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NuMI/LBNF Radiation Protection

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Outline

*Really only going to talk about **air release** radiation protection*

- Basic features of different air-released radioactive elements
- Benchmark measurement of ^{41}Ar at NuMI
- LBNF layout and switch from air to N_2 in target pile
- Input from measurement of Tritium releases at NuMI
- Selection of strategy for LBNF, balancing ^{11}C and ^{3}H concerns
- An idea for possible ALARA tritium release scheme

The half-dozen isotopes of concern

Short-lived spallation products from interactions in air ^{11}C, ^{13}N, ^{15}O

- Production est.: MARS Monte Carlo calculation of hadron flux in air (> 30 MeV) times hadronic cross section on air (N, O, Ar) is pretty straight forward
- Fraction decayed during transport through ventilation can be bracketed reasonably

Longer-lived spallation product ^{7}Be

- plates out on filters (and other surfaces)
- Watch for contamination, but properly filtered air not problematic for release

Neutron capture ^{41}Ar

- Produced by low energy neutron capture on ^{40}Ar in air
- More challenging to predict production, because low energy neutrons difficult
- Longer half-life (110 minutes), so dominant over longer ventilation paths

Spallation production of Tritium from interactions in shielding ^{3}H

- Production in shielding, horns, target are reasonably straight forward to calculate
- Highly mobile, transport through solid and release to air hard to predict
- Production in air very small compared to evaporation from shielding

From release point, transport to public

- Fermilab does continuous monitoring at air release stacks

- There is a mandated model for calculating the dose to public given the radioisotopes released, location of the release, the weather and the surroundings, all specific to Fermilab.

- Fermilab permit limits annual exposure to **Maximally Exposed Offsite Individual (MEOI)** from radioactive air emissions to be less than 100 μrem.

  (Anything above this would result in requirement for continuous EPA approved monitoring)

Coming up with basis for input to LBNF design

- NuMI utilizes 2 to 3 hour air decay time (target pile air activation to release point) which keeps short-lived isotope release to a modest fraction of MEOI limit

- Have been monitoring NuMI air at release points since beginning of NuMI
- Have been tracking tritium release to air and water
- Have done cores into concrete shielding to check on tritium migration

- As input to LBNF design (especially with concern about ^{41}Ar uncertainties)
  - Recently did a test, sampling air inside NuMI target pile for radioisotopes
  - Compared result to MARS prediction

Hopefully coming soon to a journal near you:

