νSTORM: Radiological Issues

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Outline

- Requirements
- Radiological safety issues:
  - Bulk soil shielding
  - Groundwater and surface water
  - Air emissions
  - Residual activation
  - Prompt radiation
  - RAW systems
- Summary and Status

beam line and Muons (400 kW)

Requirements

Dose to the Members of the Public

- Regulatory requirements/limits regarding the maximum annual allowable dose to the members of the public to 100 mrem/yr.
- FNAL has implemented a goal of limiting the dose at the site boundary to a maximum of 10 mrem in any given calendar year from all Fermilab sources.
- To allow operations of other experiments, beam-lines and accelerators, the goal for nuSTORM will be set at less than 1 mrem in a year, from all radiation sources generated by the nuSTORM beam-line.

Requirements

- Shielding levels required to achieve :
  - Groundwater contaminations below the EPA and Illinois EPA requirements.
  - Surface waters contamination below the DOE O458.1.
  - State of Illinois requirement of “non-degradation of natural resources”

  should also be addressed.

$$\sum_i \frac{C_i}{DCS_i} \leq 1$$

	Regulatory Limits (pCi/ml)	
	Ground Water	Surface Water
^{3}H	20	1900
^{22}Na	0.4	10
Derived Concentration Standard (pCi/ml)		

Requirements

Current Fermilab air emissions permit:

- Annual exposure of a member of public offsite to the radioactive air emissions, from **all** Fermilab sources should be less than 0.1 mrem in a year.

- Best to design nuSTORM contribution to be less than **20%** of this limit to allow for the other projects at the laboratory.

Requirements

Dose to workers:

- Current Fermilab policy allows 1500 mrem in a year to trained workers; 350 mrem/quarter.

- Maximum occupancy time in accelerator and beam line areas to allow a maximum of 100 mrem/week.

Requirements

Residual Activation of devices and shielding

- FRCM Article 111.6 states:

"Beam losses shall be limited so that the residual dose rate inside the accelerator and beam line enclosures, shall safely permit all necessary maintenance. "

- Based on the past experience in the nuSTORM primary beam enclosures beam loss and beam control devices should be employed to keep the residual radiation inside the beam line to no more than **100 mrem/hr on contact**. This allows for repair or replacement of the beam line elements with little programmatic impact and keeping the dose to the workers ALARA.

Requirements

Residual Activation of devices and shielding

- Beam-line devices, such as targets, lenses, horns or modules, that are exposed to high levels of beam sprays, are expected to become highly radioactive. Based on the predicted maximum activation levels after 10 years of operation, a sufficiently shielded work/repair cell for these devices needs to be designed such that for a 200 R/hr. object, the dose rate outside is less than 1 mrem/hr.
- The shielding of the containers used for the over the road transport of such devices should be such that the dose rate outside the container is not more than 100 mrem/hr. at 1 ft.

Shielding Design Parameters

Shielding of a beam line areas should be designed such that an upgrade from100 kW to 400 kW could be easily done. Where this is not possible, design should be for 400 kW.

