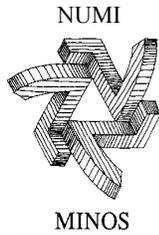


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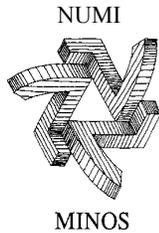
NuMI Hadron Absorber Review
Radiation Safety Issues
Radiation Safety Coordinator
Nancy Grossman
June 12, 2001



Outline

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- Overview
- Radiological Safety Assessments Status
- Prompt Radiation
- Groundwater Protection
- Airborne Activation
- Residual Activation
- Next 6 Months
- Summary



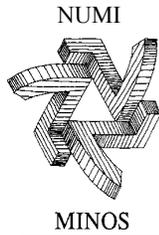
Radiological Safety Overview

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- **Regions**
 - MI/Extraction
 - Carrier Pipe Region
 - Pre-target Region
 - Target Hall
 - Decay Tunnel
 - Hadron Absorber
 - Muon Alcoves
- **Mitigation**
 - Passive shielding
 - Interlocked Radiation Detectors
 - Beam Extraction Permit System
- **Radiological Areas**
 - Prompt radiation
 - Residual activation of enclosures and components
 - Airborne activation
 - Groundwater activation/contamination
- **Designs are reviewed in accordance with Chapter 8 of the Fermilab Radiological Control Manual (FRCM).**

Beam Parameters:

- 4 E 13 protons/1.9 seconds @ 120 GeV
- 3.7 E 20 protons/year (8 years)



Radiological Safety: Overview

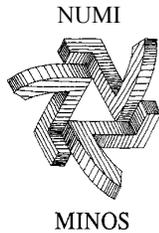
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NuMI Radiation Safety Coordinator (NRSC)

- Responsible for radiation safety for NuMI @ FNAL.
- Reports to NuMI project manager on radiation safety issues.
- Interfaces with NuMI personnel, FESS, BD Radiation Safety, & ES&H on radiation issues.

NuMI Radiation Safety Advisory Committee (NRSAC)

- Committee of radiation safety experts from Beam Division, ES&H and one member from ANL.
- Charter is to provide semi-formal reviews of NuMI radiation issues and proposed designs for shielding.
- Help prevent surprises down the road.



Radiological Safety: Assessment Process & Status

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1. Presentations to NuMI Radiation Safety Advisory Committee (NRSAC)

- Initial validation of calculation methods & Target Hall, Decay Region and Hadron Absorber “preliminary” shielding (7/99)
 - Civil construction parameters addressed appropriately
- Final groundwater methodology presentation (7/00)

2. “Preliminary Radiation Shielding Assessment” to Beams Division Radiation Safety for “Civil” review (10/99)**

- Consensus to start civil construction in 1/00.

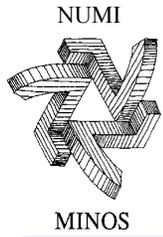
3. “Radiation Shielding Assessment” to Beams Division Radiation Safety for review and approval**

- *Reiterate shielding calculations as necessary when engineering designs are nearly complete*
- *Include residual rate estimates, hot job procedures*
- *Must do before going to the FNAL Senior Radiation Safety Officer (SRSO) for review and approval*

4. “Radiation Shielding Assessment” to SRSO for review and approval**

- Before Operation commences.
- Sign as built drawings.

** required



Hadron Absorber Radiation Safety Overview

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All results shown are based on the baseline, cylindrical geometry MARS Hadron Absorber design and cavern:

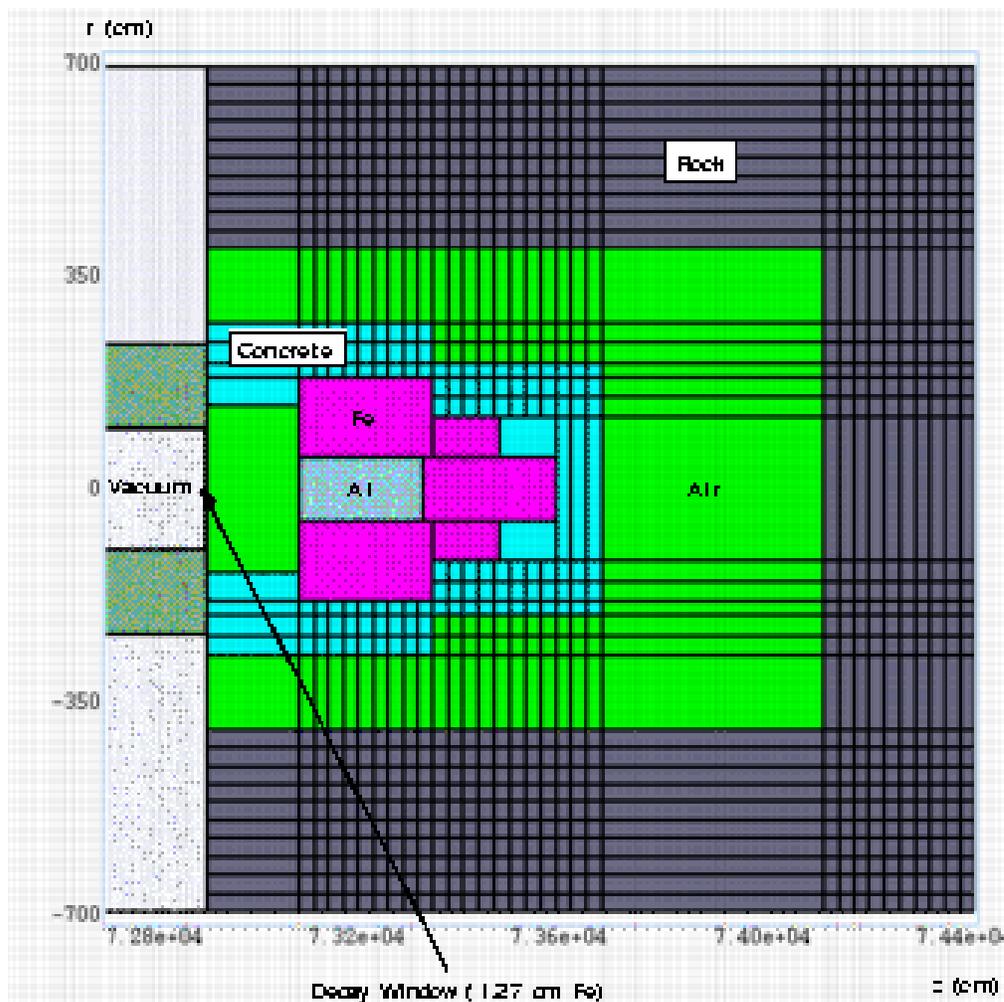
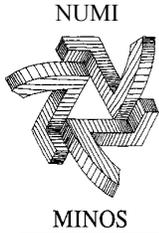