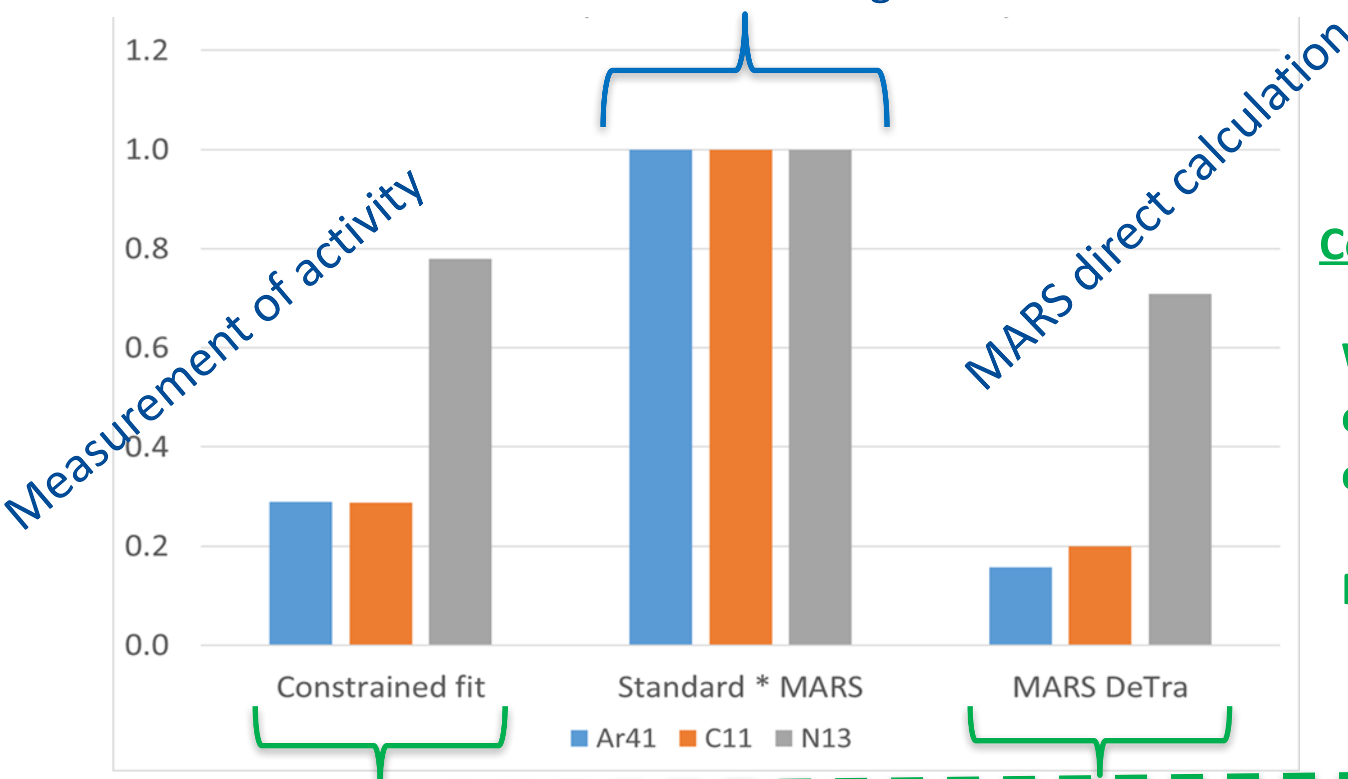
Measurements and calculations of air activation in the NuMI neutrino production facility at Fermilab with the 120-GeV proton beam on target

I.L. Rakhno *, J. Hylen, P. Kasper, N.V. Mokhov, M. Quinn, S.I. Striganov, K. Vaziri

Measurement of ^{41}Ar, ^{11}C and ^{13}N in air from NUMI target pile

- Minimal 2 minute transport of air from NuMI target pile to radiation detectors is corrected for
- Sampled after many hours of steady state running of beam

Normalized to standard way FNAL conservatively estimates for design



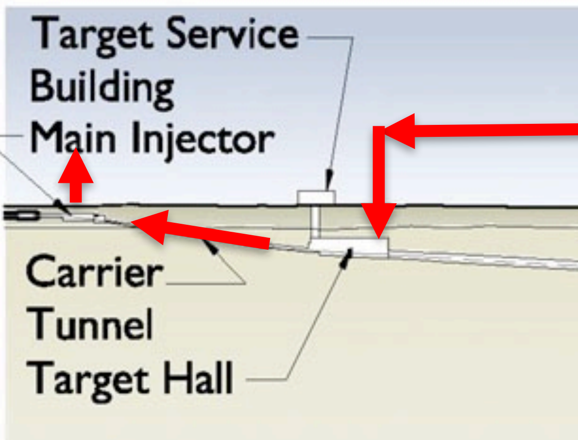
Conclusions:

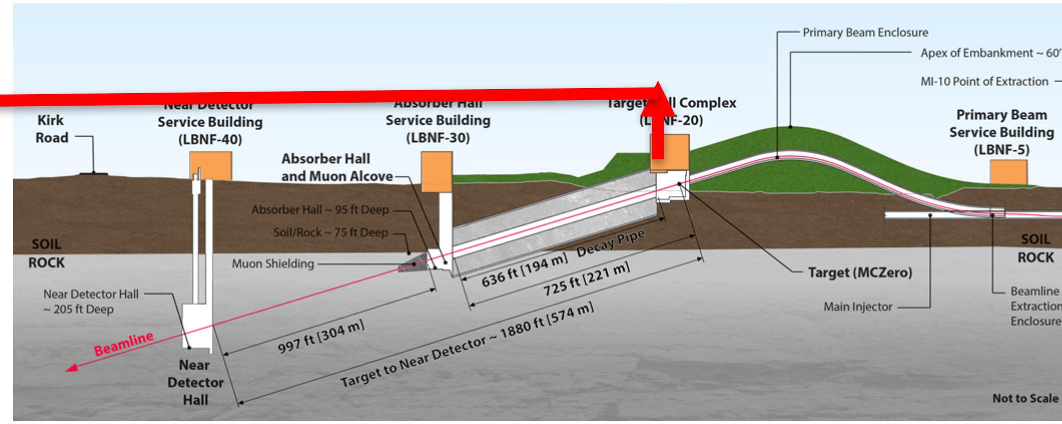
We are using conservative estimates of production of radio-isotopes