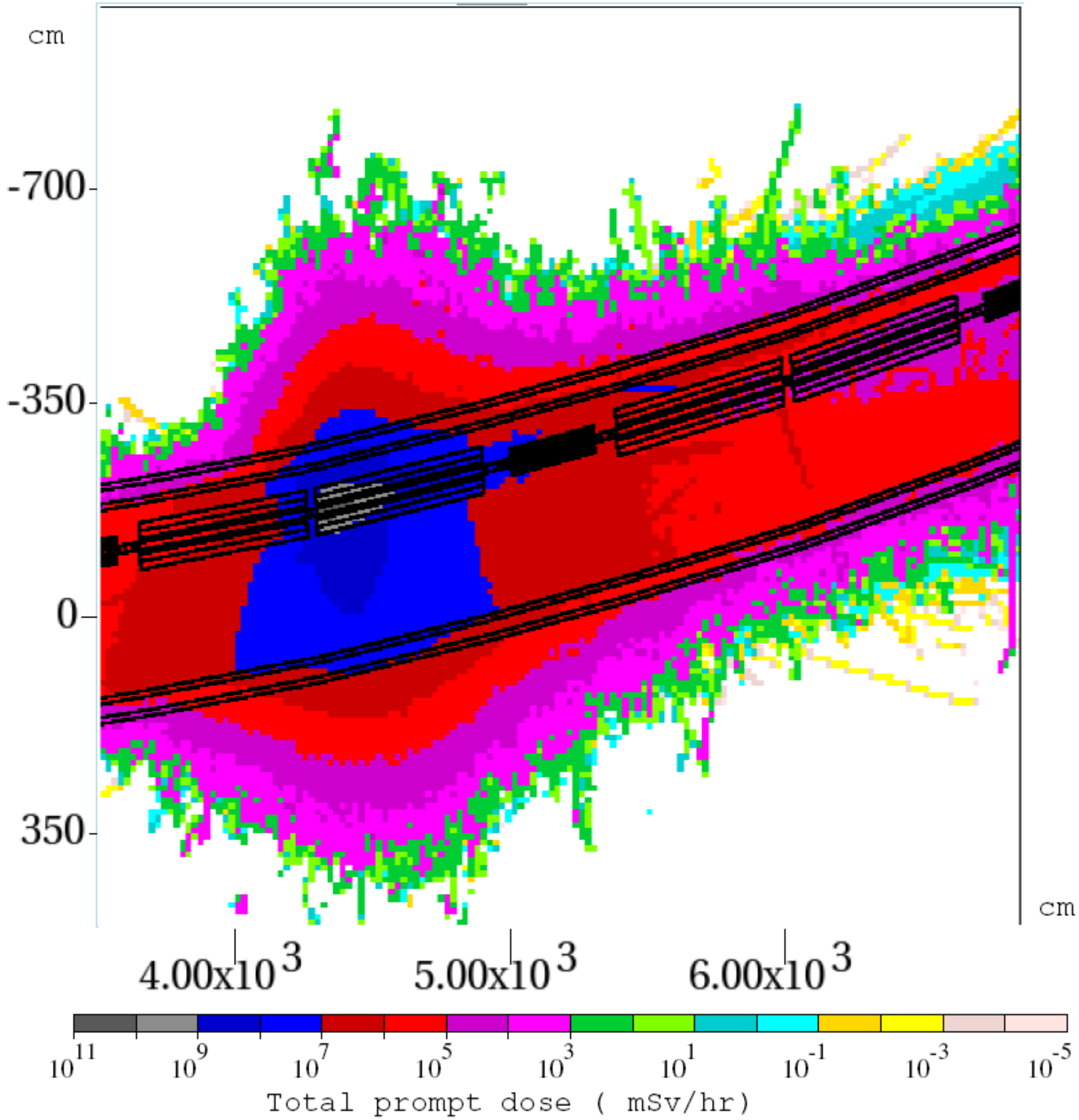
Beam Parameter	**Value**
Protons per cycle	$(1.39 - 9.71)\text{x } 10^{13}$
Cycle time (60 GeV)	1.333 sec
Proton beam energy	60 GeV
Beam power at 60 GeV	100 - 400 kW
Operational efficiency	$2\text{x } 10^{7}$ sec/yr.
Protons on target per year	$(2.07 – 8.27) \text{ x } 10^{20}$

Primary Transport-line

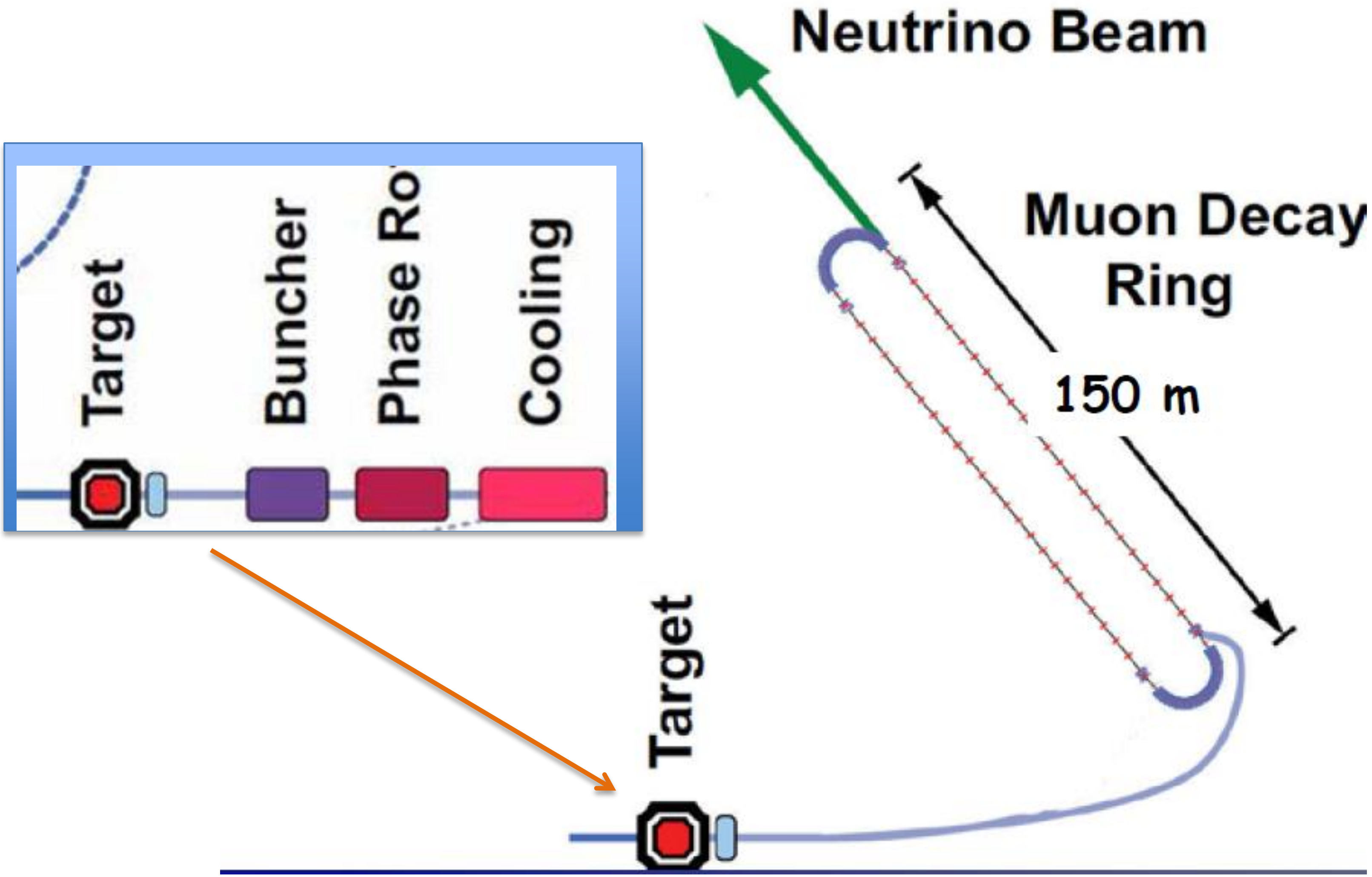
- Mars Calculation of Prompt Dose rate source term for the primary transport line.

