Comparison of Radionuclide Activity in the NuMI Decay Pipe to Results from the MARS Monte Carlo
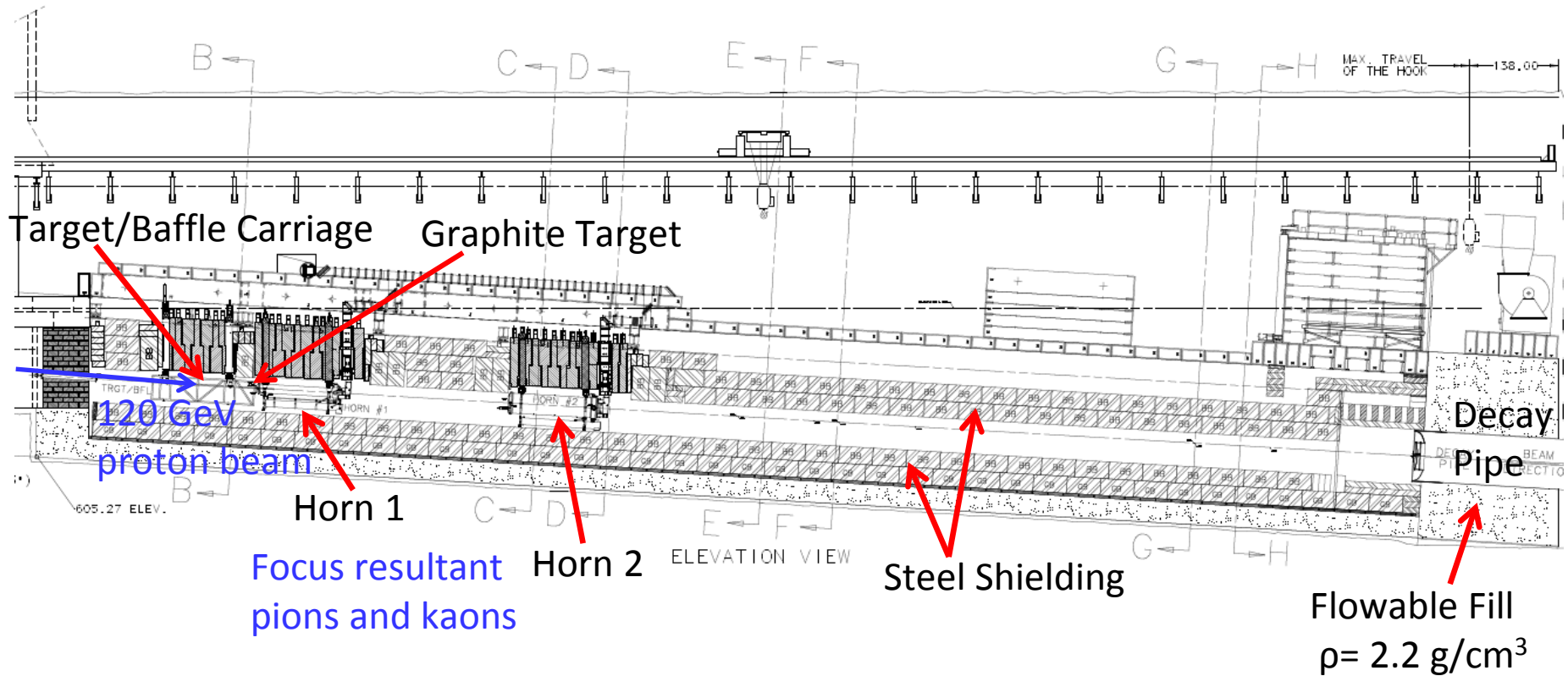
S. Diane Reitzner