MARS and data in reasonable agreement

LBNF changes: N_2 instead of air in target pile and different LBNF air exhaust route

BEFORE: air from LBNF target pile sent to NuMI for further decay



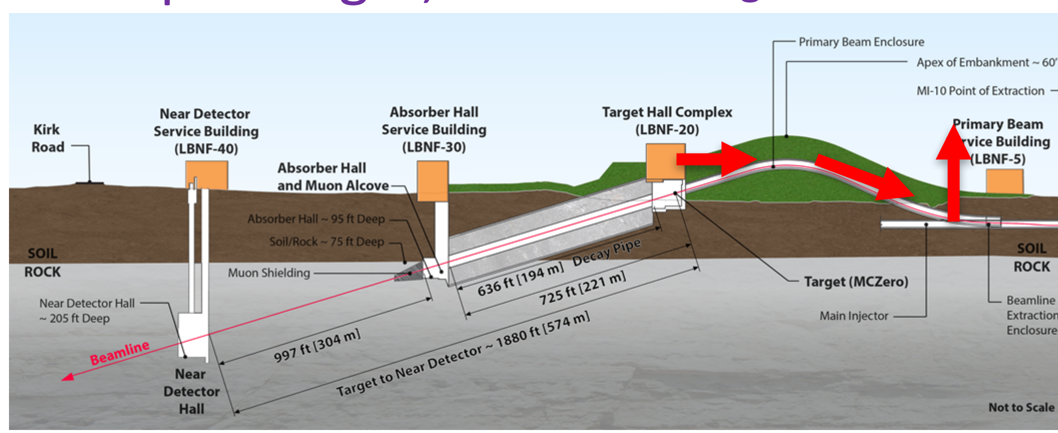


NEW: N_2 from LBNF released from pre-target; NuMI no longer needed

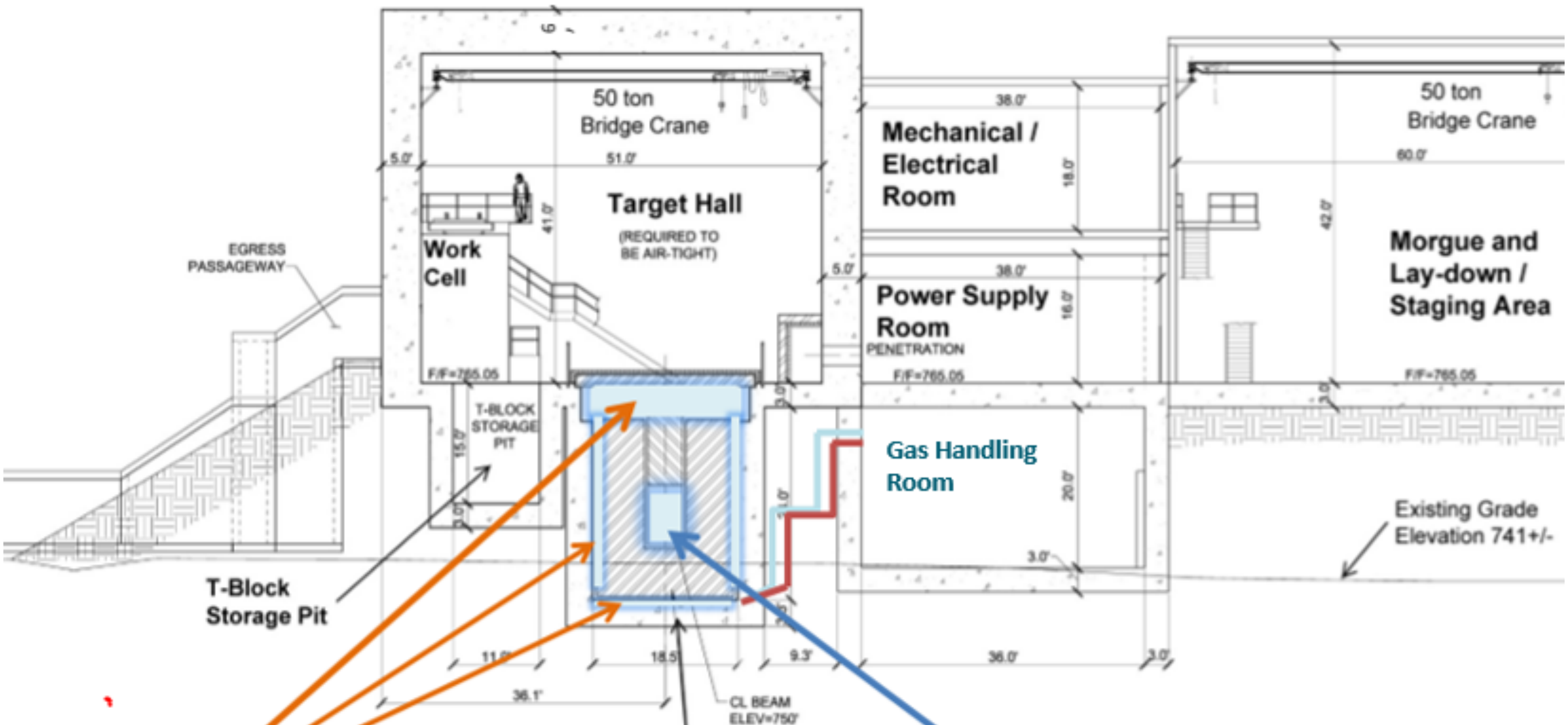
<u>Over last several years</u>

- Saw LARGE increase in Tritium release as NuMI target pile heated up
- Enlarged LBNF target pile gas vol. and target for optimized beam