- Based on full 400 kW beam lost on a magnet for one hour., Source term

= 1.74E9 mrem/hr.



beam line and Muons (400 kW)



Primary Beam Loss (400 kW) **Requirements**

- NuMI (400kW) beam losses are controlled to better than1E-5.
- Control of the nuSTORM beam Normal losses is assumed at **1E-5** for shielding purposes. This corresponds to assuming the same sensitivity/safety factor.

- For NuMI number of full primary beam pulses that could be lost in a year is severely limited by the groundwater limits (~120 pulses per year).
- During the six years of NuMI primary beam operation, more than 50 million beam pulses have been transported to the NuMI target, and a total of more than 1.2×10^{21} protons on target at 120 GeV. A total of 6 beam pulses have experienced primary beam loss at the 1% level, all due to Main Injector RF problems.
- Control of nuSTORM primary beam losses to less than 2 pulses/week is possible by just using the controls developed for NuMI beam.

primary beam line shielding(400 kW)

Dose Rate (DR) Under Normal Operating Conditions	Controls	Full beam loss			1E-5 loss rate		
		Hadrons soil (ft)	Transverse Muons soil (ft)	Longitudinal Muons soil (ft)	Hadrons soil (ft)	Transverse Muons soil (ft)	Longitudinal Muons soil (ft)
DR < 0.05 mrem/hr	No precautions needed.	35.5	23.5	351	**18.5**	16	**145**
0.05 ≤ DR < 0.25 mrem/hr	Signs (CAUTION -- Controlled Area). No occupancy limits imposed.	33	22.4	323	16.5	14	117
0.25 ≤ DR < 5 mrem/hr	Signs (CAUTION -- Controlled Area) and minimal occupancy (occupancy duration of less than 1 hr).	29	18.7	272	12	10.5	66
5 ≤ DR < 100 mrem/hr	Signs (CAUTION -- Radiation Area) and rigid barriers (at least 4' high) with locked gates. For beam-on radiation, access restricted to authorized personnel. Radiological Worker Training required.	24.5	15.0	221	7.5	7	15.3

primary beam line shielding(400 kW)

	Accident Scenario **2 full beam pulses lost**	Hadrons	Muons	
Maximum Dose (D) Expected in One hour	**Controls**	**Transverse** soil (ft)	**Transverse** soil (ft)	Longitudinal soil (ft)
$D < 1$ mrem	No precautions needed.	**20.5**	**18**	177
$1 < D \leq 10$ mrem	Minimal occupancy only (duration of credible occupancy < 1 hr) no posting	17.5	15.5	138
$1 \leq D < 5$ mrem	Signs (CAUTION -- Controlled Area). No occupancy limits imposed. Radiological Worker Training required.	18.5	16	150
$5 \leq D < 100$ mrem	Signs (CAUTION -- Radiation Area) and minimal occupancy (duration of occupancy of less than1 hr). The Division/Section/Center RSO has the option of imposing additional controls in accordance with Article 231 to ensure personnel entry control is maintained. Radiological Worker Training required.	14	13	99
$100 \leq D < 500$ mrem	Signs (DANGER -- High Radiation Area) and rigid barriers (at least 4' high) with locked gates. For beam-on radiation, access restricted to authorized personnel. Radiological Worker Training required.	11.5	11	71

primary beam line shielding(400 kW)

Longitudinal muons doses at the **site boundary**

Because of the offsite annual dose limit, the shielding for the longitudinal muons has to be at least 300 times better, or beam control should be better than two pulses per hour or make sure the forward muon plume is in the soil at least 450 ft. before it reaches at the site boundary.
This would correspond to less than 1 mrem in a year to the site boundary.

