Estimation of Flux and Residual Radioactivity for the COMET Phase-I Experiment

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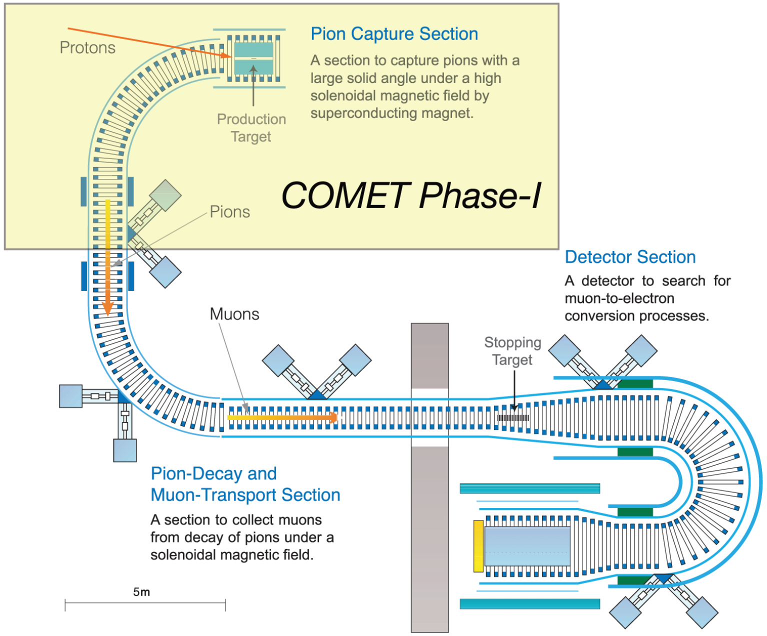
Introduction

COMET is an experiment at J-PARC, which will search for coherent neutrino-less conversion of a muon to an electron in muonic atom[1].

Experiment	Phase-I	Phase-II
Proton energy	8 GeV	8 GeV
Proton beam power	3.2 kW	56 kW
Total DAQ time	150 days	180 days
Production target	Graphite	Tungsten
	2024?	TBD



The maintenance is planned after the 150-day operation and the following 180-day cooling.

Purpose

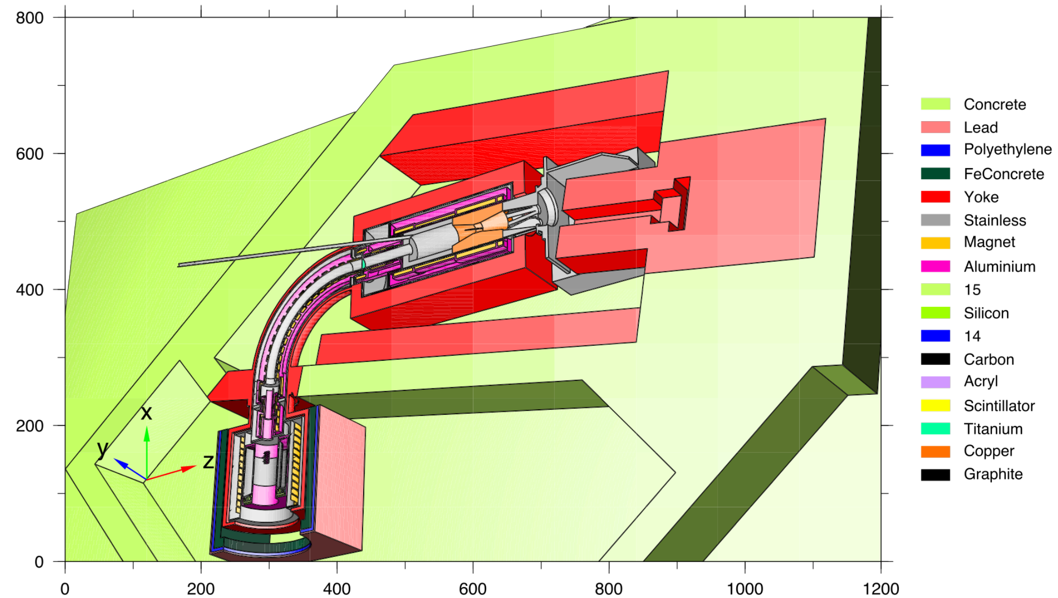
Estimation of Residual Radioactivity for Phase-I experiment