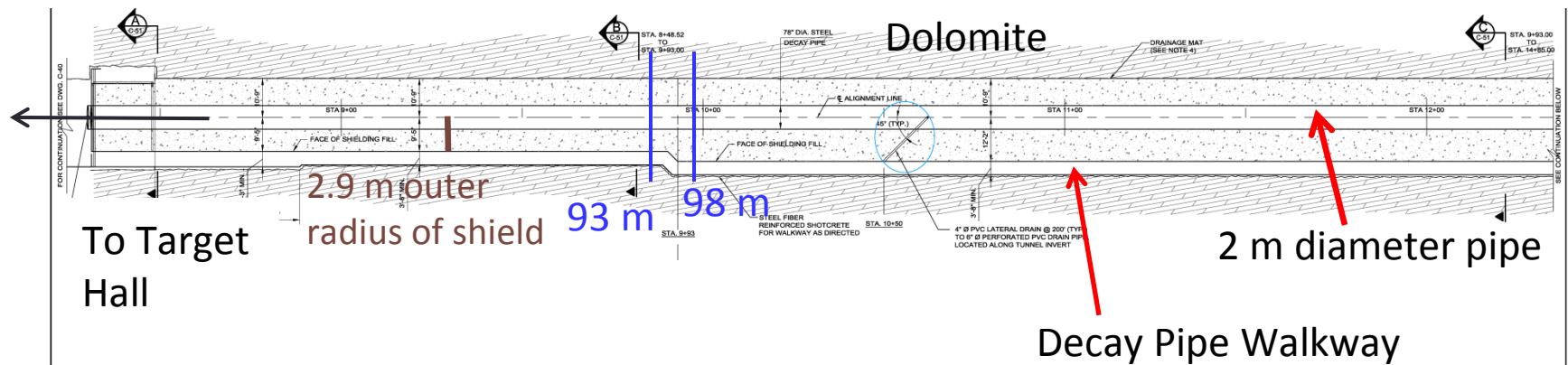Satif-12

28-04-2014

Outline

- Introduction
- NuMI beamline
- Core sample results
- MARS simulation
- Nuclide distribution results
- Activity results
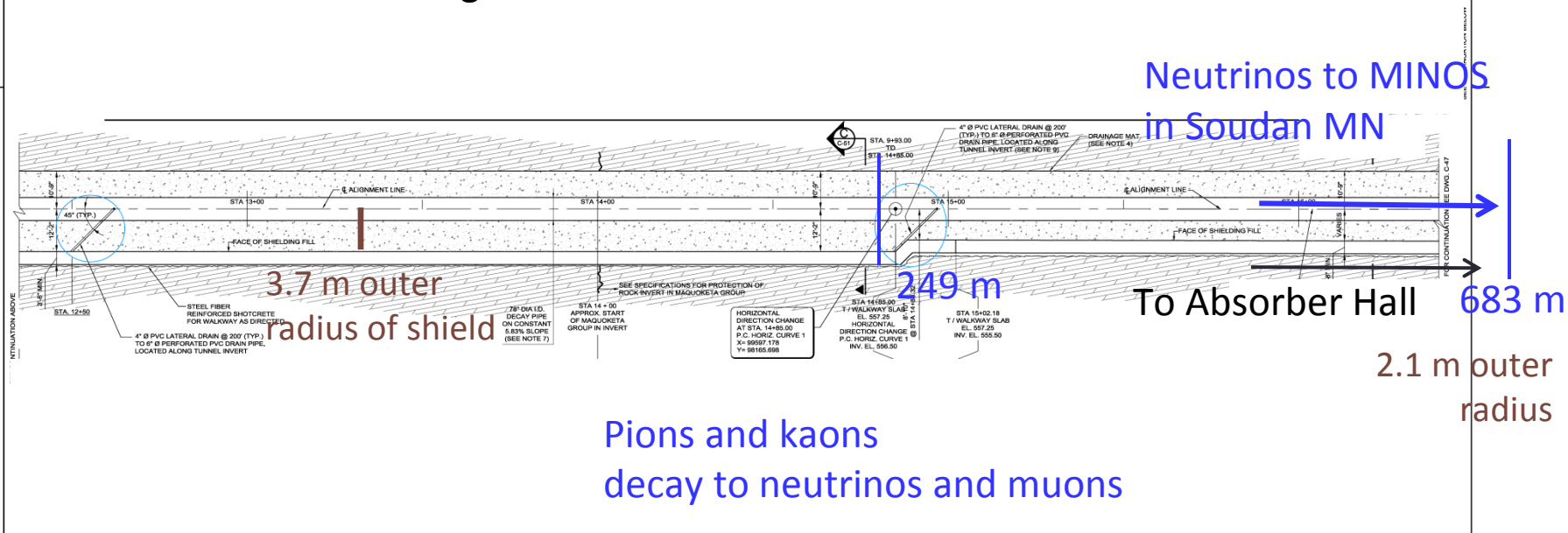- Conclusions

Introduction

- Tritium is highly mobile.
  - Transfers from one medium to another
- Important to understand tritium production in beamline shielding.
  - Develop method of tritium inventory
- Difficult to assess tritium activity in solid samples
  - Need to extract the tritium first before measuring its activity.
    - Not guaranteed to extract the tritium.
  - Tritium is difficult to contain.
- Try MC methods to predict tritium production in shielding
  - Compare MARS output to activity from other radionuclides in core samples taken from the NuMI decay pipe shield at Fermilab.

