Tritium production and release at LBNF

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How much tritium will be produced at LBNF?

LBNF Tritium production at 2.4 MW (MARS Monte Carlo)

Target station

Component	^3H/sec, $\times 10^{14}$
2m target	0.4
Steel	5.88
Concrete	0.058
Total	6.338
Power depos. (MW)	1.238

Decay channel

Component	^3H/sec, $\times 10^{14}$
Pipe_in	0.391
Pipe_out	0.228
Concrete	1.16
Total	1.78
Power depos. (MW)	0.542

Hadron absorber

Component	^3H/sec, $\times 10^{14}$
Aluminum	1.28
Steel	0.528
Concrete	0.0188
Total	1.83
Power depos. (MW)	0.40

At 56% uptime/year, M.C. predicts producing 846 Ci/year (31 Tera-Bq/yr) of which 500 Ci/yr is in target pile steel

Overview of tritium handling strategy

Majority of tritium from target pile and absorber will be exhausted up stacks to air

- Some directly through the ventilation system
- Some captured in condensate from dehumidification, then re-evaporated
- Rooms next to the exhaust path will be maintained at overpressure to combat leaks
- Calculated release is ~1/5 of FNAL's allowable total radiological release to air

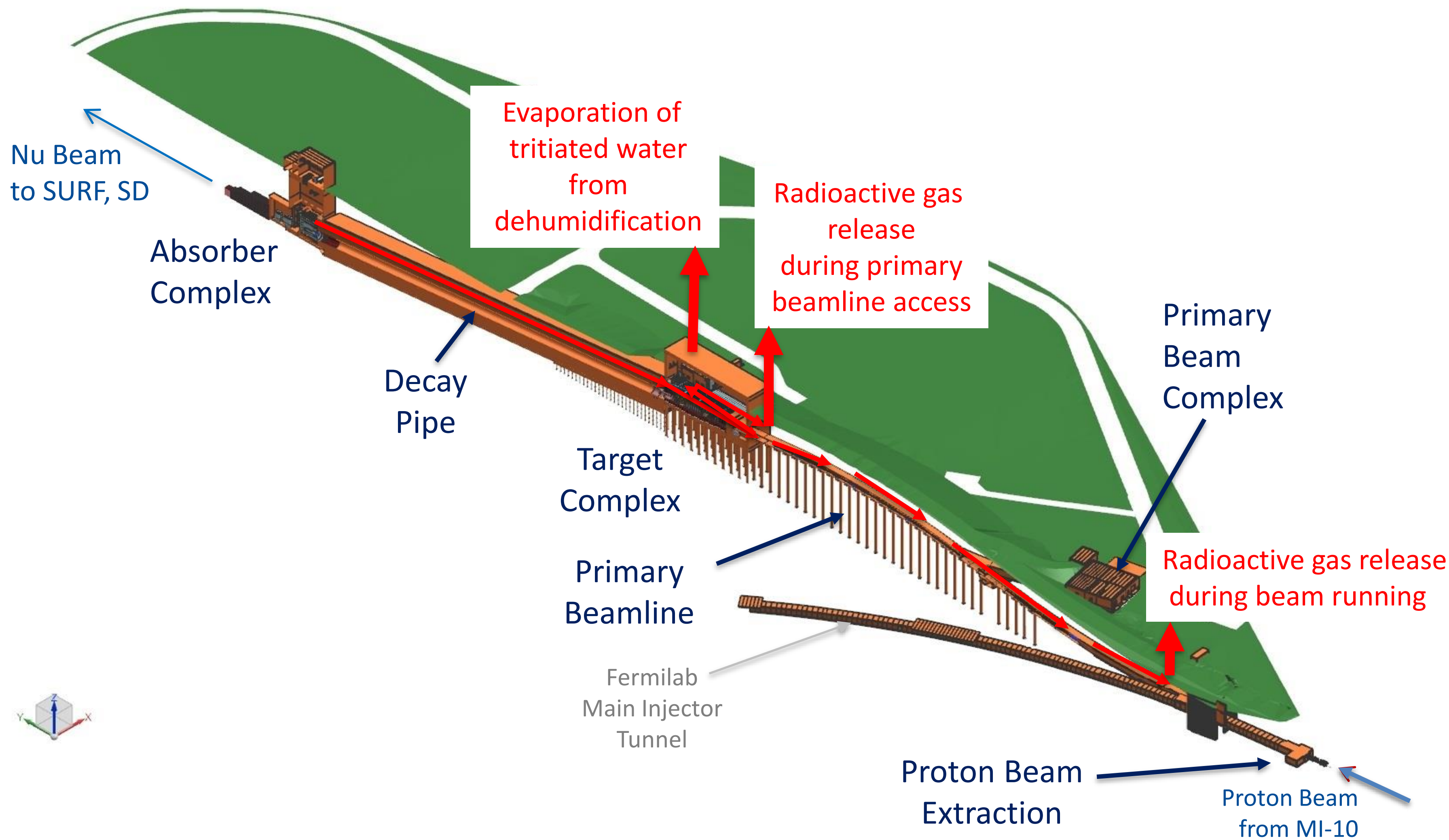
Tritium from decay pipe region will decay in the concrete (5.6 m thick)