Groundwater (400 kW)

- The nuSTORM beam line is located in the glacial till. The seepage velocities, for the layers in the glacial till, are very small.
- The concentration of the radionuclides reaching the aquifer are expected to be reduced by 5 to 7 orders of magnitude.

- However, it is prudent not to go with the surface water limits either, but keep well below it: Calculations show that if the shielding of the "target area" is about 3 ft. of concrete, one year build up of tritium in the soil will be about 0.13% of the surface limit.
- Experience show that a layer of water impermeable barrier outside this shield will mitigate other pathways of tritium as well.

Target Chase/Target Hall (400 kW)

- The Target chase shielding is designed to have an average dose rate of less than 100 mrem/hr in the target hall during the normal beam operations.

- Combinations of steel and concrete are used for shielding.

- Assumed that the most sensitive electronics lifetime dose should not be more than 1E12 neutron/cm^2 (1 krad of neutrons or 10 krad of γ, or weighted sum).

	Baffle (7 ft. iron, 6 ft. concrete)		Target (10 ft. iron, 6 ft. concrete)		Horn (9 ft. iron, 6 ft. concrete)		End of the Target Hall (6 ft. iron, 6 ft. concrete)	
	(mrem/hr)	n/cm^2/yr	(mrem/hr)	n/cm^2/yr	(mrem/hr)	n/cm^2/yr	(mrem/hr)	n/cm^2/yr
400 kW	58	3.60E+07	37	2.30E+09	38	2.40E+09	86	2.60E+09

	Baffle (7 ft. iron, 6 ft. concrete)		Target (10 ft. iron, 6 ft. concrete)		Horn (9 ft. iron, 6 ft. concrete)		End of the Target Hall(6 ft. iron, 6 ft. concrete)	
	(mrem/hr)	n/cm^2/yr	(mrem/hr)	n/cm^2/yr	(mrem/hr)	n/cm^2/yr	(mrem/hr)	n/cm^2/yr
100 kW	14	9.00E+06	9	5.70E+08	10	5.90E+08	21	6.40E+08

Activated Air Emissions (400 kW)

Produced Radionuclide		Parent Stable Nuclide
Nuclide	Half-life	Nuclide
^{3}H	12.32 y	^{14}N
		^{16}O
^{7}Be	53.22 days	^{14}N
		^{16}O
^{11}C	20.33 min	^{12}C
		^{14}N
		^{16}O
^{13}N	9.96 min	^{14}N
^{15}O	2.04 min	^{16}O
^{16}N	7.13 s	^{18}O
^{38}Cl	37.24 min	^{40}Ar
^{39}Cl	55.6 min	^{40}Ar
^{41}Ar	1.83 h	^{40}Ar

Comparisons with the calculations done for the Main Injector and NuMI, suggest that this beam line can release about 20-50 Curies per year.

To reduce this amount slow flow and/or long transit times can be used:

- Transport from target to the D0 sector is fairly long.
- Additional lengths of the Tevatron tunnel may be available.

Skyshine and Direct Prompt Doses (400 kW)

The combined annual direct and skyshine doses should be calculated at the site boundary and at Wilson Hall.

Since this beam line will be placed at the same level as the Main Injector with the similar soil overburden, shyshine radiation will not be an issue.

RAW Systems (400 kW)

- Beam-on dose rates are high due to the high concentrations of short lived radio-isotopes in the RAW systems.
- RAW room needs shielding.
- DI-bottles will have their own shielding.
- Several levels of **spill control** should be built into the design of the RAW room and skids.
- A predetermined cooling time is required, before access to RAW room is allowed.
- Removed RAW is disposed of as low level waste.
- Integrated annual dose to the electronics could be large and it is best to remove or shield them.

RAW Systems (400 kW)

Simply scaled from NuMI systems

400 kW	Target	Horn	Hadron absorber
Dose Rates(Rad/hr)	387	15.5	0.19
after 1 ft concrete (mrad/hr)	14985	601	7.3
after 2 ft concrete (mrad/hr)	85.7	3.44	0.04
after 3 ft concrete (mrad/hr)	0.3	0.01	0.0002

Summary and status

- This was a very rough overview no detailed evaluations can be done at this stage. But,

- Radiological goals are reasonable and achievable.