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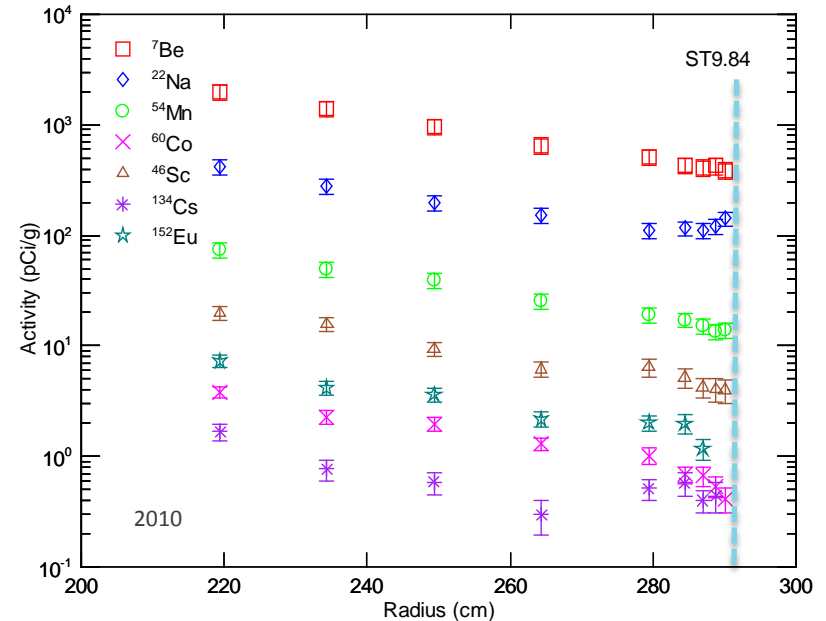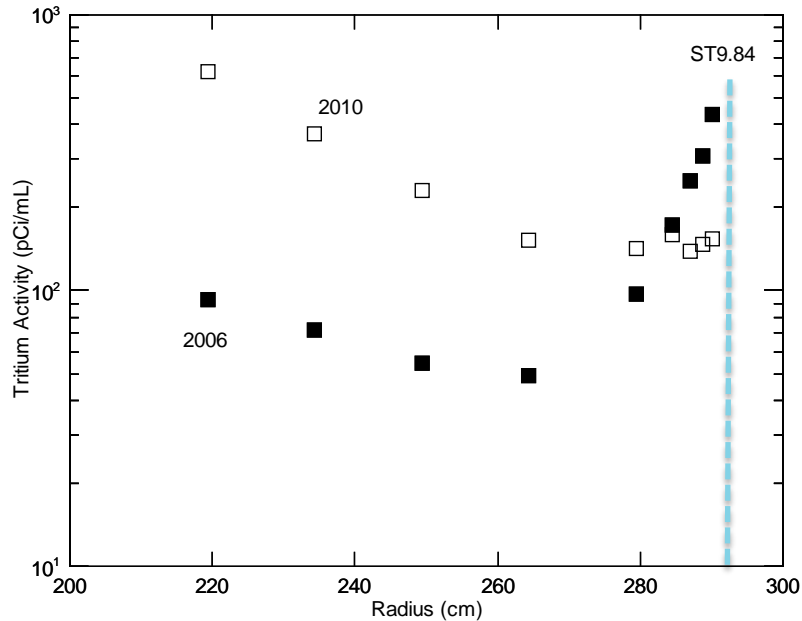
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NuMI Target Hall

Target/Baffle Carriage · Graphite Target · 120 GeV proton beam · Focus resultant pions and kaons · Horn 1 · Horn 2 · Steel Shielding · Decay Pipe · Flowable Fill ρ= 2.2 g/cm³

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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