- Flux during the operation
- Residual radioactivity
- Effective dose rate distribution

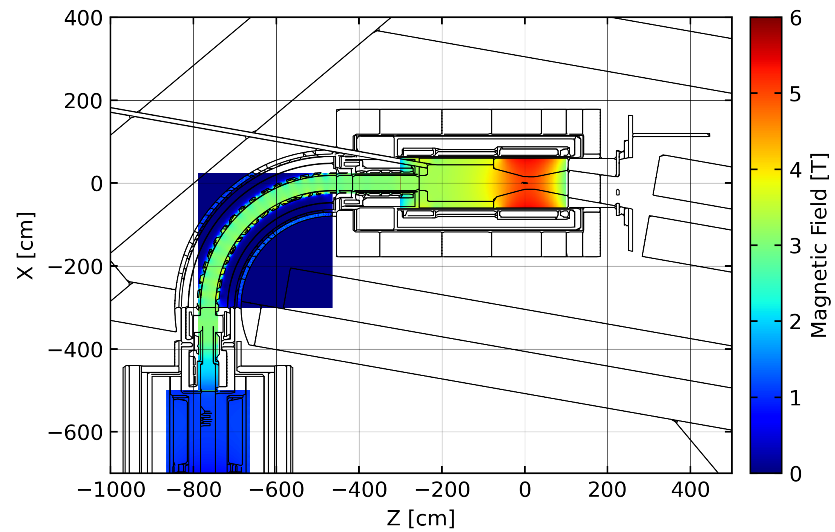
[1] The COMET Collaboration *et al.*, Prog. Theor. Exp. Phys., Volume 2020, Issue 3, March 2020, 033C01

Simulation

- PHITS version 3.22[2]
  JENDL-4.0 (En < 20 MeV)
  INCL4.6 + GEM (E < 3 GeV)
  JAM (E > 3 Gev)
  fixed the bug concerning
  the behavior of charged particles
  in magnetic field
- DCHAIN-PHITS version 3.21[3]
  JENDL / AD-2017, JENDL-4.0,
  ENDF / B-VIII.0, JEFF-3.3, FENDL / A-3.0



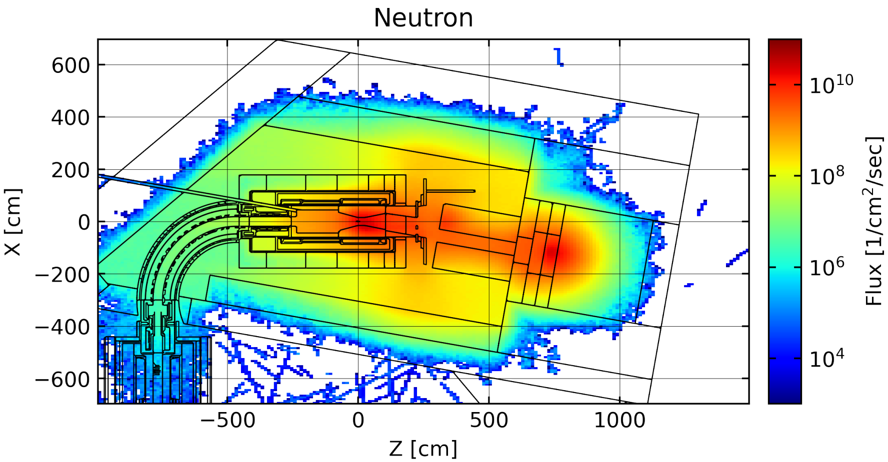
PHITS	neutron flux(< 20 MeV) nuclear production yield history number: 140,000 CPU time: 840 hours
⇩	
DCHAIN-PHITS	radioactivity, gamma-ray spectrum
⇩	
PHITS	effective dose rate distribution

