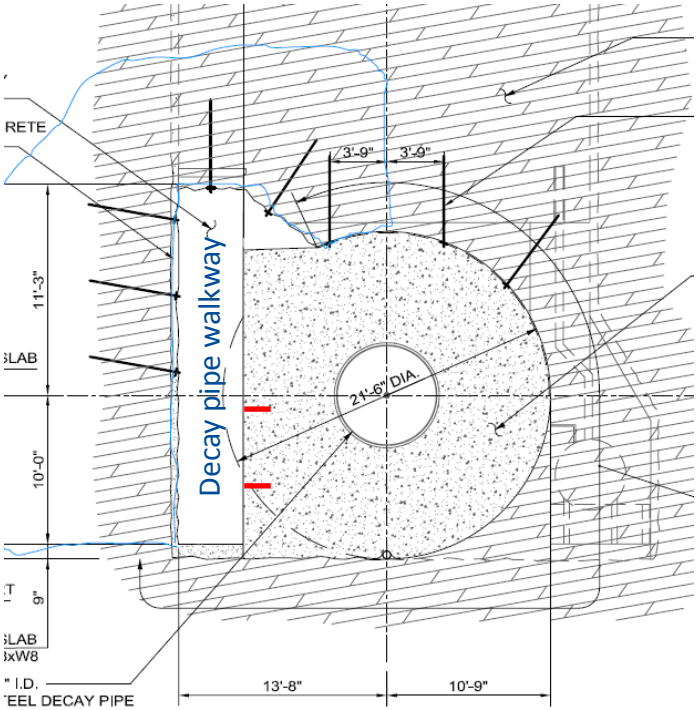
NuMI Target Hall



- NuMI Beamline is subject to inflow of ground water.
  - Provides an easy route for tritium migration.
- Dehumidifiers in target hall are used to remove water from the air.
- Air from the target hall is moved down the decay pipe passageway.


Dolomite
2.9 m outer
radius of shield
93 m
98 m
To Target
Hall
2 m diameter pipe
Decay Pipe Walkway
NuMI Decay Pipe
675 m long
Neutrinos to MINOS
in Soudan MN
3.7 m outer
radius of shield
249 m
To Absorber Hall
683 m
2.1 m outer
radius
Pions and kaons
decay to neutrinos and muons

Sample Locations



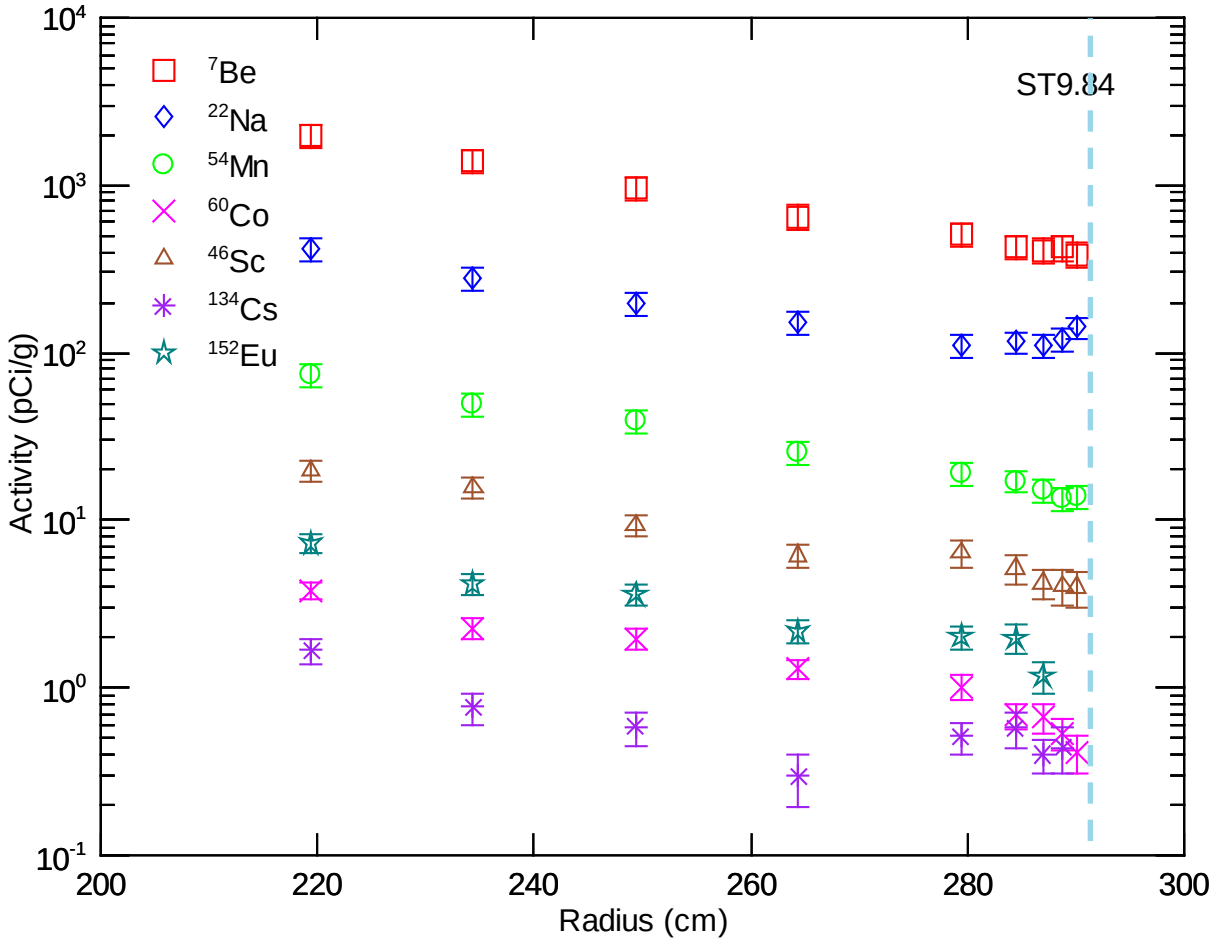
Decay pipe cross section. The red lines show locations of samples.