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Face of the NuMI decay pipe shield where the core samples were extracted.
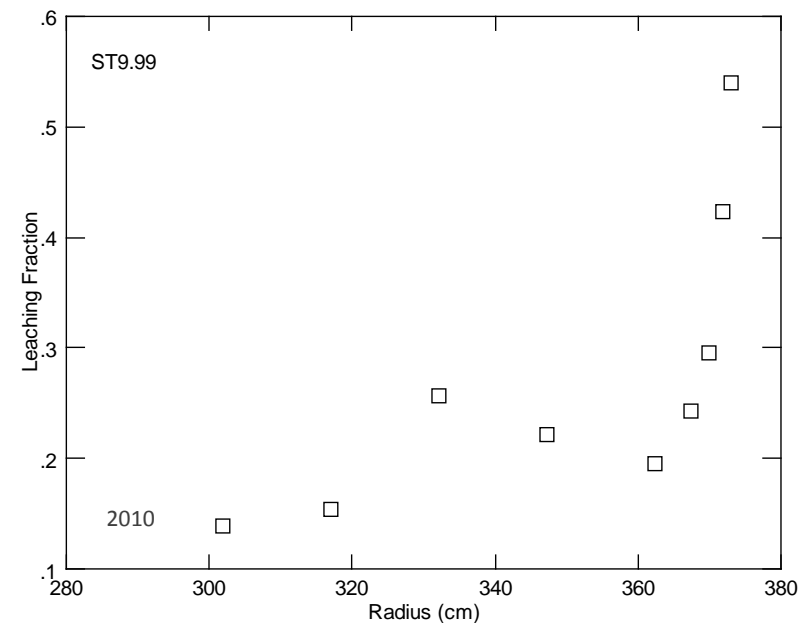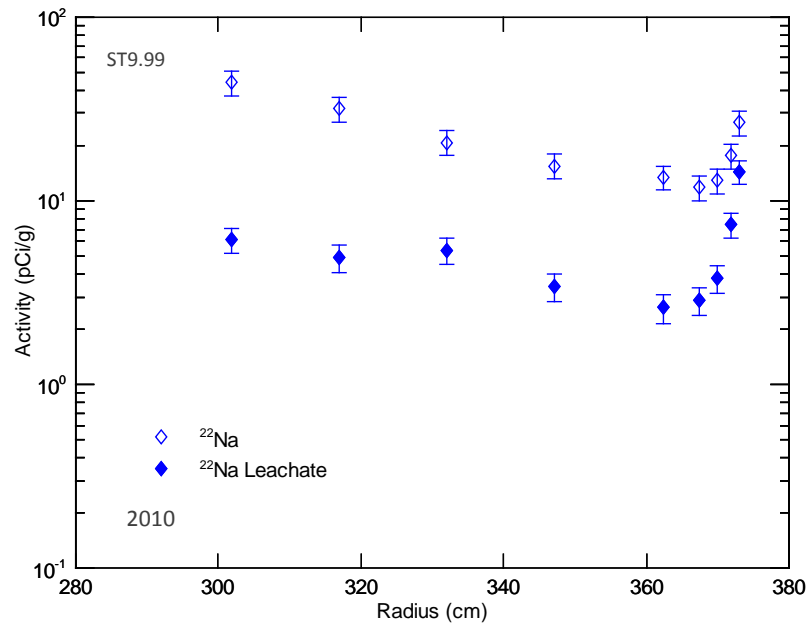
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Activity in Decay Pipe Shield

Tritium Activity

Dehumidifiers installed in target hall between 2006 and 2010

Fixed Radionuclide Activity

Maximum depth from surface: 30"

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Activity in Leachate

Comparison of ^{22}Na Activity in solid sample to leachate

Leaching fraction for ^{22}Na as a function of depth

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MC Analysis of Nuclide Production

- Use MARS to predict nuclide distribution in the NuMI decay pipe shield.
  - Compare to fixed nuclide distributions such as ^{7}Be and ^{54}Mn