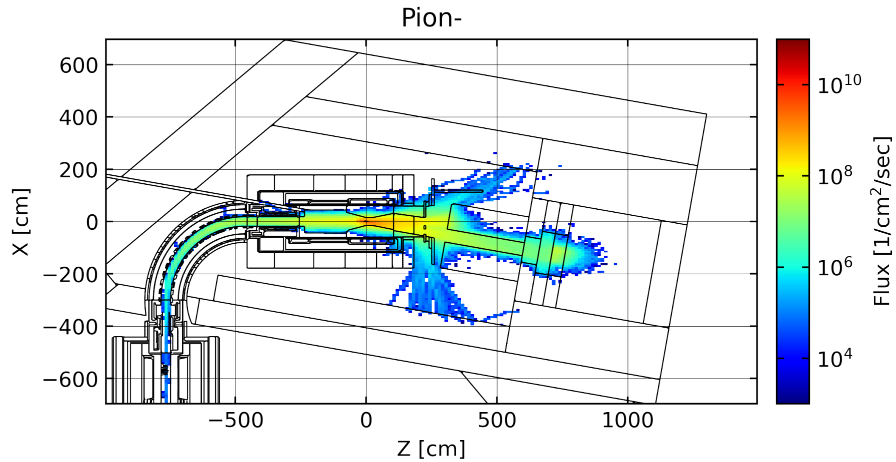


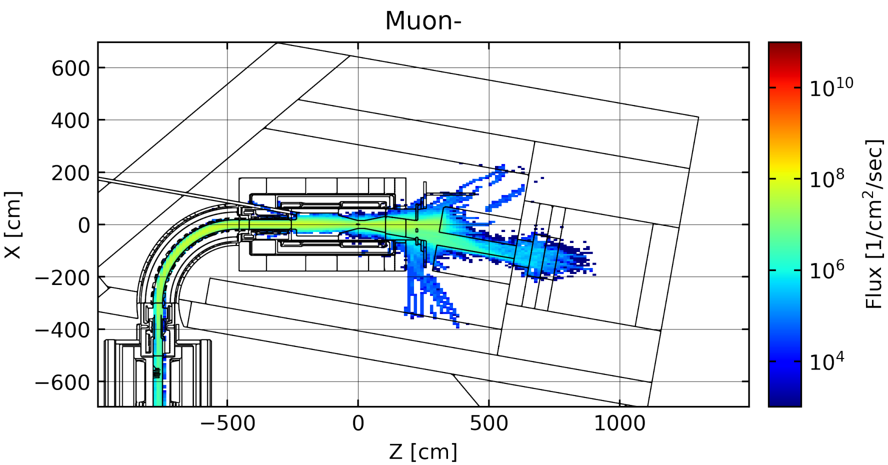
[2] T. Sato *et al.*, Features of Particle and Heavy Ion Transport code System (PHITS) version 3.02, J. Nucl. Sci. Technol. 55, 684-690 (2018)

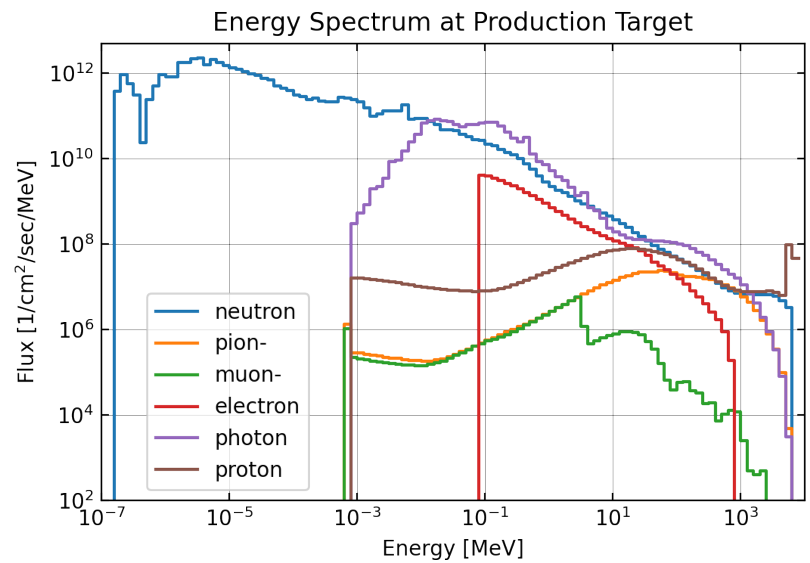
[3] Hunter N. Ratliff *et al.*, Modernization of the DCHAIN-PHITS activation code with new features and updated data libraries, Nucl. Instrum. Meth. B, 484, 29-41 (2020)