Face of the decay pipe shield where some core samples were collected

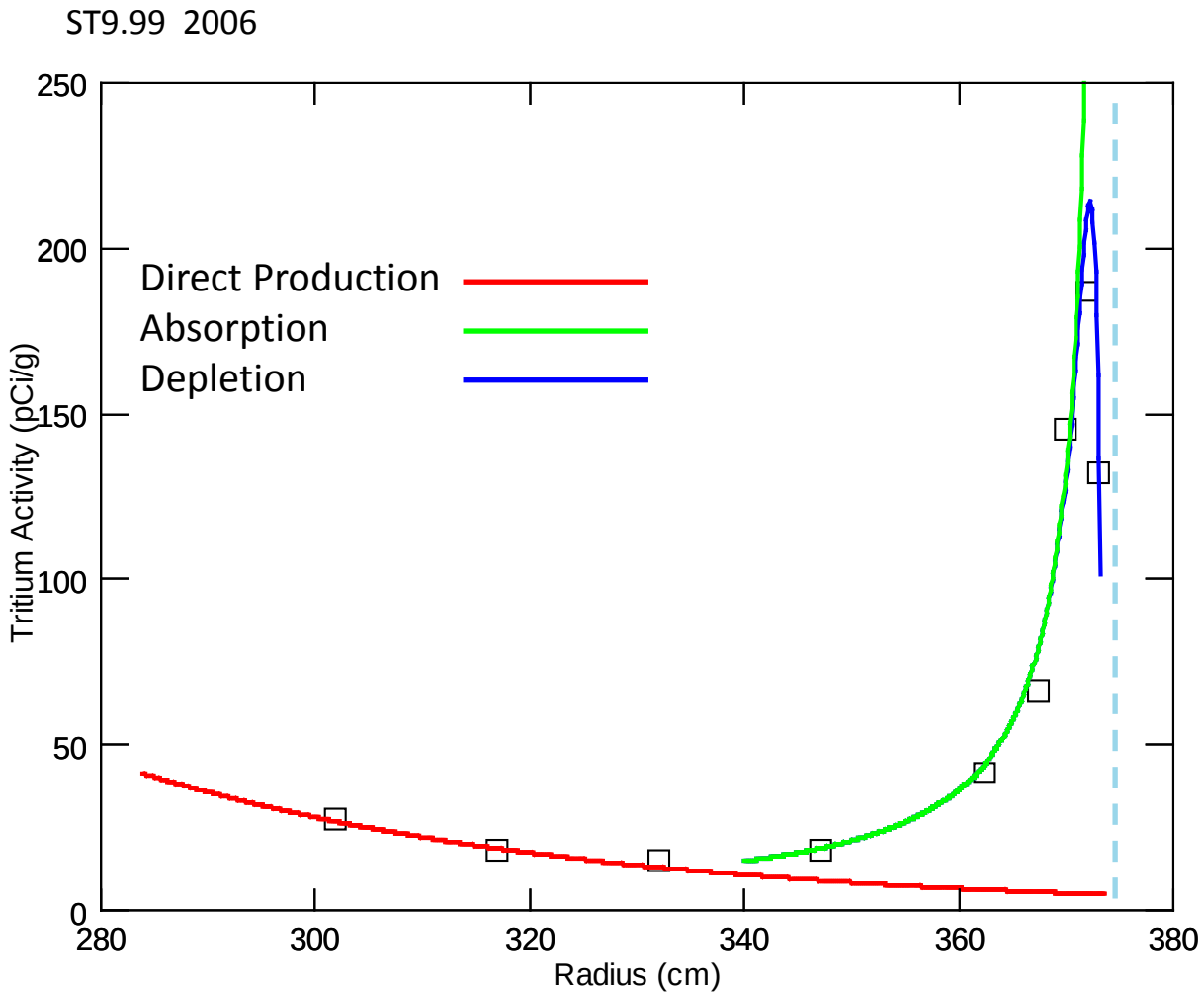
Data Analysis

- Several samples collected at different depths from each sample location.
  - Sample collection occurred after several days of beam off.
- Samples first analyzed using a high purity germanium detector for radionuclide activity.
  - ^{7}Be, ^{22}Na, ^{54}Mn, ^{46}Sc, ^{60}Co, ^{134}Cs and ^{152}Eu where found.
- Tritium's low beta endpoint energy and no decay gamma means that it cannot be counted directly from the samples.
  - Tritium was leached from the samples and the leachate analyzed using a Tri-Carb LSC analyzer.
    - Not all tritium is collected from a single leaching process.
  - ^{22}Na was also detected in the leachate