- Simple model of NuMI target hall and decay pipe in MARS

- Detailed horns and target

- Idealised horn magnetic field

Horn2

Target

Horn1

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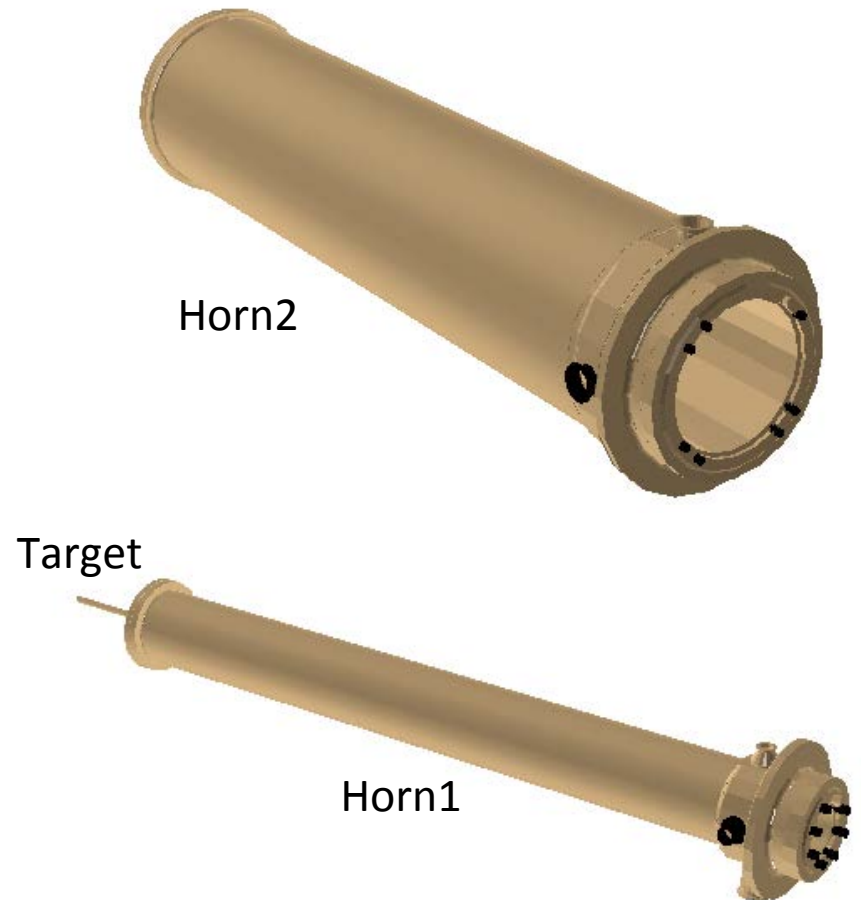
NuMI Target Hall in MARS
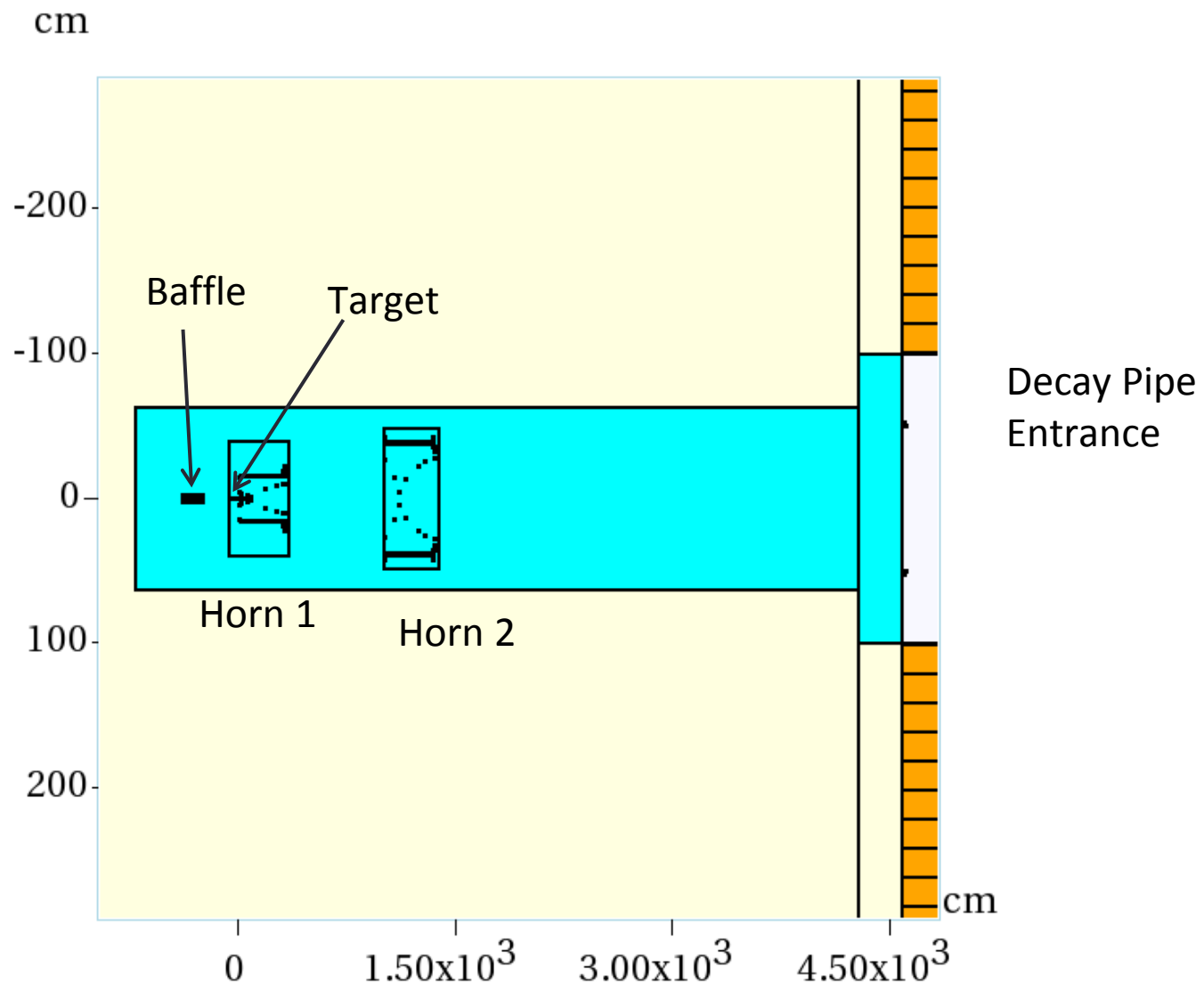
# MC Analysis

- Core samples extracted at large radius.
  - 1.5 m < R < 3.7 m
  - Inner radius of decay pipe shield: 1.0 m
  - Thick shielding problem.
  - Decay pipe shield has large volume.
- Use star densities with fine bins to extract spatial distributions.
- Use coarse radial bins for nuclide production.
  - Run MARS in MCNP mode
    - $E_{n,th}$ = 1 meV