- Some can penetrate pipe windows, and exhaust up stacks to air

Tritium captured in water cooling systems (horns, absorber core, target pile cooling panels) will be barreled and shipped offsite for disposal

So we are good during beam running; will discuss access

Radioisotope paths to stacks



Recent work: controlling dose to workers on access

DAC (Defined Air Concentration)

- DAC is amount of radiation in air that:

  Would give 5 rem dose to workers in 2000 hr work year.

  = 2.5 mrem/hr, = 100 mrem in 40 hr work week.

- For tritium in form of HTO, DAC corresponds to 20 pCi/cc of air.
- At 25 C, 100% RH, it translates to about 852,000 pCi/ml of water

  At FNAL, we don't let water get tritiated much beyond 800,000 pCi/ml, so that leaks/spills can't get the air above a DAC.

- Work restrictions required if Tritium in air > 10% DAC

  We are designing to stay below 10% DAC for workers on access

Factors about dose to workers on access from tritium

Experience (as basis for design):

- Majority of tritium produced in NuMI target pile steel is (collected and) released as HTO during beam running; (release drops during access)
- Maximum exposure for workers on access to NuMI target pile was 4% DAC

LBNF designed for 340% the beam power of NuMI

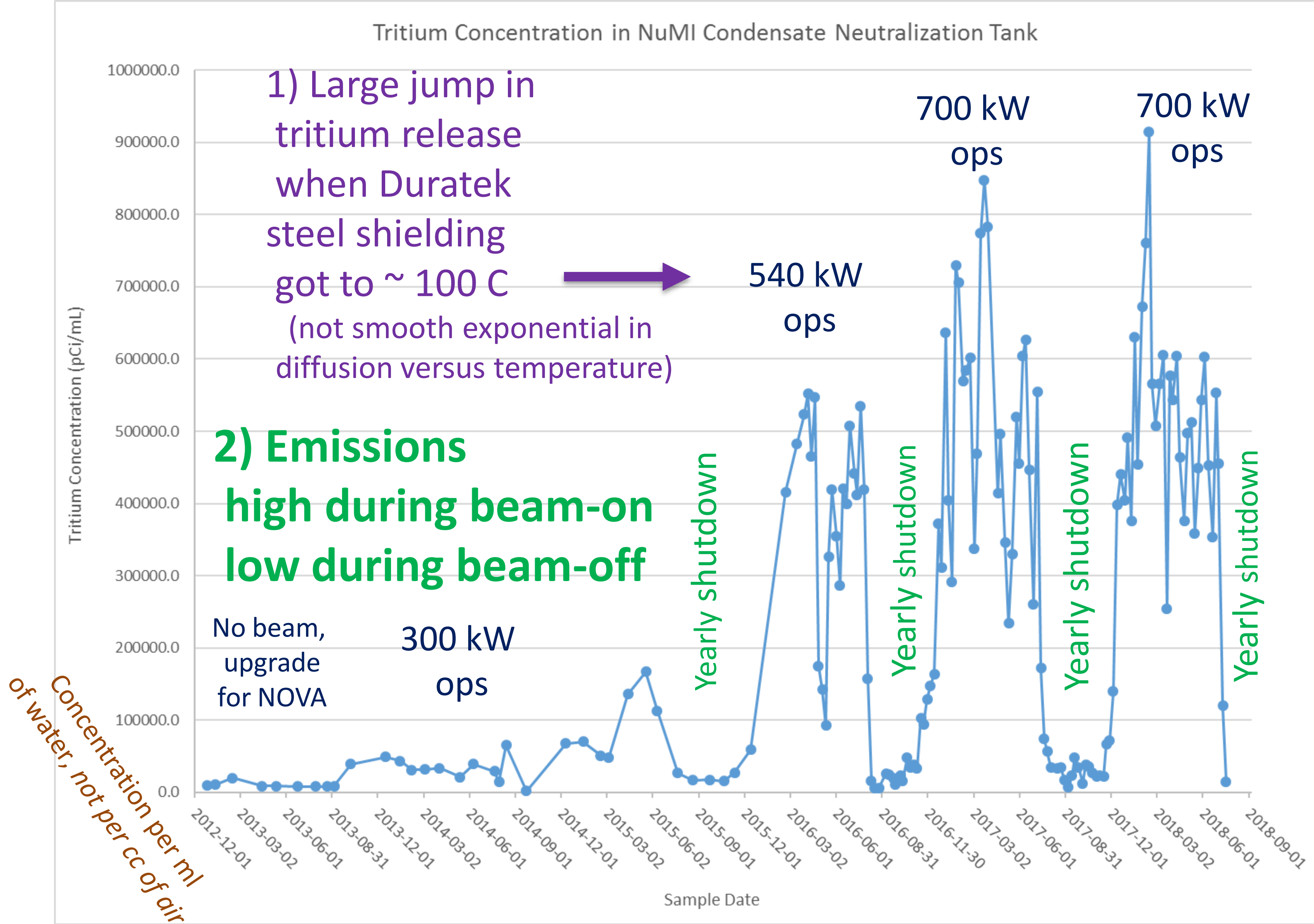
LBNF will have a sealed target pile in N_2 during beam running

which could save up tritium for release on access with humidity in air

Goals:

- Fairly quick access to target pile (few days)
- Keep exposure for workers on access to LBNF < 10% DAC

NUMI Tritium concentration in dehumidifier water, evaporated to air



NuMI Tritium Production and Release

MARS $Ci/10^{20}$ POT	***Monte Carlo*** **Produced in**
24	target pile steel
11	decay pipe concrete
2.5	decay pipe steel
0.22	chase air
0.03	decay pipe helium
??	absorber
1.3	horns
1.7 - 4.2	Target
41 - 44	**TOTAL**