Figure 2

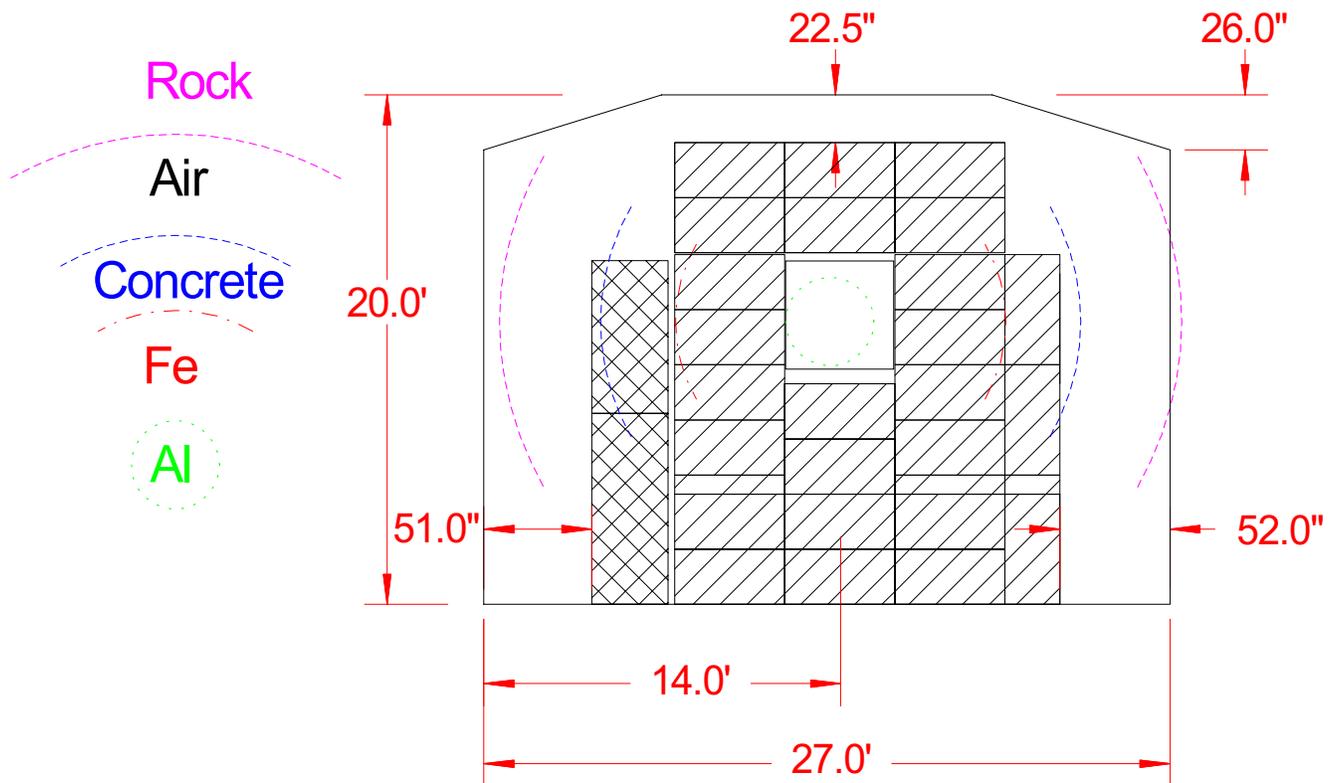
This figure shows the geometry of the Absorber model and its materials. It begins at $z=72700$ cm, which is 200 cm ahead of the end of the decay pipe. The absorber core starts at $z=73083$ cm. This figure is best viewed in color.