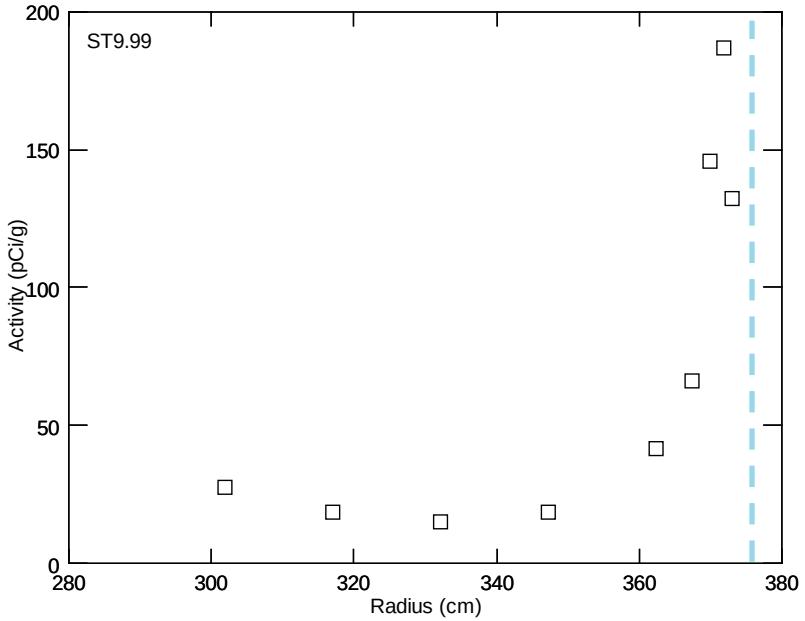
Activity at Upstream End of Decay Pipe

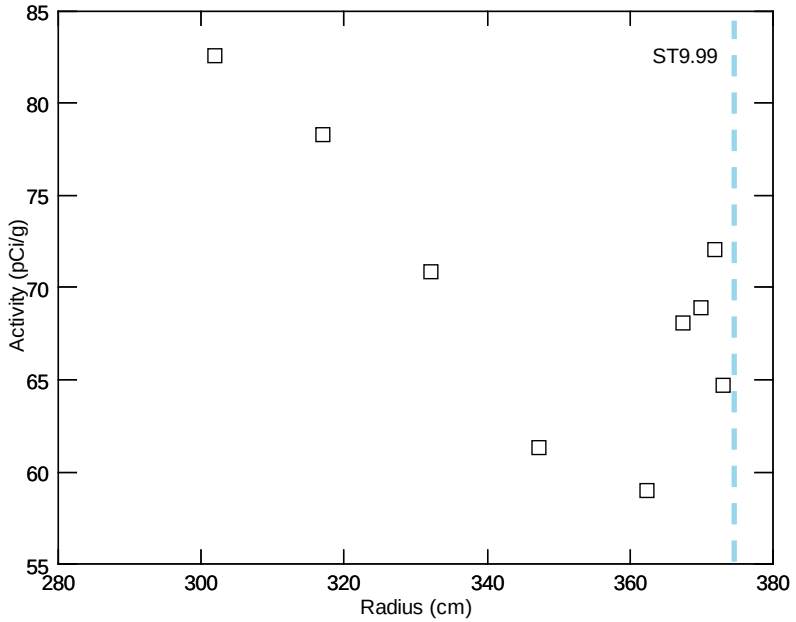


Tritium Activity at Upstream End of Decay Pipe in 2006



Tritium Activity at Upstream End of Decay Pipe





2006

No dehumidifiers in target hall

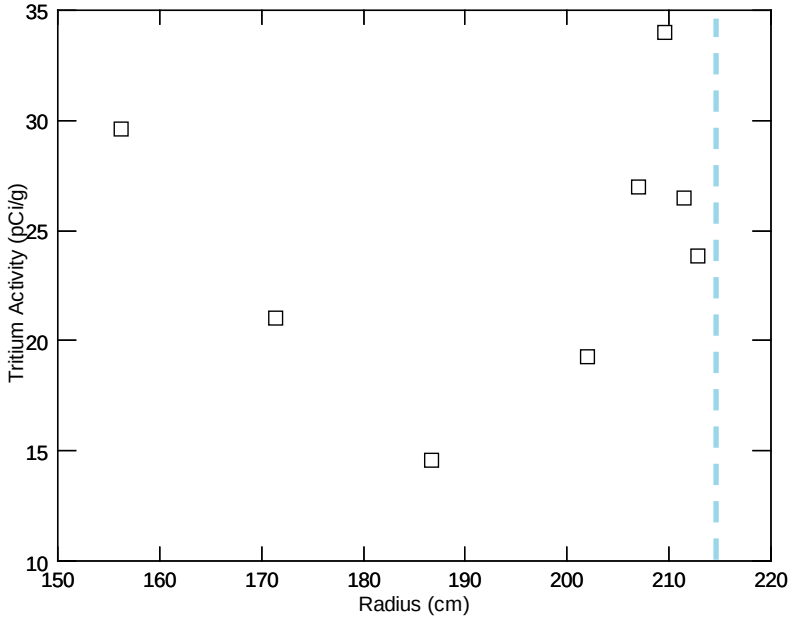
375 days total, 75 days beam off

2010

Dehumidifiers in target hall