MARS Monte Carlo
of Tritium production
in NuMI

6 $Ci/10^{20}$ POT Measured Release 2008 – 2011 at 300 kW

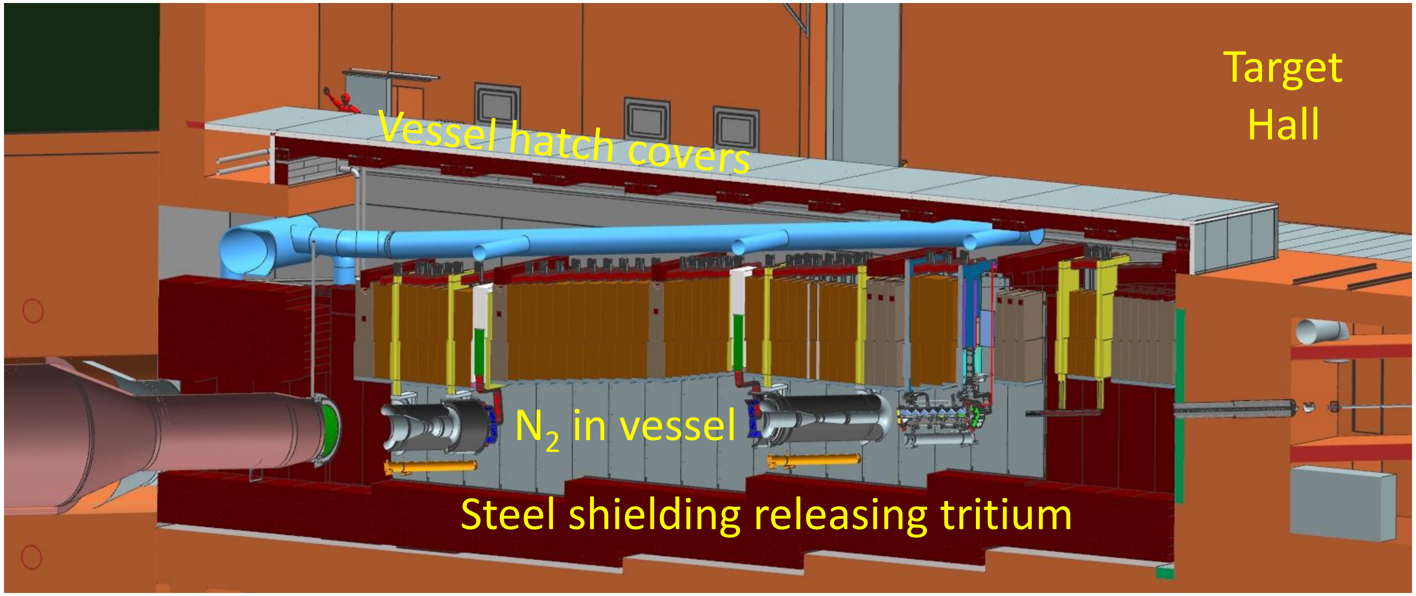
~ 26 $Ci/10^{20}$ POT Measured Release 2016 at 520 kW

Release jumped non-linearly with beam power as steel temperature ~ 100 C, and is approximately equal to M.C. production rate in steel components

Majority of tritium in target pile steel appears to be coming out

LBNF: scrub tritium out of target pile with humidity during beam

Goal: Don't build up large amount of tritium, which would come out in puff when opening up



Require addition of mist injection of humidity

Dehumidifier for N_2 gas was already in design

Plan to remove most of the tritium released from the shielding during beam running the same way we do for NuMI – pick it up with water vapor to HTO, and dehumidify.

Calculations indicate parameters shown will
- maintain the tritium transport path
- keep built up tritium to reasonable levels

We are also optimizing ventilation to protect workers during access

Comparison	NuMI	LBNF
Target pile gas	air	N_2
H_2O in gas (ppt)	5	1
Condensate (gallon/day)	170	17

Can tritium come out of steel, or will it decay inside the steel?

Diffusion scales – sanity check

From literature search, get typical range of diffusion constants.
The average distance that tritium moves in time t is <X> = sqrt(4 D t).
Plug in Tritium lifetime as t, and compare to typical distance scales.

	Diffusion constant (cm^2/s)	Ave. distance in Tritium lifetime (cm)	Distance Scale NuMI (cm)	Distance Scale LBNF (cm)
Steel in Target Pile	$2 - 8 \times 10^{-5}$	176 - 353	10 - 65	10 (cooling panel)
Concrete in Decay Region	$2 - 22 \times 10^{-7}$	18-58	137 – 300 to outside	560 to outside

Yes, most of the Tritium in steel will get to the surface of the steel, can release to air.

But most Concrete Tritium decays before it can get outside. (Can go inside).

What is characteristic time scale for tritium to reach surface of steel?

Operational time scales

- Base operation schedule: 10 months operation, then 2 months open
- In case of failure during running*, aiming for few weeks downtime for repair*

Diffusion through steel

- Look at Tritium diffusion through steel to set time scale to judge rest of potential time constants. (The inner cooling panels are the most heavily trtiated)

- Time scale for tritium diffusion: average distance for random walk of tritium is

  $\langle X \rangle = \mathrm{sqrt}(4Dt)$

  D (diffusion constant) for steel ~ 2 to 8 E-5 cm^2/s; panel thickness 5 to 10 cm
- So for water cooling panels, distances ~ 5 cm, characteristic time ~ 1 to 4 days
- Longer for thicker shield blocks

Aside: numbers in this model are not for stainless steel; our shielding is not stainless.