Hadron Absorber Radiation Safety Overview

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While the present Hadron Absorber design and cavern is:

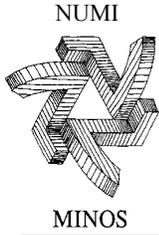


Looking Upstream

(Cylindrical contours are from report NuMI B-727, MARS13)

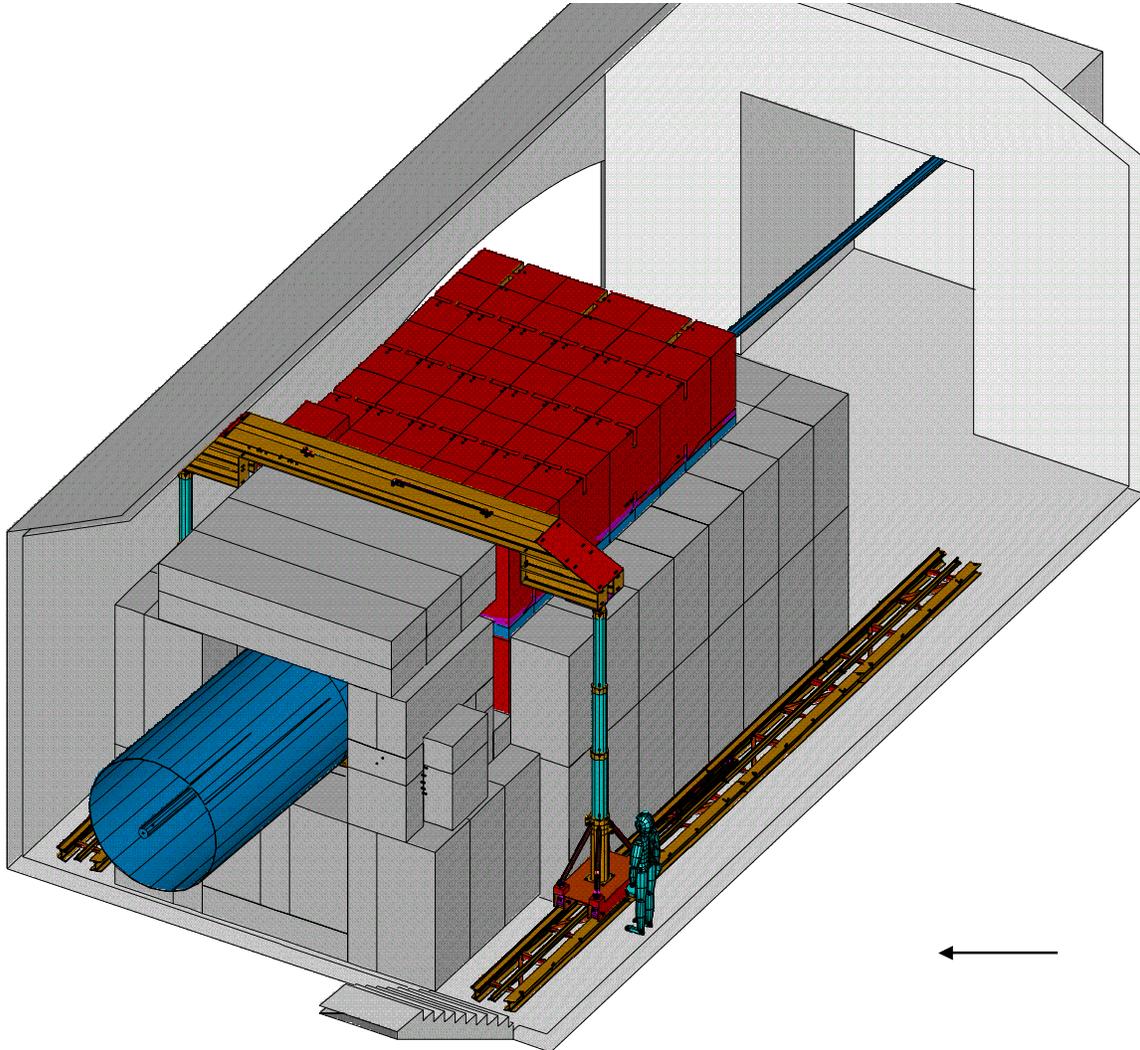
Accident condition has not been studied:

- 1 hour where the beam misses the target (is this possible?)
- Needs to be done for the labyrinth/penetration source terms
- Not an issue for air
- Need to check for groundwater, should be fine



Present Absorber Cavern View

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Upstream shielding has penetrations for:

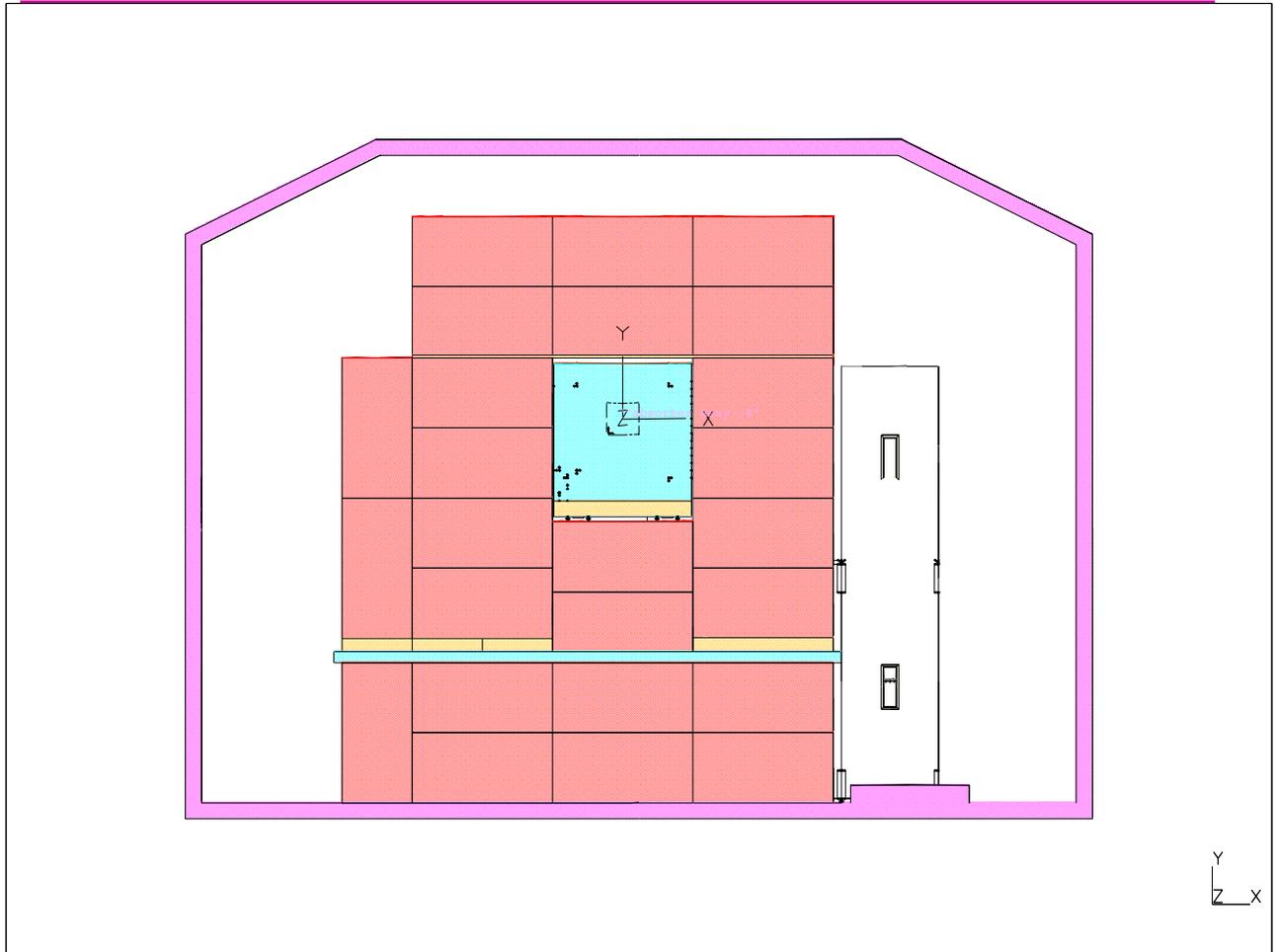
- Decay Pipe Access Port
- DS Hadron Monitor
- Pipe to Vacuum Pump



MINOS

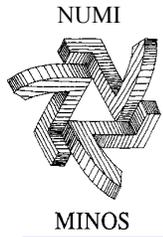
Hadron Absorber Front View

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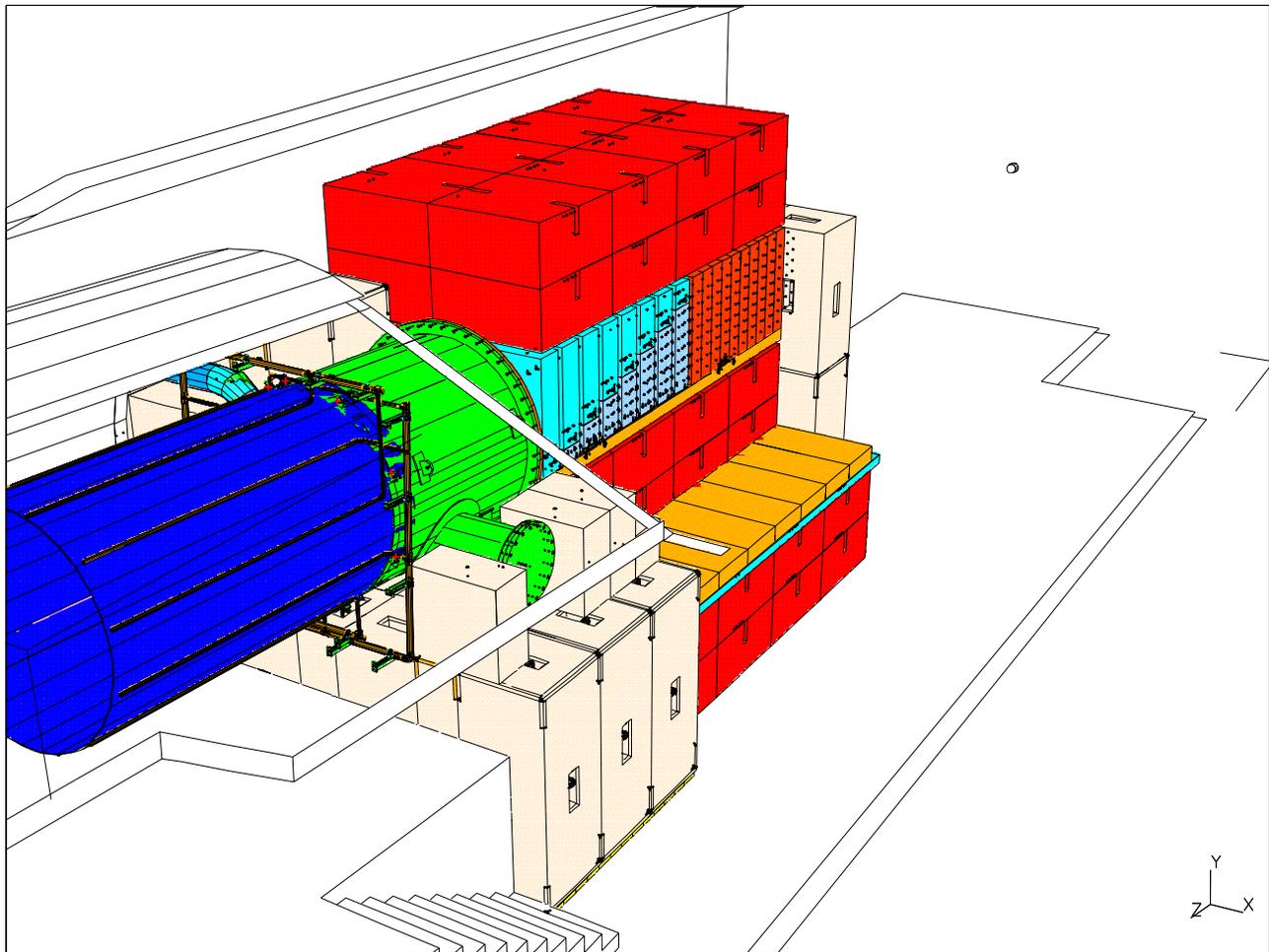
Plotted by villegas on 11-Jun-2001, File: x_section_nancy.pff