Result (Particle Flux During Operation)

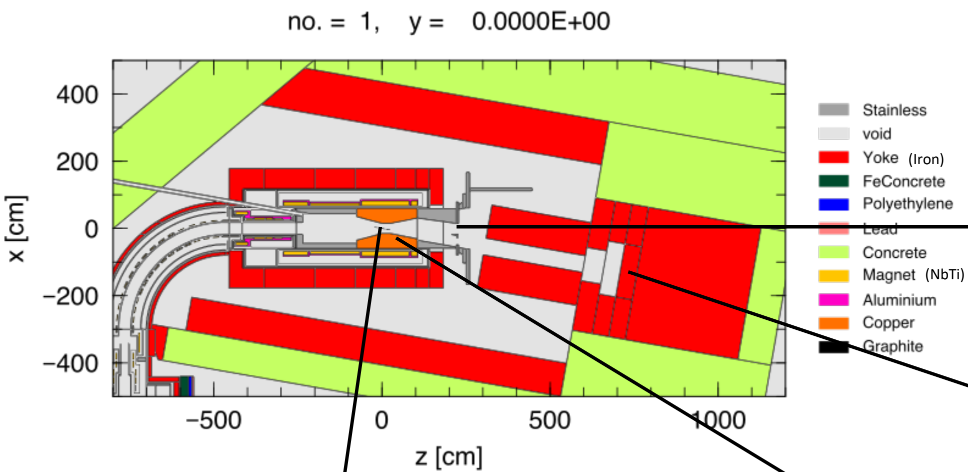


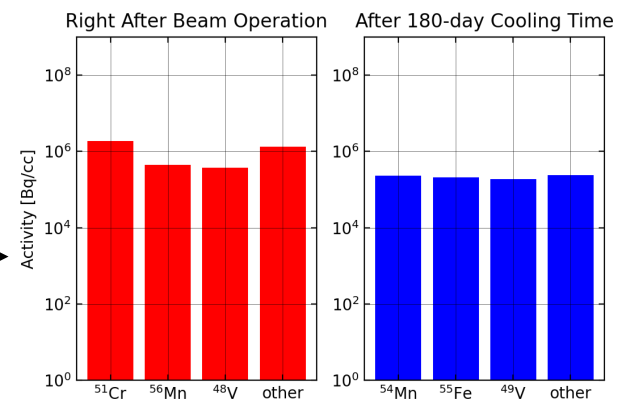






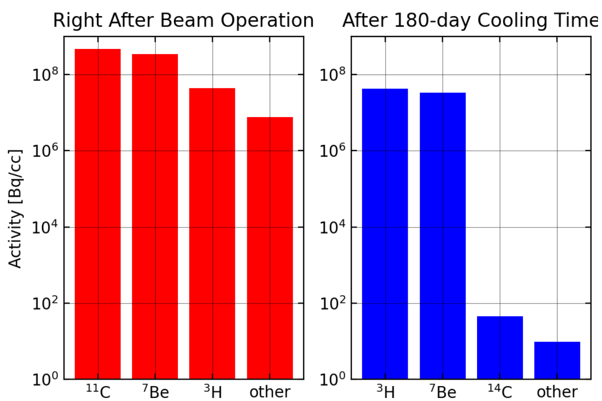
Result (Residual Radioactivity)