Motivated change, air -> N_2



LBNF target hall complex



Concrete is outside N_2 vessel
Steel shielding is inside vessel

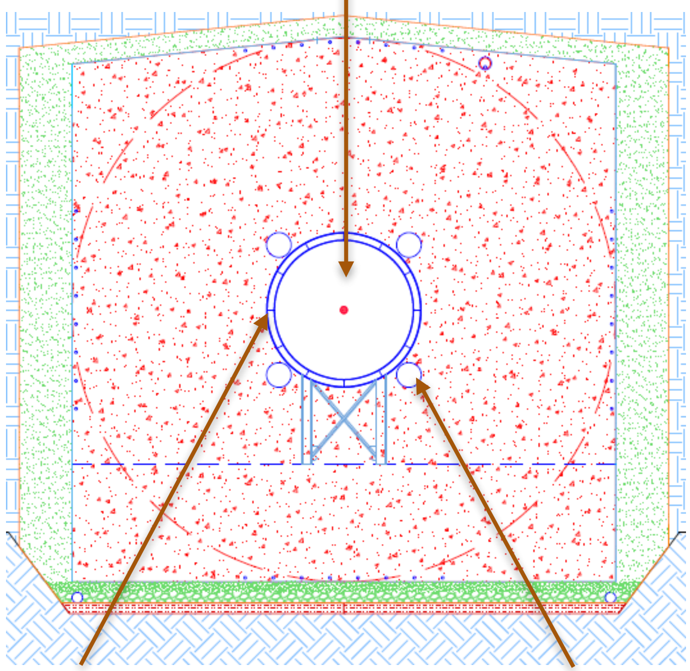
Outer Target Pile

Inner Target Pile

Blue is N_2

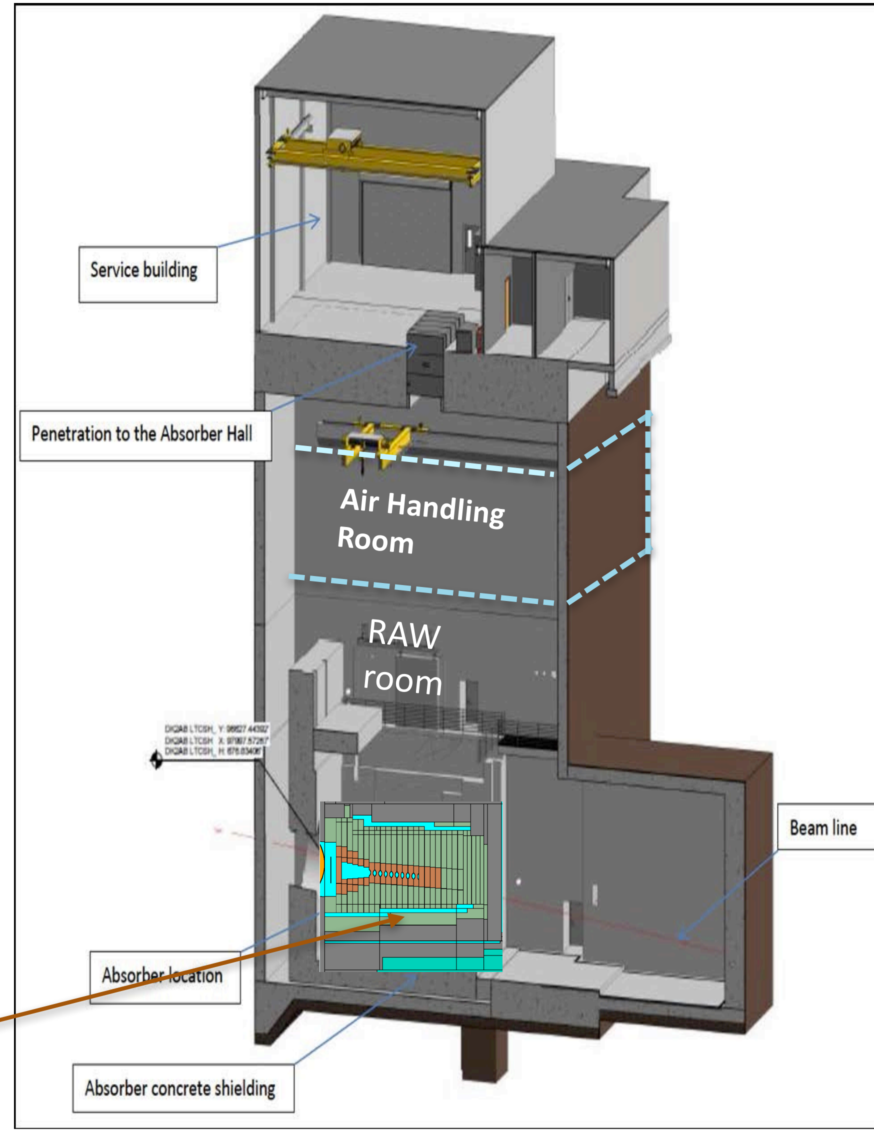
Decay pipe and Absorber included in model

static Helium fill



N_2 gas cooling

N_2 return



Absorber outer shielding forced air cooled

Digression: Gas versus water cooling design philosophy

Because LBNF must operate reliably in high radiation areas for decades, a goal for the LBNF design is:

- **all water cooling lines should be replaceable**
  - Water-cooled parts are accessible or in modules that can be replaced
  - Gas cooling is used in inaccessible spaces

Gas cooling is used for the decay pipe steel and its concrete shielding.

Heat load ~ 550 kW (2.4 MW beam, optimized horn design)

Gas cooling is used for the target pile bulk shielding.

Heat load ~ 500 kW (depends also on details of water cooling panels)

Gas selection

The large heat loads incline us toward N_2 rather than He

As comparison, SHIP at CERN design has 2 kW helium heat load

I don't know number for T2K or other target piles

Short-lived isotope strategies ?