- Concrete on walkway side
- Gate on steel side to not allow easy access (locked)



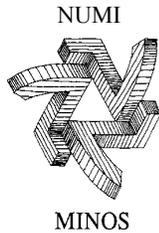
Hadron Absorber: Cutaway View

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Plotted by villegas on 08-Jun-2001 , File: core_ossy_installed.pff

- Concrete on walkway side
- Gate on steel side to not allow easy access (locked)



Prompt Radiation

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Labyrinth and penetration exit dose rates (labyrinth source terms where bulk shielding is present are not well known)

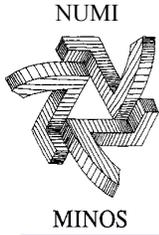
- Goal to be below 100 mrem/hr at labyrinth exit
- Old Hadron Absorber labyrinth exit dose rate: ~0.1 mrem/hr
- Present Hadron Absorber labyrinth is quite different:
 - Two gutters along floor line (6"x12.5")
 - Duct with RAW water pipes, vacuum pipe and cables along ceiling
 - Using cylindrical geometry Hadron Absorber source term:
 - 14 mrem/hr - 170 mrem/hr (need updated source term)

RAW water calculations, secondary containment, etc:

- RAW water tritium production calculations need to be done with source terms from MARS
- Secondary containment is being studied now and a conceptual design exists.
 - More effort will be put into this in the future to determine worst probable accident scenarios and the resulting containment needed.

Location of interlocked gates and radiation fences need to be agreed to once dose estimates have been updated