If we don't mitigate, what DAC concentrations might LBNF have?

1st order estimate of LBNF Target Hall (TH) air tritium concentration

Take NuMI measured tritium release per 10^{20}POT,
  and various Monte Carlo calculations of production,
Scale by POT/yr, divide by LBNF TH ventilation over a year
  → Get average tritium concentration in air going through target hall

NuMI table meas	NuMI MC w/o Abs	LBNF MC prod	LBNF TH alone		
26	44	44.4	22.9	Ci/e20POT	
22.1	22.1	22.1	22.1	e20 POT/ yr	LBNF 2.4MW op 56%
575	972	981	506	Ci/yr	LBNF 2.4MW op 56%
1091	1091	1091	1091	cfm	beam-on ventillation
525600	525600	525600	525600	minute/real-yr	assume for vent time
35	60	60	31	pCi/cc	ave tritium concentration
20	20	20	20	pCi/CC	DAC concentration
177%	299%	302%	156%		percent of DAC concentration

Get estimates of a few DAC, far above the <10% DAC desired
under assumption of continuous release;
if tritium is trapped during beam operation, could be significantly worse during access

Mitigation strategies being implemented

- Remove most tritium during beam operations by scrubbing with humidity (NuMI experience)

- Operate inner layer of steel (the cooling panels) at higher temperature (~100 C) during operation, then cooler (room temperature) during access to encourage higher/lower release during running/access. (NuMI experience)

- During access, increase air ventilation rate to dilute the HTO
  – 1,091 cfm -> 22,300 cfm of air through target hall

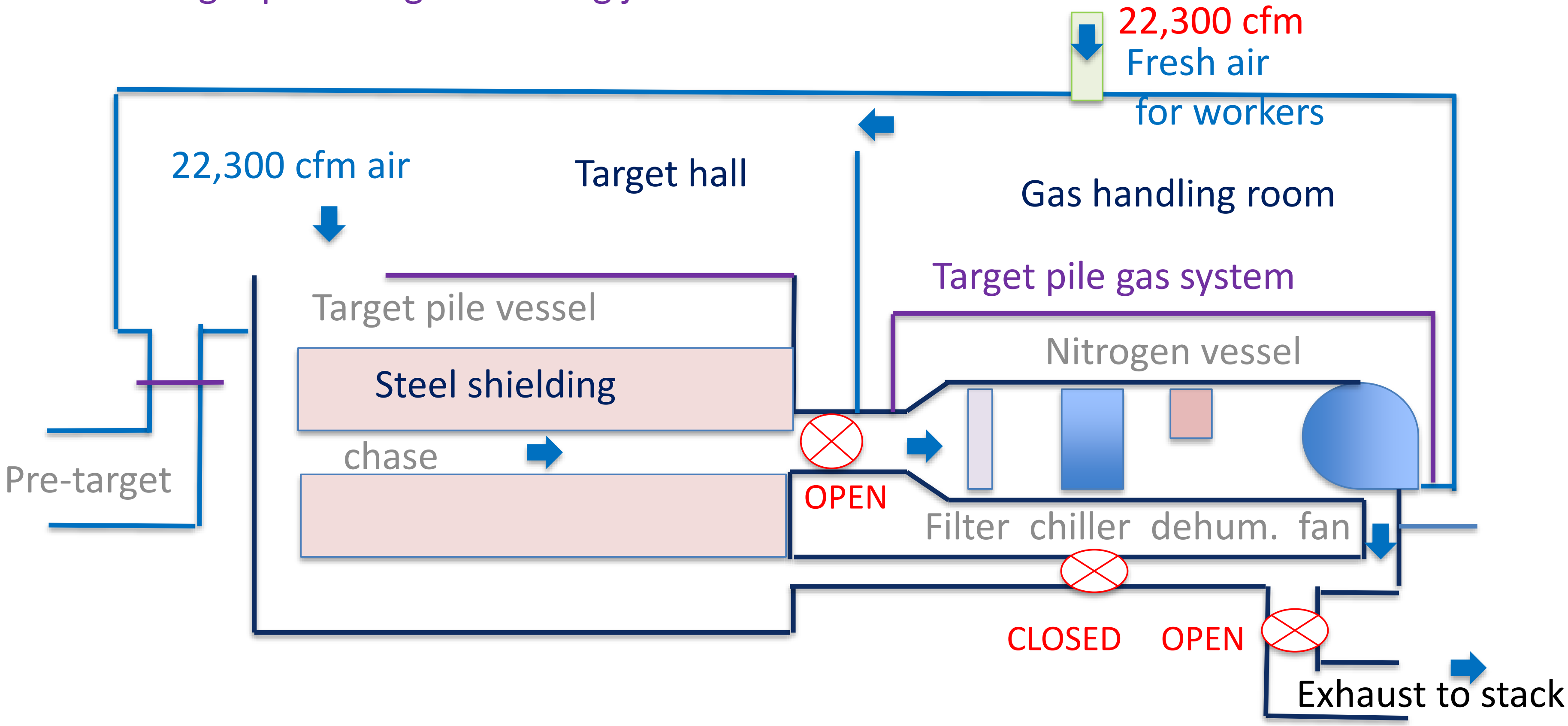
- Draw the air (to the extent practical) away from workers to a release stack
  – Ventilation once-through, from target hall down into target pile, then up stack