Three possible strategies:

1. **Long ventilation path** before release, time for decay of short-lived (like NuMI)
2. **Seal vessel** and let short-lived isotopes decay before opening box
3. **Remove precursors**
   a) removing ^{40}Ar gets rid of ^{41}Ar (longest-lived of the short-lived)
   b) removing N_2, O_2 and H_2O gets rid of ^{11}C, ^{13}N, ^{15}O

*Removing O_2 and H_2O is also desirable to reduce **corrosion**.*

For reasons of:

- Compromise with tritium mitigation vs. short-lived isotope mitigation
- Reasonable gas cooling of shielding (1 MW deposited heat)
- Cost and complexity

LBNF has picked a mixed strategy of:

Small amount of 1. (ventilation path through target hall and pre-target enclosure)

Large effort on 2. (much better seal of target pile vessel)

Partial 3. (remove ^{40}Ar, O_2 and H_2O) ***Pure N_2 in target pile***

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Tritium input information

NuMI experience says majority of the tritium produced in the steel shielding can come out, *especially when shielding gets hot at high beam power*

~ 6 Ci / 10^{20} POT released during low power beam (~300 kW) (POT = Protons-On-Target)

~ 23 Ci / 10^{20} POT released during high power beam (510 kW ave.)

42 Ci / 10^{20} POT produced (MARS) in target hall + decay region + horns + target

Caveats:

Absorber is still pretty cool, and don't see much tritium coming out there

Some of what is coming out of target pile might be build-up from previous years and eventually be depleted

The large increase in release of Tritium means we have to take greater note of it in LBNF design.

MARS results indicate release / POT cannot get hugely worse.

T2K has indicated that when opening up their sealed helium vessel, need to ventilate with air for an extended period to reduce tritium to acceptable level for access.

(NuMI = continuous air release 9 m^3/min while running; no ^3H-induced wait for access)

Tritium Strategies ?

Three possible strategies:

1. **Trap** ^3H in place; seal (surface coat?) steel shielding or possibly keep steel very cool, to prevent ^3H leaking out
2. **Extract** ^3H from recirculating gas in vessel, store it and send it to rad-waste dump
3. **Continuously release** ^3H to air, preventing buildup (like NuMI)

NuMI shows large temperature dependence of ^3H release from the steel shielding

For LBNF, pick **continuous release** while shielding is hot (beam running)

- don't build up inventory, so potential source reduced before access
- shielding is cool during access, slowing release of what is left
- minimizes long-term stored tritium risk & risk of catastrophic release
- looks like most cost-effective strategy with least R&D

Leads to "Goldilocks" design for target pile vent rate

- Not too large (or ^{11}C release is too much)

- Not too small (or will get ^{3}H build-up)

  – Hopefully LBNF design is "just right"*

- *Aiming for ~ 50 to 200 liter/minute N_2 release each, target pile and decay pipe cooling system*