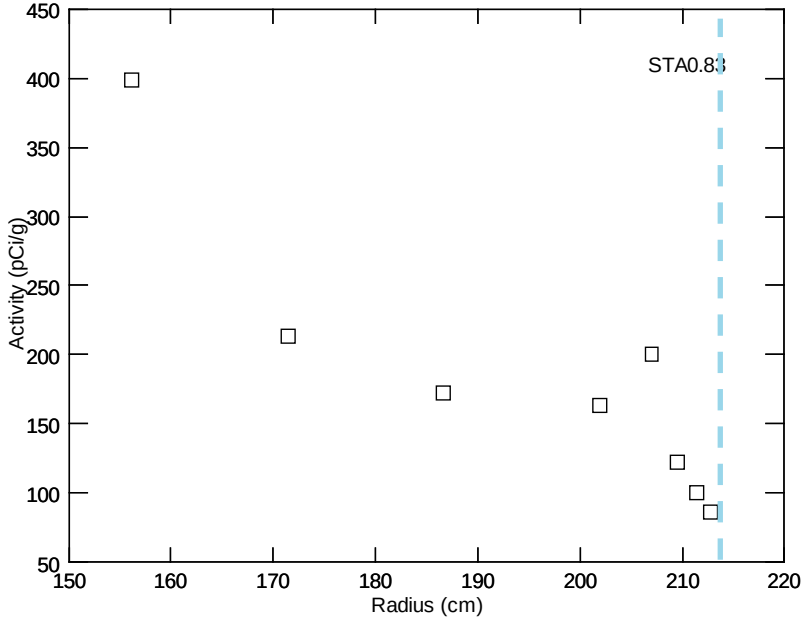
1899 Days total, 28 days beam off

Tritium Activity at Downstream End of Decay Pipe



2006

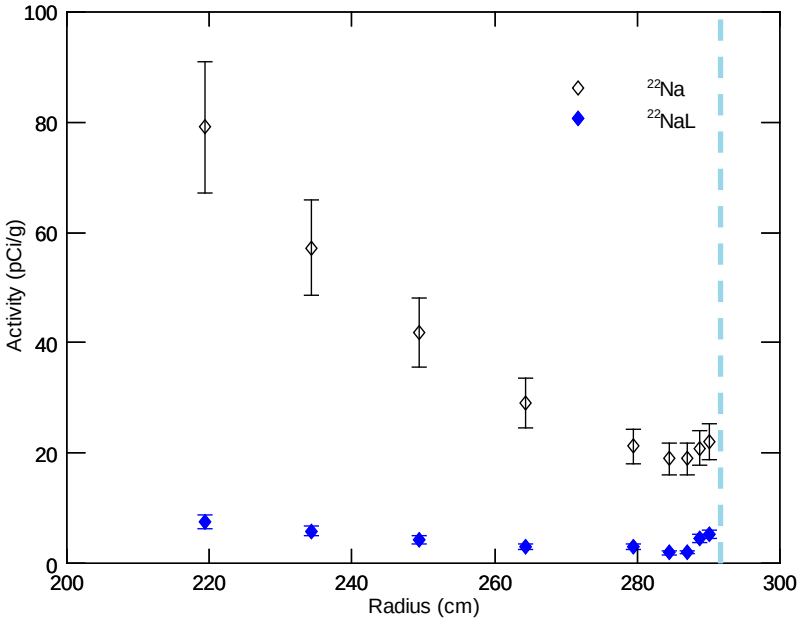
No dehumidifiers in absorber hall



2010

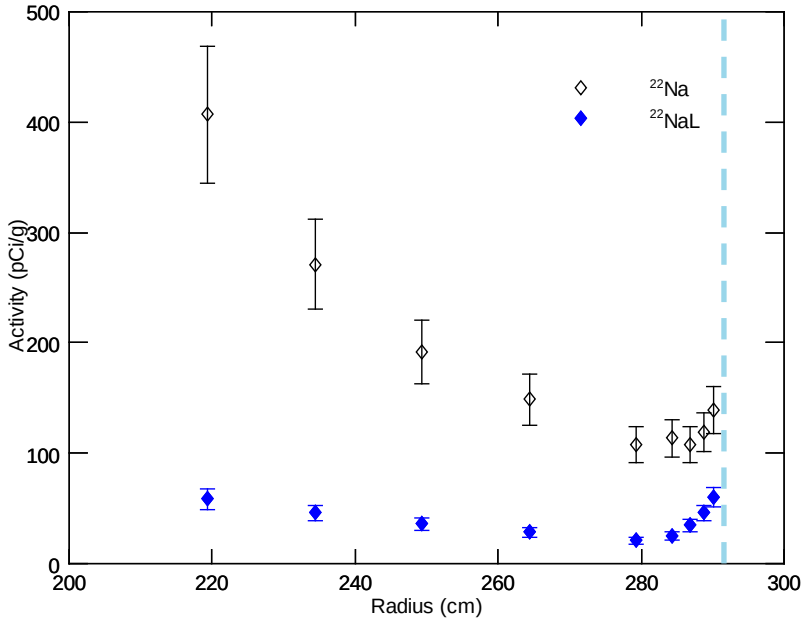
Dehumidifiers in absorber hall

^{22}Na Gamma vs Leachate



2006

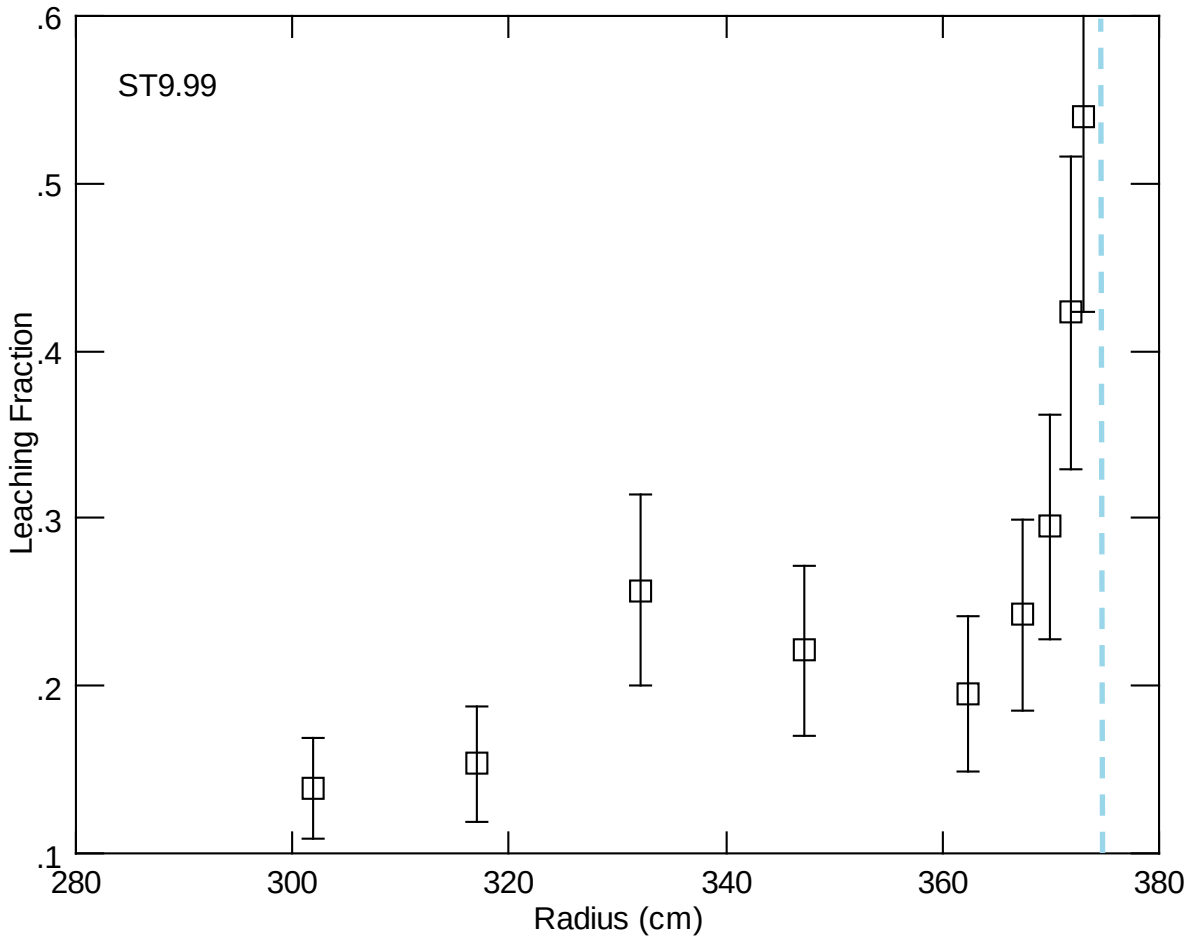