During Target Pile access

Ventilation to help mitigate high Tritium release in target pile vessel

- Pull tritium away from workers in nitrogen vessel
- Use existing filter to pick up contamination before exhaust

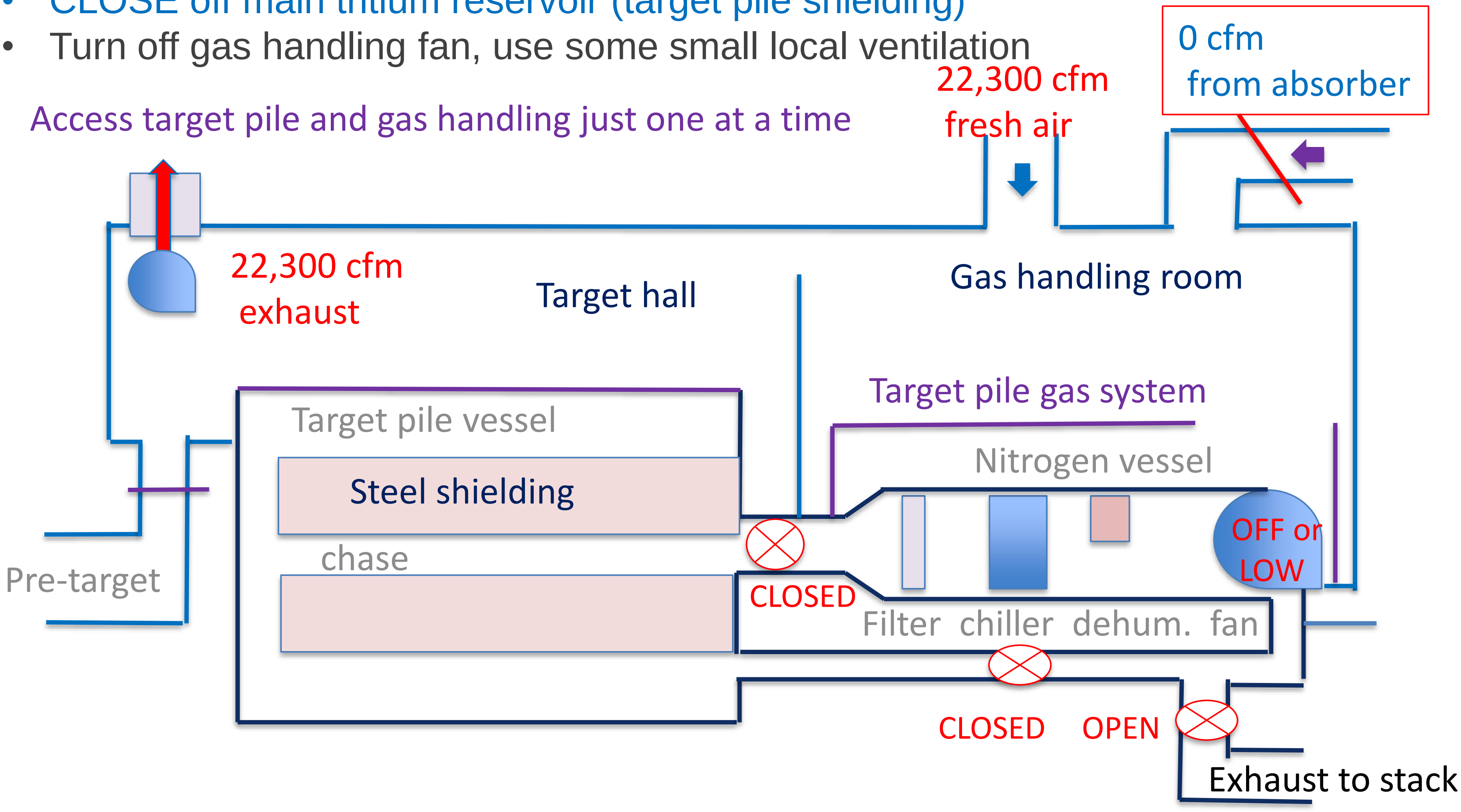
Access target pile and gas handling just one at a time