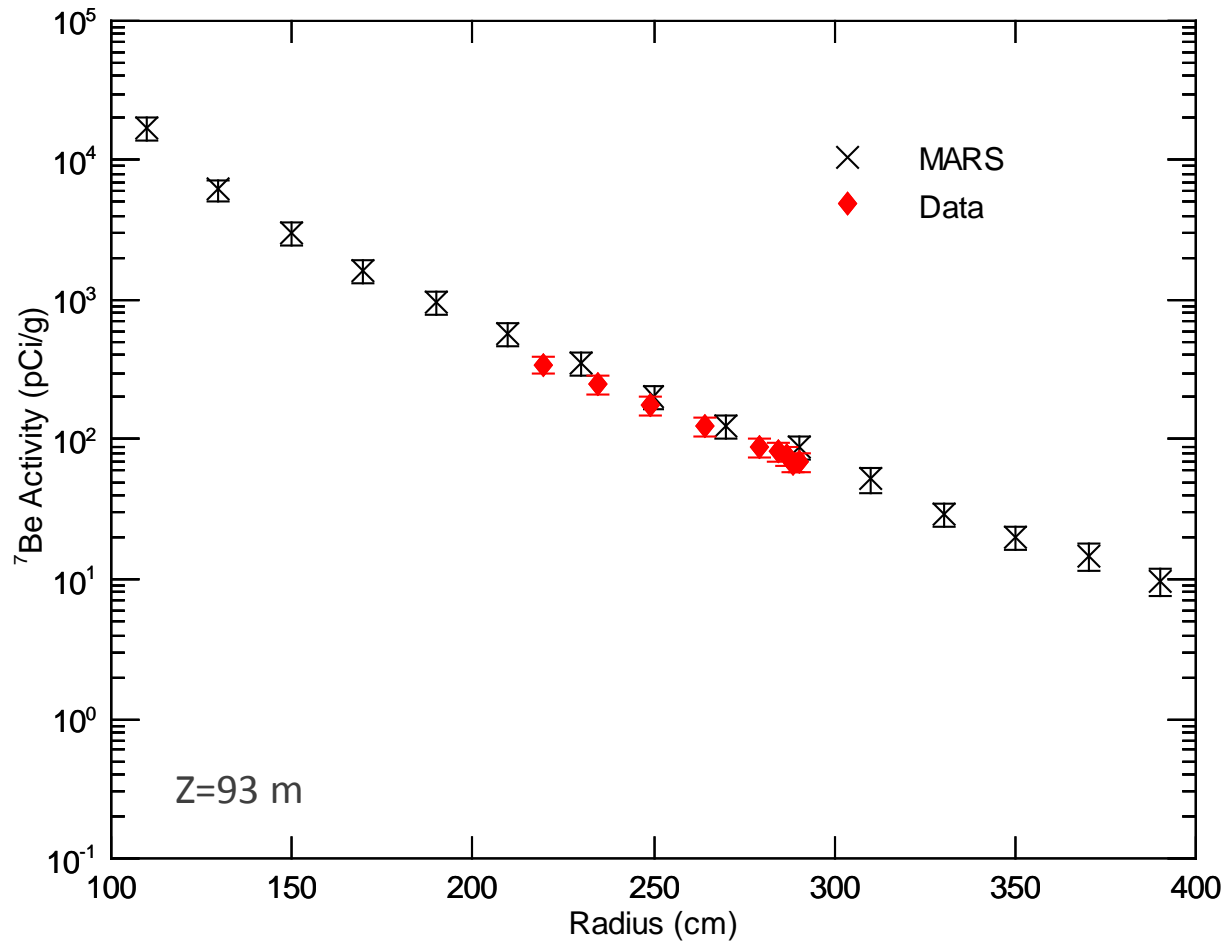# Star Density per Proton in the Decay Pipe Shield