Upstream, thin shield



2010

Upstream, thin shield

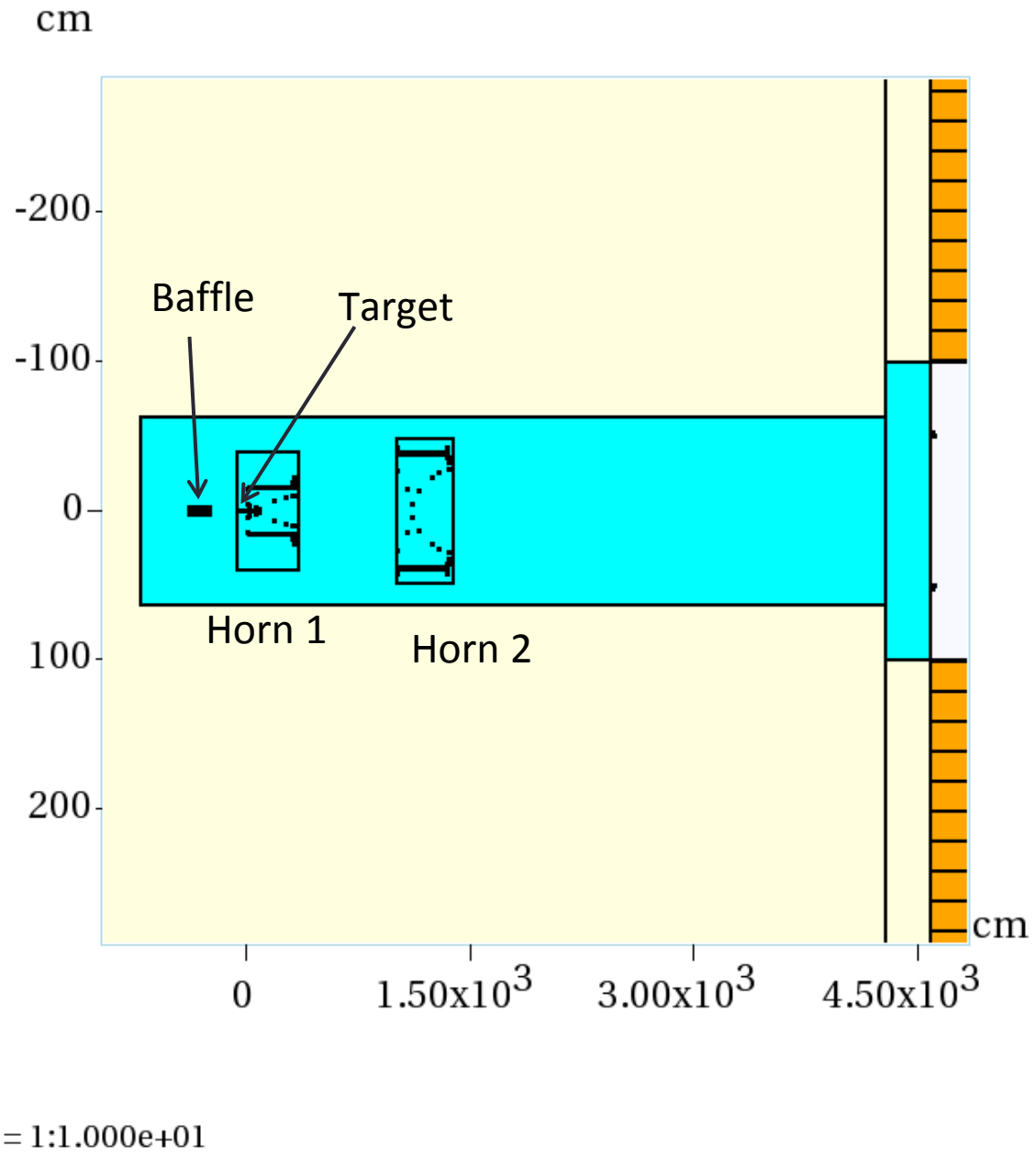
Leaching Fraction for ^{22}Na



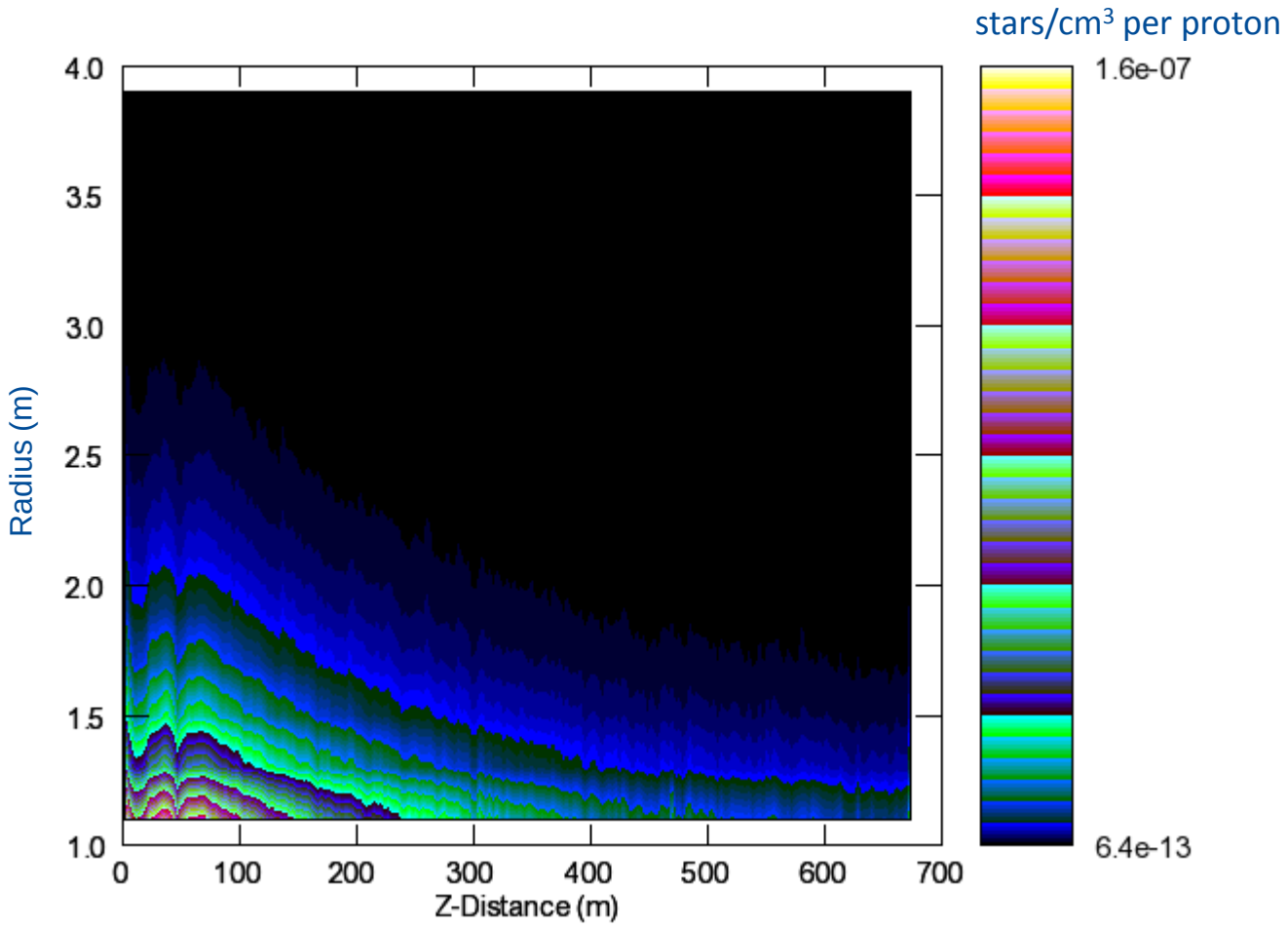
MC Analysis

- Direct inventory of tritium is difficult to do for shielding
  - Diffusion effects at surface
  - Not all tritium leached from shielding for analysis.
- Try using MARS to predict tritium activity in shielding.
  - Test against other radionuclide production found in the shielding.
  - Deduce leaching fraction for tritium by comparing activity ratios of tritium to other radionuclides
- Use simple geometry model of NuMI target hall and decay pipe.
- Extract out star densities in decay pipe shield for nuclide spatial distributions.
- Extract nuclide production per star for R>1.7 m.