During Target Pile Gas Handling access

Ventilation modification stay away from high Tritium release in target pile vessel

- CLOSE off main tritium reservoir (target pile shielding)
- Turn off gas handling fan, use some small local ventilation

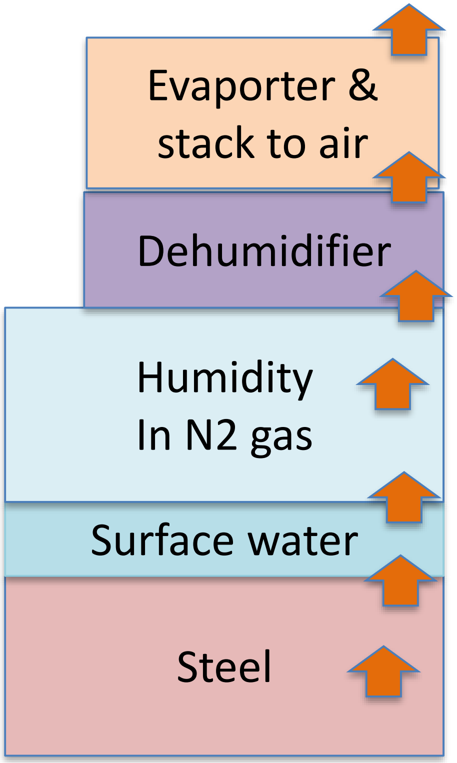


For the tritium scrubbing with humidity

Have set up a framework for tritium transport,

and done 1st pass calculations:

- Model elements – follow the Tritium path:
  - Tritium production in steel shielding (MARS MC)
  - Diffusion rate of tritium through steel
  - Steel to surface water layer tritium transfer
    - (surface water is few molecules thick)
  - Surface layer tritiated water to humidity exchange
  - Humidity turnover rate (injection and dehumidification)



The model calculations indicate the parameters shown earlier are sufficient to:

- Maintain the surface physical-water layer that underpins the transfer calculations
- Maintain a high gradient from steel to surface water layer for tritium transport
- Keep the amount of tritium stored in the target pile humidity to reasonably low level

The model will be further refined and checked, and some prototyping may be done

Model parameters: scrubbing tritium with humidity (page 1)