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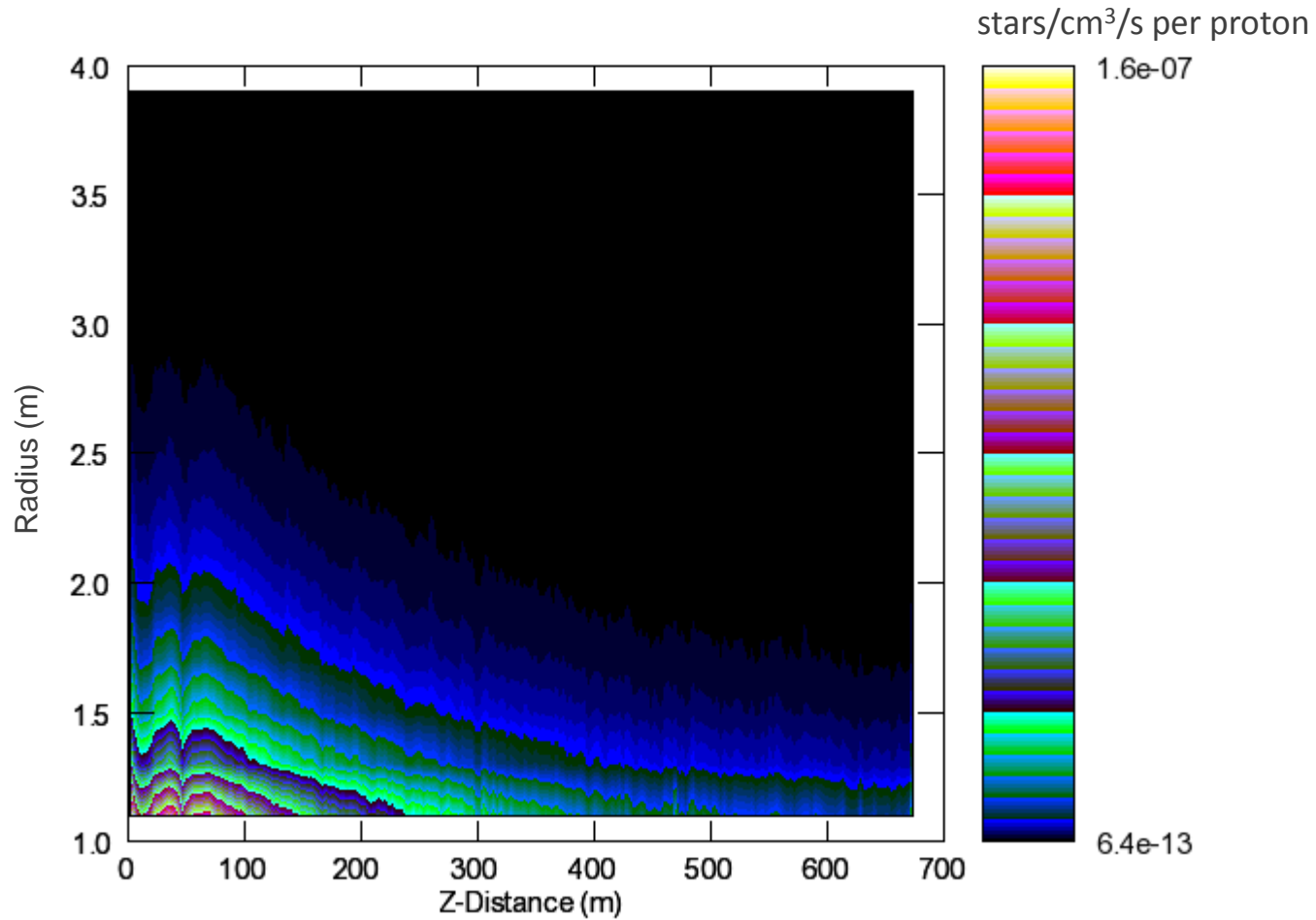
Longitudinal Distribution Comparison