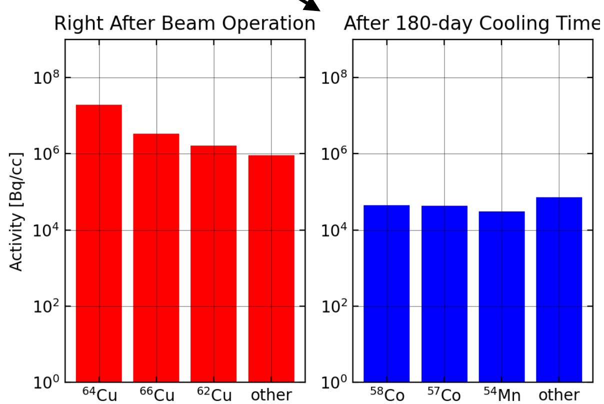


flange (stainless)

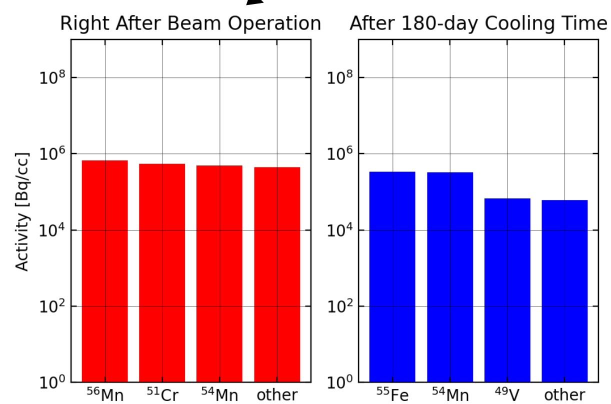
Nuclide	Half Life
^{51}Cr	27.7 days
^{56}Mn	2.5 hours
^{48}V	16.0 days
^{54}Mn	312 days
^{55}Fe	2.7 years
^{49}V	330 days
^{11}C	20 minutes
^{7}Be	53 days
^{3}H	12.3 years
^{14}C	5730 years
^{64}Cu	12 hours
^{66}Cu	5.1 minutes
^{62}Cu	9.7 minutes
^{58}Co	70 days
^{57}Co	271 days



production target (graphite)