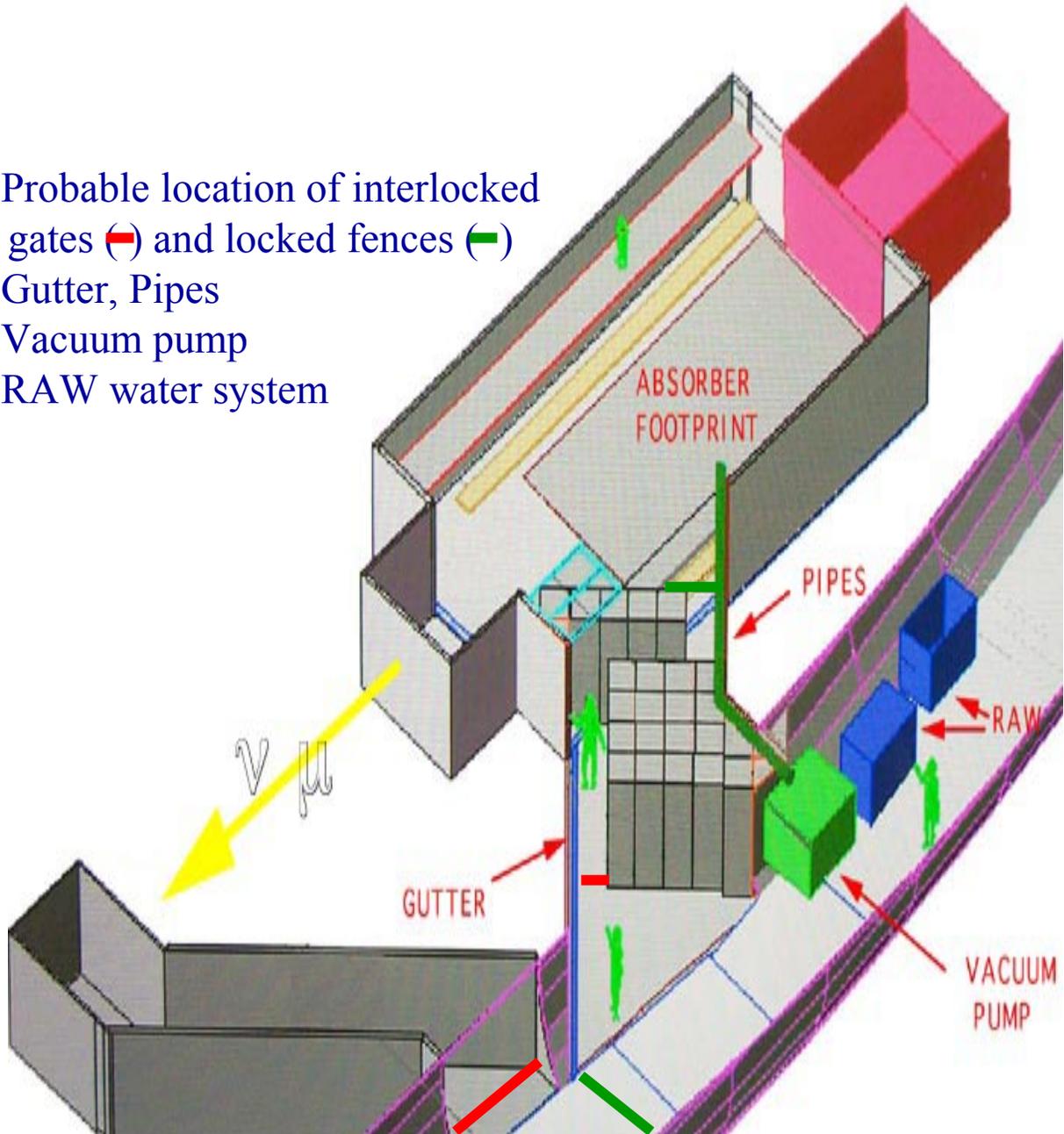
- Make measurements when start running and we can move them if we have to.

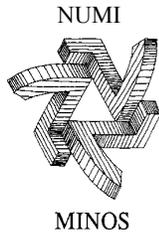


Labyrinth & Environs

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- Probable location of interlocked gates (—) and locked fences (—)
- Gutter, Pipes
- Vacuum pump
- RAW water system



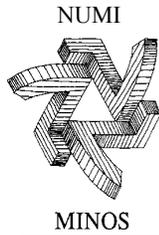


Groundwater Protection

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- Hired several groundwater consultants to determine water levels and flow rates around the unlined regions of the NuMI tunnel.
 - All water within 10' of tunnel flows into the tunnel (within the aquifer region)
 - Most water flows in rapidly through the fractures
 - Determine an average inflow velocity based on groundwater consultant's inflow estimates

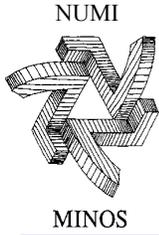
- Use the Fermilab Concentration Model, modified to allow for water flow
 - Fermilab Reports TM1851, TM2092, TM2009 (NuMI).
 - Updated to include our latest understanding of groundwater contamination by ^{22}Na and ^3H (NuMI-B-495)
 - Flow dependent residency time (inflow or outflow) where applicable.
 - Irradiation time = residency time (not 8 years)
 - Accident condition: 1 hour missing target
 - Normal operation: time water is in the activation region



Groundwater Protection

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- Calculations must be below the regulatory limit including uncertainties (FNAL, DOE)
 - Use uncertainties in all parameters to determine overall uncertainty
 - **Determine effect on results and add in quadrature**
- Calculations are conservative:
 - Comparing concentrations in inflow water, which will be pumped to the surface to groundwater limits
 - In “dry” regions, grout less to allow more inflow
 - Model includes worst case conditions, most likely will not encounter
 - Does not include decay during migration to a well
 - **Water along the unlined beamline tunnel can not get to any well other than the NuMI beamline “well”**
 - Does not include dilution & dispersion in transit to a well
- Ensure compliance with monitoring well(s) will be used to monitor contamination (^{22}Na and ^3H concentrations)



Groundwater Protection

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Star Density plot for cylindrical geometry:

- ~ 6 E -12 stars/cm³/p in 99.9% volume

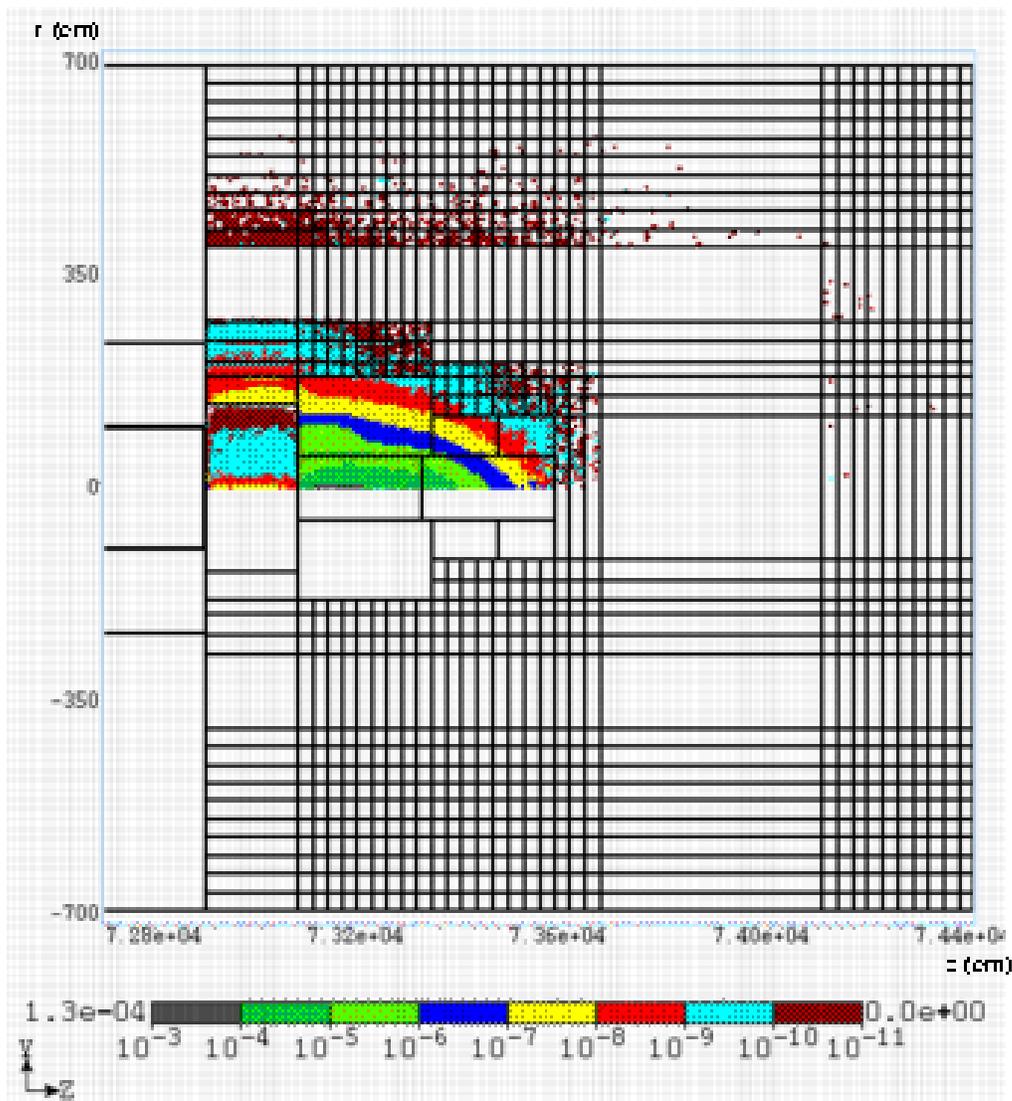
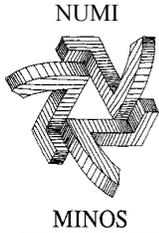


Figure 3

This figure is a superimposition of a star density plot and an Absorber Geometry plot. It starts at 72700 cm, which is 200 cm ahead of the end of the decay pipe. The star density units are stars $\text{cm}^{-3} \text{p}^{-1}$; the star densities are best viewed in color. The absorber core begins at $z = 73083$ cm.

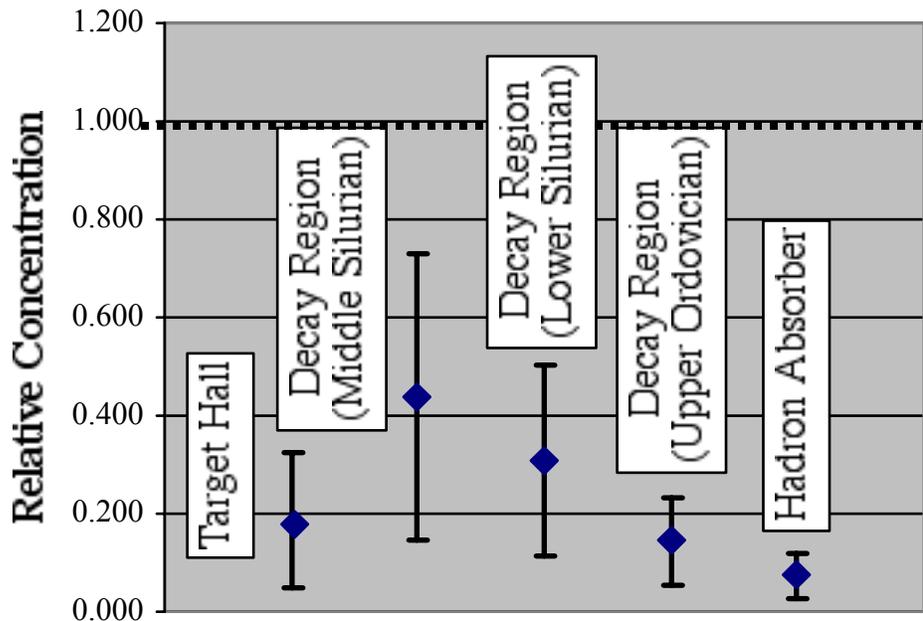


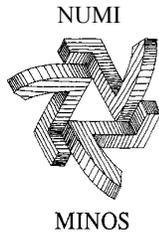
Groundwater Protection: Secondary Beam

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- Hadron Absorber values need to be updated for the present cavern and Hadron Absorber design
- Regulatory limit value is $4E-11$ stars/cc/p
- Cylindrical MARS runs calculated $6E-12$ stars/cc/p
- Updated MARS run needs to be completed to make sure that there is sufficient shielding in the Hadron Absorber for groundwater protection.