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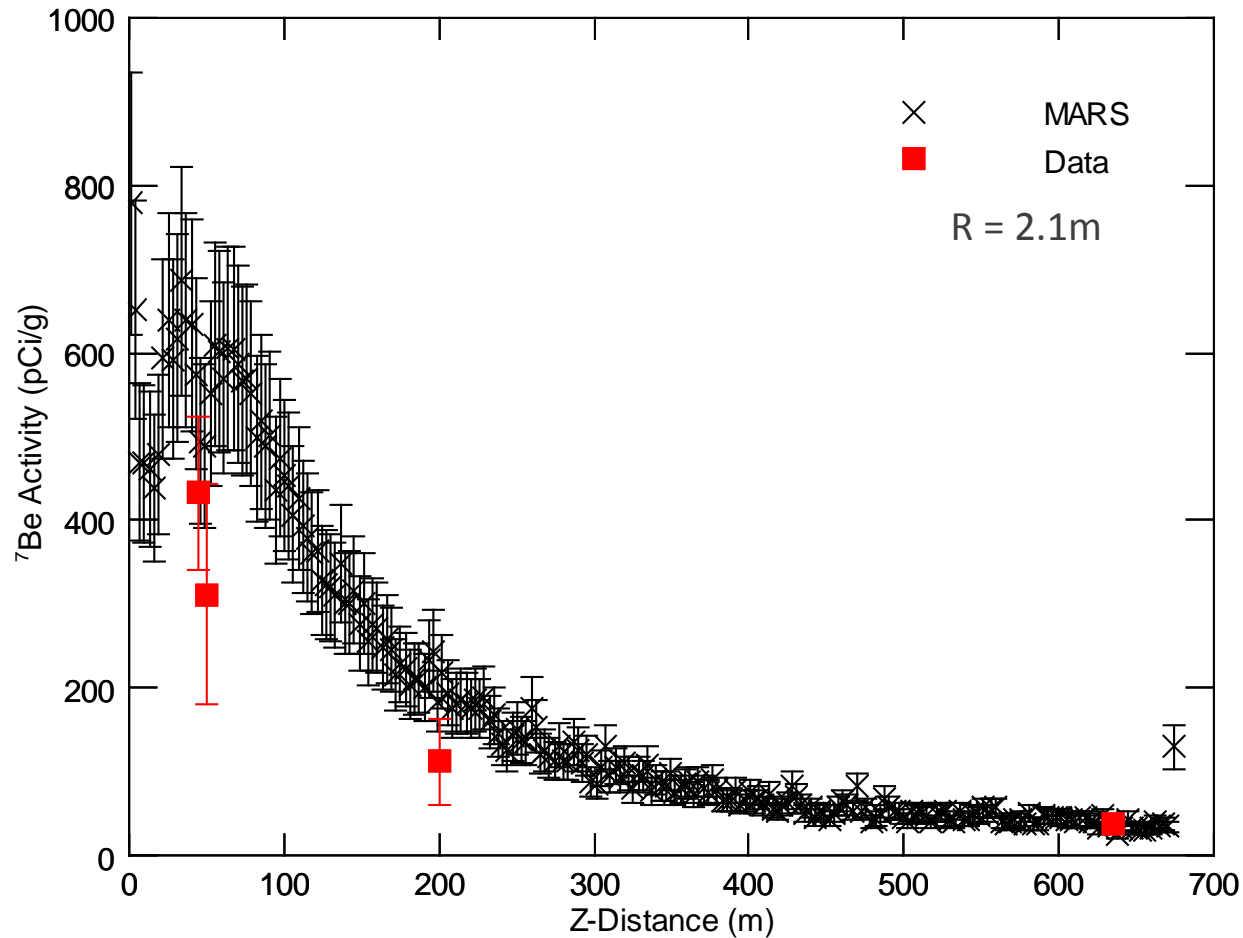
Radial Distribution Comparison

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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
  - $a_2 e^{-b_2 r}$
  - $b_2 = 0.0229 \pm 0.0011$

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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 (300 day beam on, 75 day s beam off) to compare to 2006 results
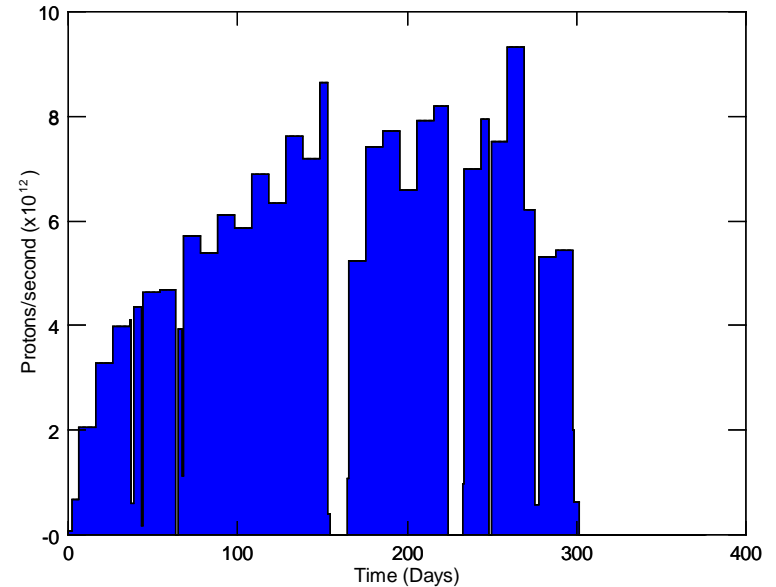
Intensity profile input to DETRA

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

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Tritium Leaching Predictions from MARS

- Unknown value for leaching fraction L_{3H}
    - Lower bound of 0.10 from ^{22}Na data.
    - Upper bound of 0.88 from the assumption that all of the tritium is collected in two leachings.
- Use ratio of ^{7}Be/^{3}H in MARS to predict L_{3H}
    - $$L_{3H} = \frac{(^7Be/^3H)_{MARS}}{(^7Be/^3H)_{DATA}}$$

Predicted Leaching Fraction

Location from Horn 1	Year	Radius	$^7Be/^3H$ 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

Ratio of $^7Be/^3H$ from MARS:

2006: 2.0

2010: 1.2

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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.

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