LBNF parameter	Value
Nitrogen gas volume	33,178 ft^3
Nitrogen gas recirculation flow rate	35,000 ft^3/minute
H2O molecular concentration	1 part per thousand
H2O relative humidity at room temperature	4% RH
Total humidity in vessel (liquid water equivalent)	0.18 gallon
Mist injection / dehumidification rate (liquid water)	17 gallon/day
Average time water molecule is in N2	16 minutes
Average circuits around system of a water molecule	17
Physical water layer on steel	Few 10^{-4} mole/m^2

Model parameters: scrubbing tritium with humidity (page 2)

LBNF parameter	Value
Target pile steel	8,000 tons
Thickness of steel cooling panels (highest tritium deposit)	5 cm
Tritium production rate in target pile steel (for 2.4 MW beam)	5.9×10^{14} T/s
Diffusion constant in steel	$2\text{-}8\times10^{-5}$ cm^2/s
Characteristic time of tritium in steel cooling panel	< 4 days
Estimate solubility of T in steel	~ 0.3 $mole/m^3$
Estimate solubility of T in surface water layer	~ 4×10^4 $mole/m^3$
Tritium concentration in condensate	0.04 mCi/ml
Tritium stored in target pile humidity	28 mCi
Target pile humidity tritium level inside pile	1.5 DAC
Tritium collection, 2.4 MW beam & 56% uptime	500 Ci/year

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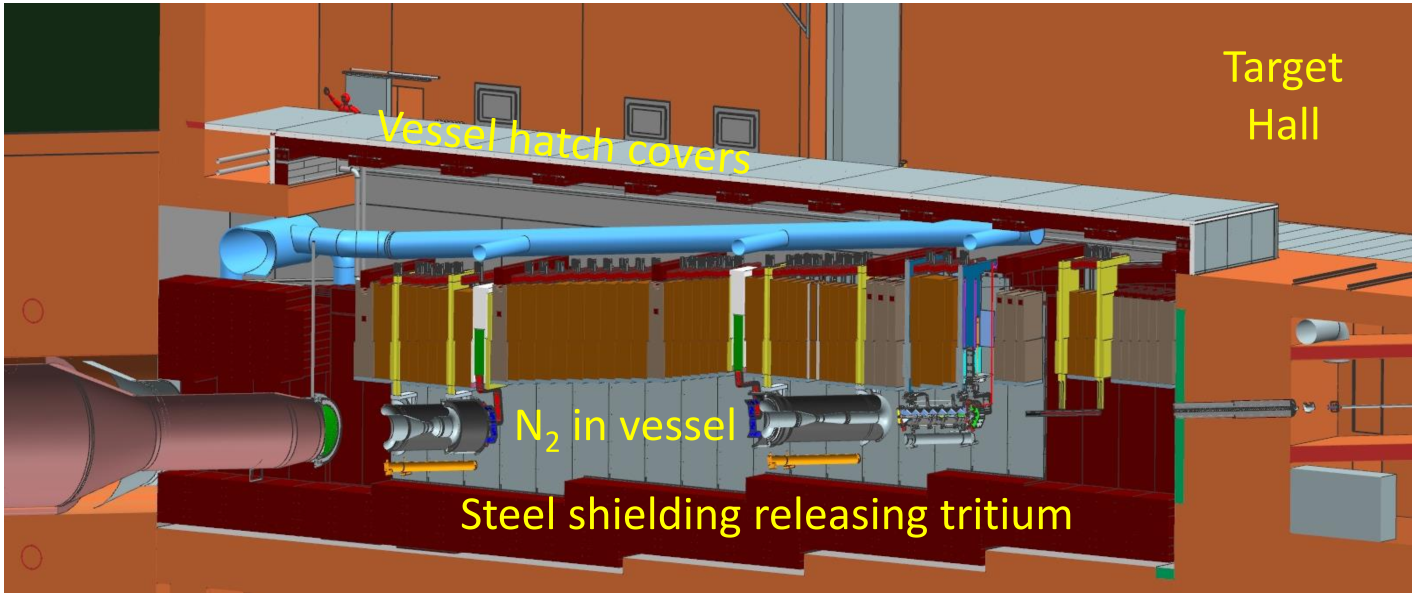

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