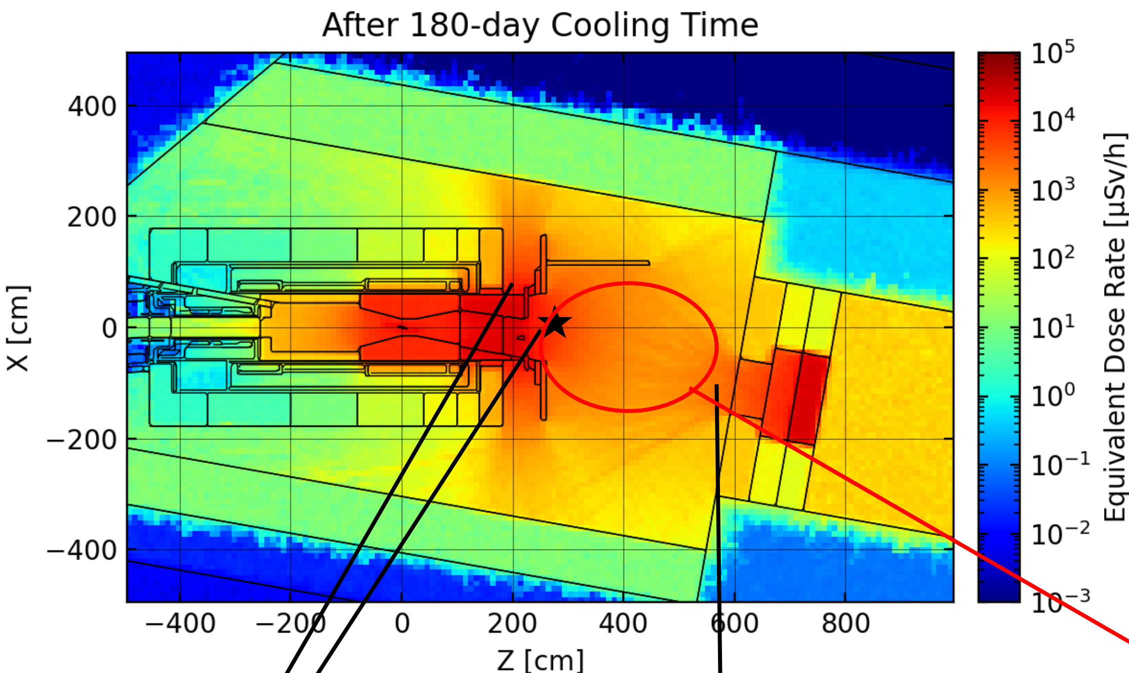


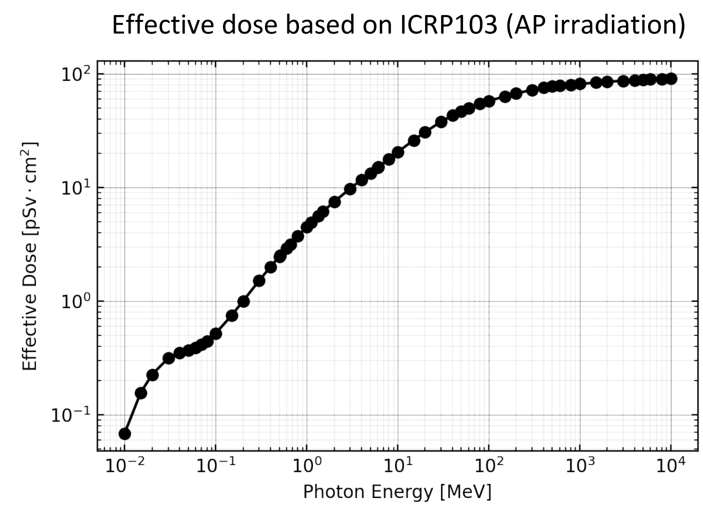
shield for magnets (copper)



dump (iron)

Result (Effective Dose Rate Distribution)