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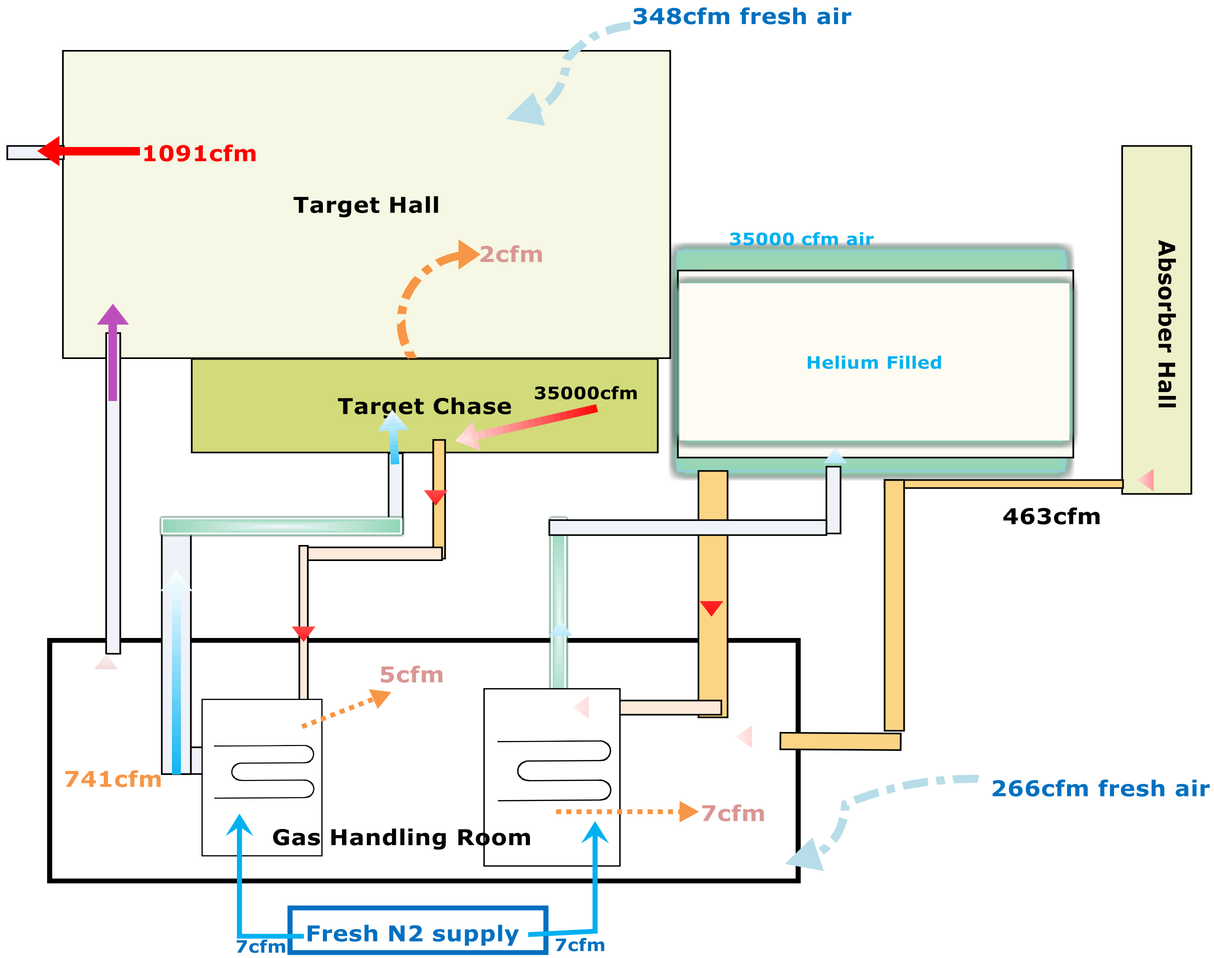