NuMI Target Hall in MARS

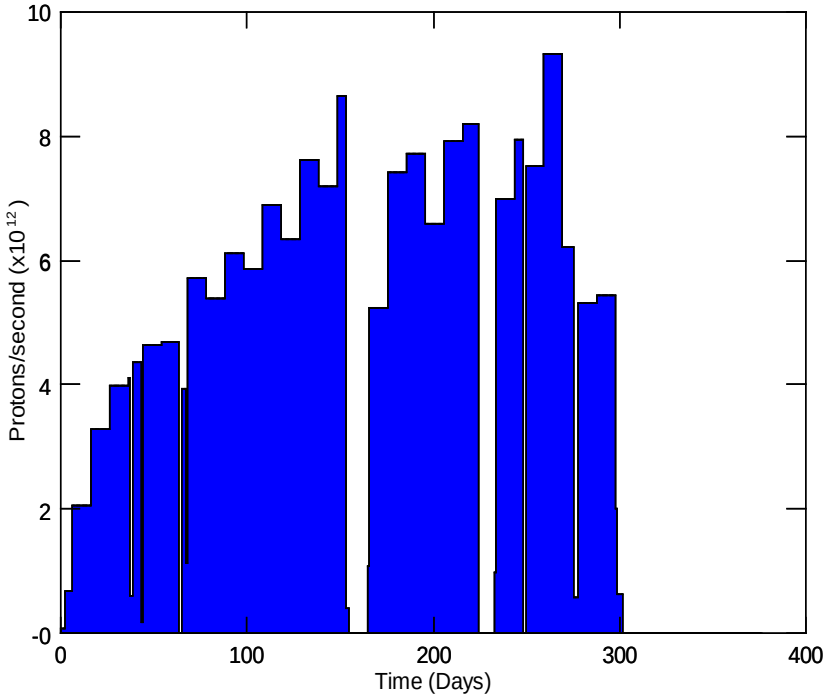


Star Density per Proton in the Decay Pipe Shield

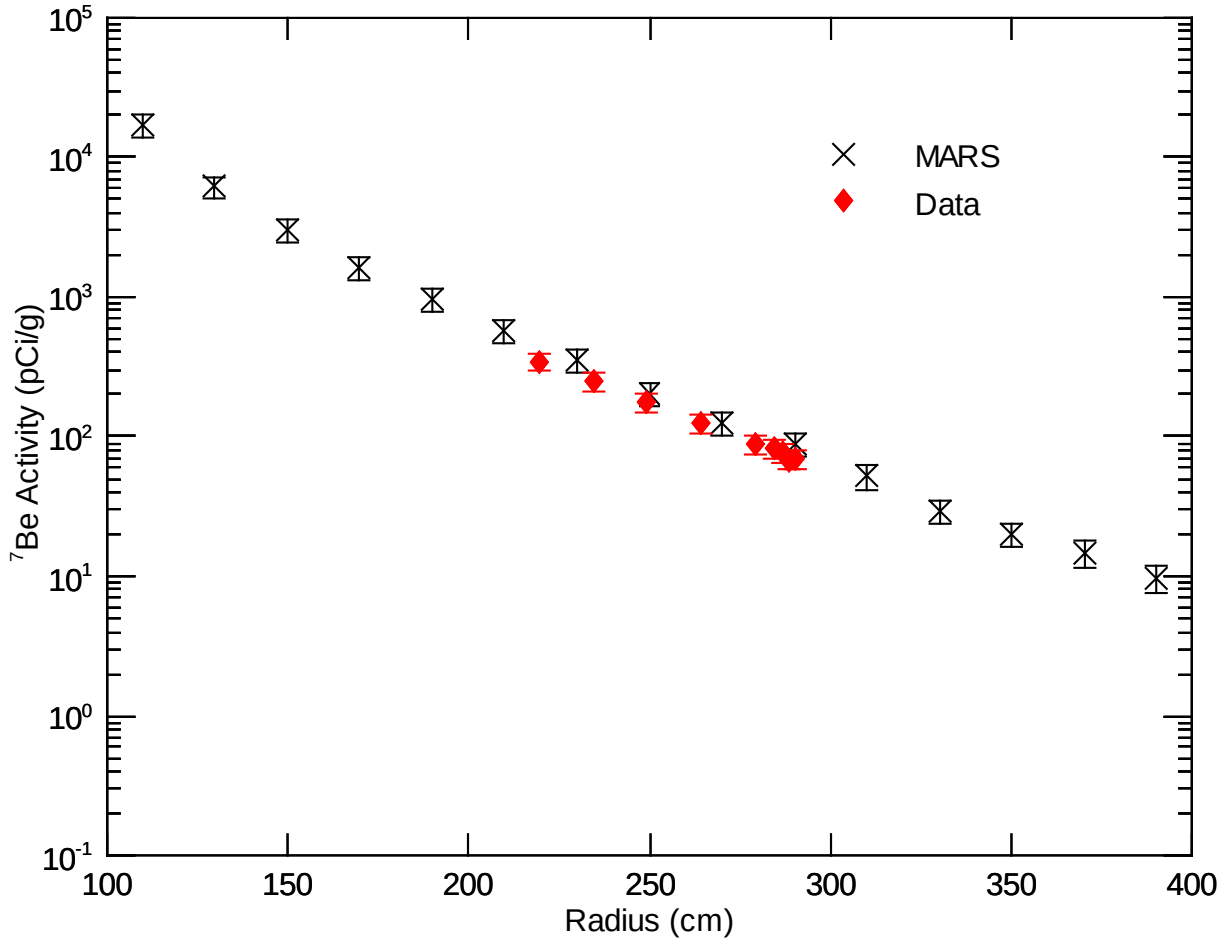


Nuclide Production Calculation

- Extract nuclide production per proton for R>1.7m
- Use DETRA to calculate activity A_{tot}.
- Intensity based on NuMI POT data.
- Integrate over 375 days to compare to 2006 results
  - 300 day beam on
  - 75 day s beam off
- Use Ratio of stars per bin over stars for R>1.7 m to scale activity.



2006 ^{7}Be Radial Distribution



Radial Distribution Fits

- MARS Fit:
  - $a_1 e^{-b_1 r} + a_2 e^{-b_2 r}$
  - Identify first term with rapid drop-off at small radius
  - Identify second term with attenuation at large radius
  - $b_1 = 0.077 \pm 0.002$, $b_2 = 0.024 \pm 0.001$
- Data Fit:
  - Core samples not deep enough to fit the first term
  - $a_2 e^{-b_2 r}$
  - $b_2 = 0.0229 \pm 0.0011$

Nuclide Activity Comparison

Nuclide	MARS Activity (pCi/g)	DATA Activity (pCi/g)	MARS Ratio ^{7}Be/X	Data Ratio ^{7}Be/X
^{7}Be	454±91	346±52	1	1
^{22}Na	111±22	78.7±11.9	4.1±0.7	4.4±0.9
^{54}Mn	25.1±5.0	19.7±3.0	18.1±3.4	17.6±3.7
^{3}H	229±46	57.9±0.9	2.0±0.4	6.0±0.9

The activity at R=2.1 m and Z=93m (from Horn 1) in the NuMI decay pipe for 300 days of beam on followed by 75 days beam off.

- Activities for ^{7}Be, ^{22}Na, and ^{54}Mn agree with the activity seen in the core samples.
- Ratio of ^{7}Be/^{22}Na, ^{7}Be/^{54}Mn agree very well with data.