Radionuclide Concentrations Relative to the Regulatory Limit



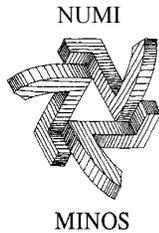


Airborne Activation

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Radioactive Air calculations need to be revisited with the present Hadron Absorber design.

- Site-wide permit submitted including NuMI operations in 3/99
- Goal for NuMI is < 45 Ci/year:
 - ~0.025 mrem/year (1/4 continuous monitoring limit)
- Releases dominated by the inner target chase activated air (~10's of Ci/yr, depending on how well the chase is sealed)
- Hadron Absorber and 1/2 of the decay region:
 - Previous estimate was 0.5 Ci/year at a ventilation rate of 2250 ft³/min
 - We will measure once we start operating
 - Ventilation rate is adjustable
 - Air dose rate after 1 hour is negligible

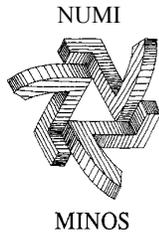


Residual Activation

Based on Hadron Absorber design with cylindrical geometry (no cracks or bare steel) with a outer concrete layer

- Want <30 mrem/hr at back and walkway side
- Want < 100 mrem/hr elsewhere (10 hour cooldown)
- Rates for core based on MARS14 results for residual rates.
- Rates for all other areas based on extrapolations from MARS13 star densities
- Now concrete on back and walkway side and only part way up
- Need MARS14 with largest cracks modeled (and neutrons followed as necessary) to get better estimates

Location	Dose Rate (on contact)
<u>Hadron Absorber: Core Sides</u>	~ 10's rem/hr
<u>Hadron Absorber: Core Near Beam</u>	~ 100's rem/hr
<u>Hadron Absorber: Steel Blocks</u>	~ 1's rem/hr
<u>Hadron Absorber: Labyrinth Side</u>	~100 mrem/hr
<u>Hadron Absorber: Back</u>	< 30 mrem/hr
<u>Decay Region: Edge of Concrete</u>	~100 mrem/hr



Residual Activation: AP0 Experiment

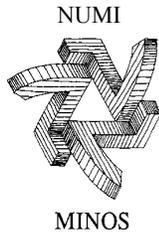
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Irradiated samples above and below the steel modules at AP0 to investigate:

- Residual rates versus MARS predictions (in and outside thick shielding)
- Isotope production in the materials we plan to use in the Target Pile (Al, concrete and various kinds of steel) - especially short-lived
- Cooling curves for the above samples
- Neutron Fluxes above and below the modules and inside 2” and 6” thick poly cubes above the modules
- MARS predictions of neutron fluxes vs. measurements

Updated residual code was added to MARS13 -> MARS14

- Can calculate residual activation levels for 3 different energy regimes (including thermal neutrons)

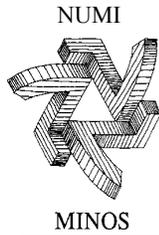


Residual Activation: Preliminary Results

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Preliminary Results:

- Residual rates versus MARS14 predictions (in and outside thick shielding).
 - Inside thick shielding agreement is within a factor of 2.
 - Outside thick shielding agreement is within a factor of 4.
- Isotope production in the materials we plan to use in the Target Pile (Al, concrete and various kinds of steel) - especially short-lived.
 - No unexpected isotopes were seen and no unusual levels were scene.
 - Caveat: could not get to the samples until after 28 hours had passed.
- Cooling curves for the above samples.
 - Have cooling curves from the horn aluminum, structural steel, the T-block steel and FNAL concrete.
- Neutron Fluxes above and below the modules and inside 2” and 6” thick hollow polyethylene cubes above the modules
 - **Has not been analyzed yet.**
- Plan to look at the effect of the cracks at AP0 on residual rates.



Next 6 Months

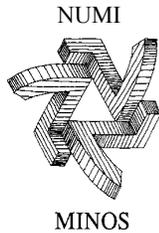
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Next 6 Months:

Detailed MARS14 Geometry of present Hadron Absorber design and cavern (Larry Wai) to get source terms for:

- Groundwater (accident also)
- Air
- Labyrinths/penetrations (accident also)
- RAW water
- Residual rates

Agree upon best locations for the interlocked gates and locked radiation area gates.



Summary & Plans

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Summary

- All Hadron Absorber radiation calculations are based on an outdated design
 - Original estimates were not near any limits
 - BUT, the design has changed quite a bit and thus there is some concern.
- MARS14 residual activation “benchmarking” is in progress.
 - Comparisons look good both inside and outside thick shielding.
 - Neutron spectrum comparisons look very good also.

Future:

- Complete the Hadron Absorber MARS14 simulation effort.
- Presentation to NRSAC of Hadron Absorber design and MARS results.
 - Groundwater Activation
 - Air Activation
 - Residual Rates
 - Labyrinth source term (and labyrinth preliminary design?)
 - RAW water system/tritium levels