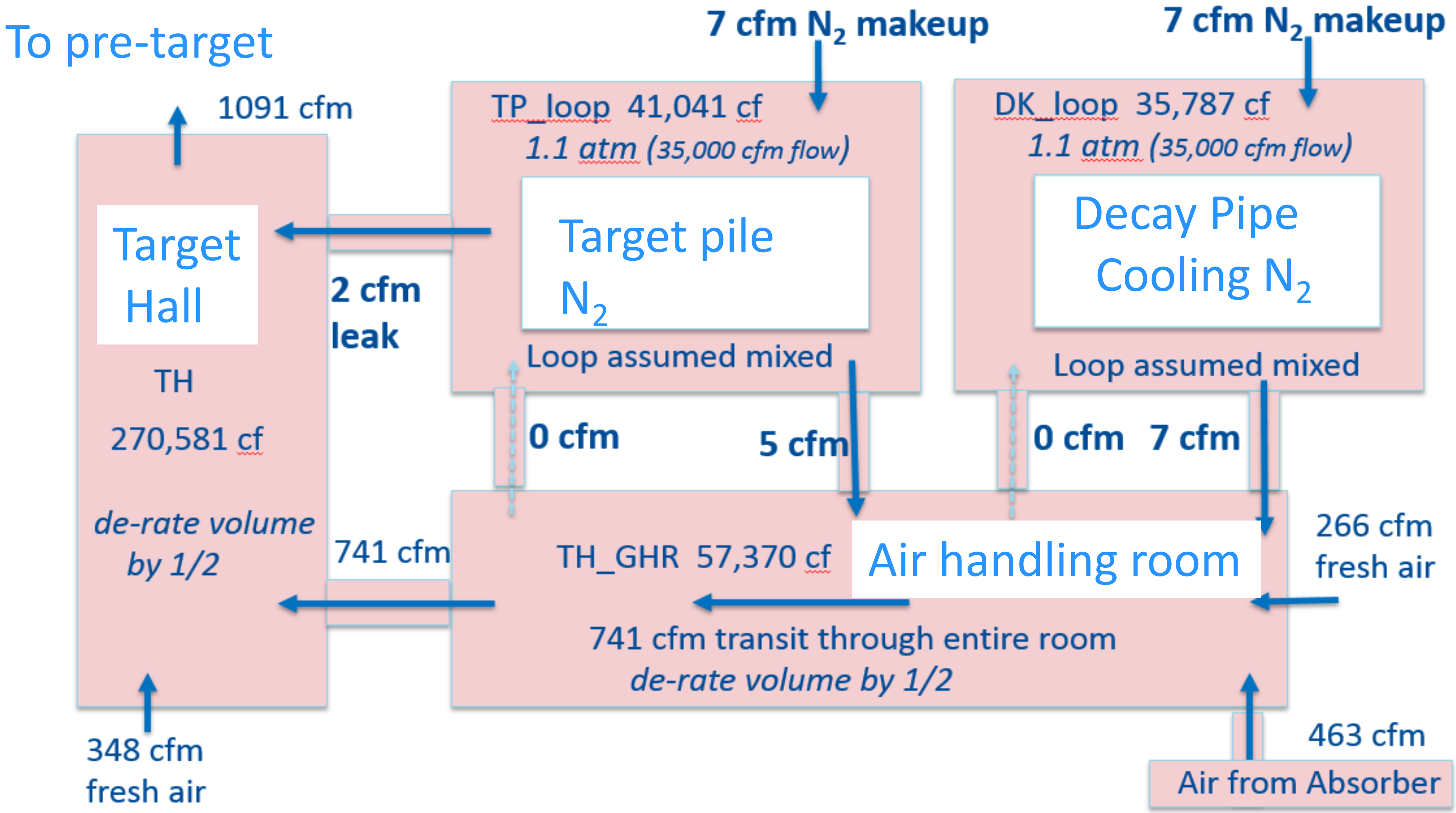
Sketch of gas flow paths for air release model