- MARS reports greater activity for tritium
  - Tritium underreported in data as a single leach cycle does not collect all of the tritium

Prediction of Leaching Fraction using MARS

- Unknown value of leaching fraction L_{3H}
  - Lower bound of 0.10 from ^{22}Na data.
    - Past experience with soil and sand show that L_{22Na} is smaller than L_{3H}
  - Upper bound of 0.81 from multi leaching data assuming that all the tritium is collected in two leaching processes.
- Use ratio of $^{7}Be/^{3}H$ from MARS to predict L_{3H}
  - $L_{^3H} = \frac{(^7Be/^3H)_{MARS}}{(^7Be/^3H)_{DATA}}$

Predicted Leaching Fraction

Location from Horn 1	Year	Radius	$^{7}Be/^{3}H$ from Data	Estimate L_{3H}
93 m	2006	2.1 m	6.0	0.33±0.09
683 m	2006	1.5 m	8.0	0.25±0.07
93 m	2010	2.1 m	2.9	0.41±0.11
98 m	2010	3.0 m	1.8	0.66±0.17
249 m	2010	3.0 m	2.9	0.41±0.11
693 m	2010	1.5 m	3.0	0.40±0.10
Average				0.41±0.14

Ratio of $^{7}Be/^{3}H$ from MARS:
2006: 2.0
2010: 1.2

Conclusions

- Activity in samples taken from the NuMI decay pipe shielding in 2006 and 2010 demonstrate the mobility of ^{3}H.
- Fixed nuclides like ^{7}Be and ^{22}Na can be used to benchmark Monte Carlo codes used for radionuclide production in shielding.
  - MARS prediction of nuclide distributions match data.
  - Predicted activity of fixed nuclides agree with data.
- Comparison of tritium activity predicted by MARS to the activity seen in the samples implies that only 41% of the tritium collected in the deep samples.