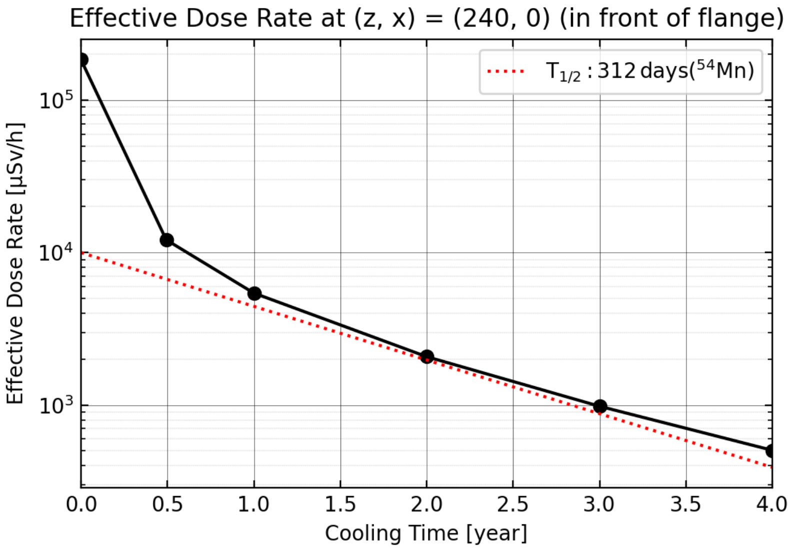
working area

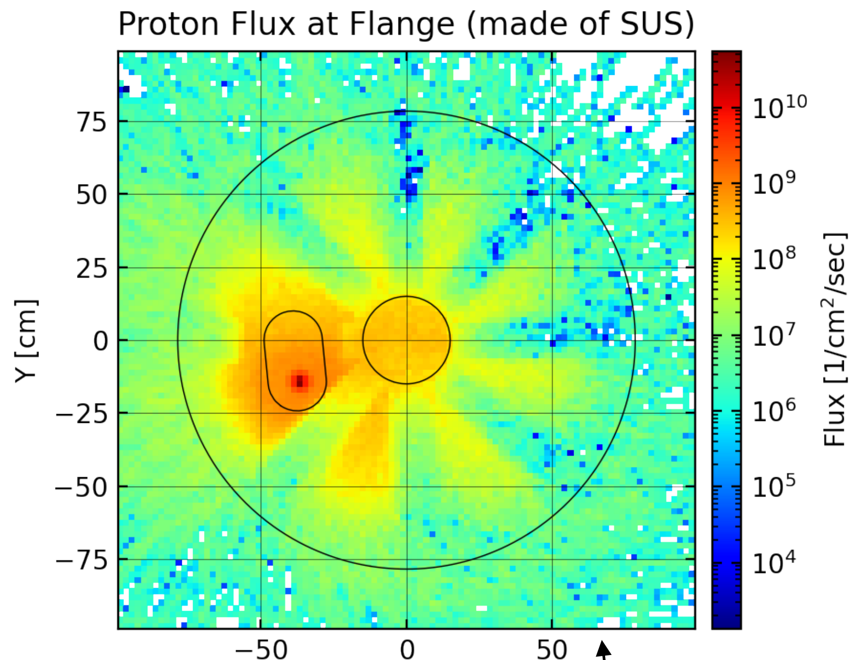
10 mSv/h

2.5 mSv/h

Effective dose rate is too high for maintenance

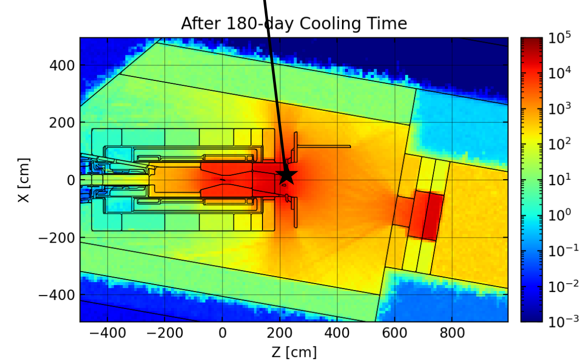
Discussion





How to reduce the effective dose rate

1. Longer cooling time
   Effective dose rate decreses by half in about a year
2. Larger beam window
   High proton flux around the beam window
3. Shorter production target
   Secondary particles produced in the target are proportional to its length



Summery and Future Works

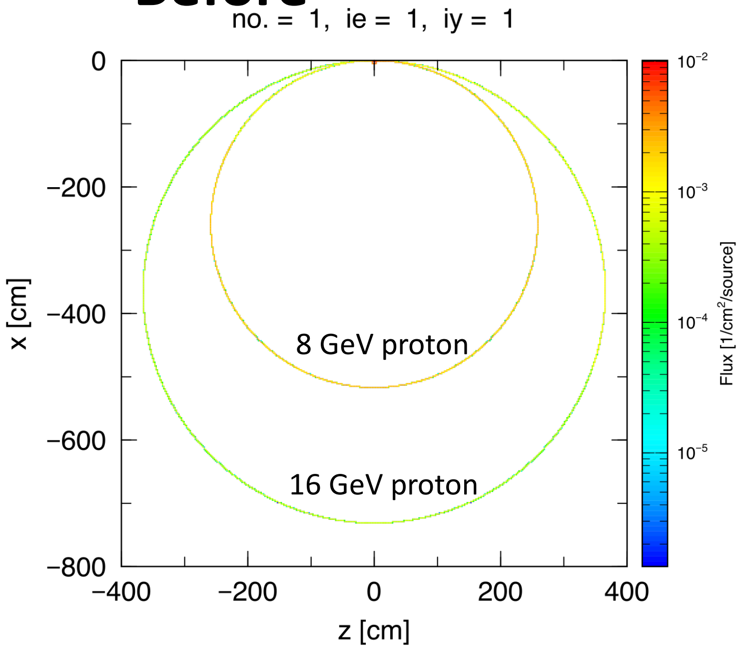
- Calculated fluxes and residual radioactivities by PHITS and DCHAIN-PHITS
  - The result shows that effective dose rate is too high.
- Possible ways to reduce the effective dose rate
  - Longer cooling time
  - Larger beam window
  - Shorter production target
- Other option
  - Working remotely
- Trade-offs exist in each options