(Part of) Gas flow model for isotope release calculation



Result of LBNF air release study

<u>Input conditions</u>

- 2.4 MW proton beam power, with LBNF stated design uptime per year
- Target pile Nitrogen filled (slow purge)
- Decay pipe cooling also employing Nitrogen (slow purge)
- Absorber employing Air cooling
- Release through air-handling room + target hall + pre-target
- Optimized horn configuration
- Tritium release scaled from NuMI high power running
- Using the Fermilab standard (conservative) isotope production methodology

Release Point	MEOI from short-lived	MEOI from Tritium	Total MEOI (fraction of limit)
LBNF pre-target upstream end	6%	17%	23%

Estimated air radiation release well below limit

dominated by Tritium

An idea for further Tritium mitigation

- Tritium likes to replace one H in water, forming HTO
  - *This is how most NuMI tritium is released*

- Releasing to air as HT is much more ALARA (As Low As Reasonably Achievable)
  - *Release limit for HT is **10,000 x** as much as for HTO*

- In LBNF target pile, where there should be practically no water vapor, could one poison the N_2 with small amount of H_2, encouraging the formation of HT in the radiation field ? (Released to outside air then in N_2 continuous purge).
  - *If it works, could be very simple and cheap*
  - *Needs R&D*

Conclusion

Slow controlled purging of LBNF target pile with N_2 should:

- get rid of Tritium continuously in a controlled fashion
- keep release of ^{11}C, ^{13}N, and ^{41}Ar to acceptable levels

Nitrogen in target pile:

- Is cheap
- Is a good gas for ~ 1 MW of gas-cooling of shielding
- (when combined with continuous purge)
  allows rapid access into target pile when needed for repair,
  and rapid return to operational state (~ 1 day each way)
- Mitigates corrosion