Optimization is necessary with all possible means.

PHITS BUG FIX

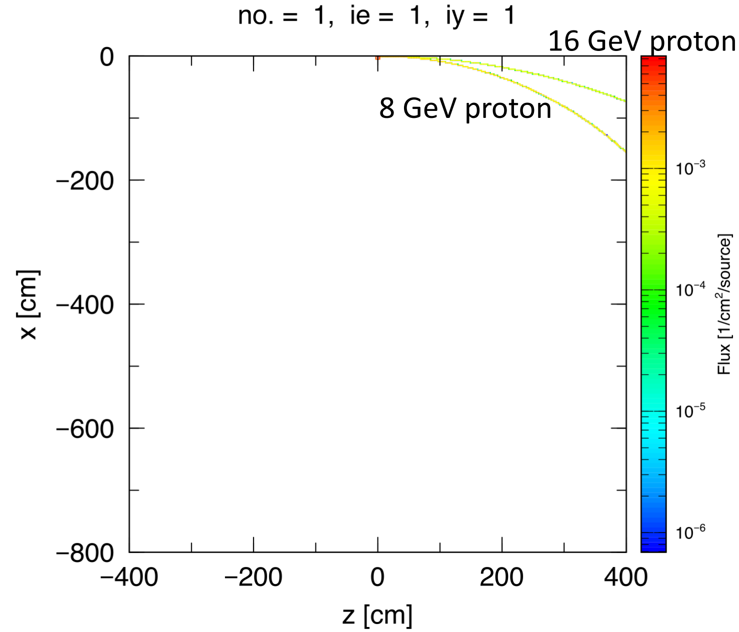
uniform magnetic field of 5 T

Before



- $v = \sqrt{\frac{2T}{m_0}}$
- $\boldsymbol{a} = \frac{q}{m_0}\boldsymbol{v}\times\boldsymbol{B}$

After



- $\gamma = 1 + \frac{T}{m_0 c^2}$
- $v = \frac{\sqrt{\gamma^2 - 1}}{\gamma} c$
- $\boldsymbol{a} = \frac{q}{m_0 \gamma}\boldsymbol{v}\times\boldsymbol{B}$

Material

```
$$ stainless steel: D=-7.93
MAT[ 8 ]
      58Ni.50c  -0.068077
      60Ni.50c  -0.026223
      61Ni.50c  -0.00114
      62Ni.50c  -0.003634
      64Ni.50c  -0.000926
      54Fe.50c  -0.0406
      56Fe.50c  -0.64204
      57Fe.50c  -0.0154
      58Fe.50c  -0.00196
      50Cr.50c  -0.0869
      52Cr.50c  -0.167578
      53Cr.50c  -0.019002
      54Cr.50c  -0.00473
```

```
$ Concrete D=-2.2
MAT[ 40 ]
      1H.50c      -0.0056
      16O.50c     -0.4983
      27Al.50c    -0.0456
      28Si.50c    -0.3158
      40Ca.50c    -0.0826
      32S.50c     -0.0012
      56Fe.50c    -0.0122
      24Mg.50c    -0.0024
      23Na.50c    -0.0171
      39K.50c     -0.0192
```

Nuclear Data Library

- JENDL/AD-2017
  - activation and decay
- JENDL (Japanese Evaluated Nuclear Library)
- JEFF (Joint Evaluated Fission and Fusion)
- FENDL (Fusion Evaluated Nuclear Library)