# Source Calibration System Radiation

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# Contents

We discuss the radiation from the Mu2e calorimeter calibration source system in this document. The design of the source calibration system is described in DocDB-12464. Other documents addressing radiation doses from this system include DocDB-4142, DocDB-16124, DocDB-15878, and DocDB-19114. However, the present document is regarded as primary.

The source calibration makes use of a deuterium-tritium (DT) neutron generator to activate a fluorinated fluid producing nitrogen-16, which $\beta$ decays to oxygen. The oxygen product sometimes emits a gamma, mostly at 6 MeV. The activated fluid is pumped through piping from the DT generator to the Mu2e calorimeter. Calibration is performed roughly weekly with operation of nominally ten minute duration, but possibly up to about an hour each time. The DT generator can produce up to $10^9$ neutrons per second.

# 1 Radiation from DT generator

The radiation dose expected from operation of the DT generator is estimated using the MARS program (`https://mars.fnal.gov/`). The environment is Equipment Alcove 3 in the Mu2e hall, where a pit was constructed to contain the DT generator and shielding. The shielding covering the pit includes eight inches of lead, approximately 12 inches of HDPE (high density polyethylene), and 12 inches of concrete.

## 1.1 Pit geometry

The MARS coordinate system is right-handed with $x$ increasing toward the PS ("west"), $y$ increasing toward the DS trench ("south"), and $z$ increasing upward. The $x-y$ origin is centered on the DT source. The $z = 0$ plane is the bottom of the pit, a distance of 9 inches below the DT source and 74 inches below the Mu2e hall floor. The color code for the simulated materials is given in Table 1. The detailed MARS input files (`MARS.INP`, `GEOM.INP`, `MATER.INP`, and `XYZHIS.INP`) are copied in the appendix.

We note that the $z$ position of the source is changed from the original plan of 14 inches above the pit floor. The original value was constrained by the piping plan. This constraint is no longer present, because the piping has been re-routed to address the pipe chase as-built geometry. The source (and associated bath) can be lowered by an additional inch if there is a reason to do so.

The simulated geometry is shown in various views in Figs. 1–5.

Table 1: The color code for the materials in the MARS simulation. The stainless steel and the iron may not show up unless the picture is a highly expanded view.

| Color | Material |
|---|---|
| dark gray | concrete |
| cyan | air |
| yellow | HDPE |
| magenta | lead |
| red | FC-770 fluorinert |
| blue | stainless steel |
| light gray | iron |
| beige | tissue (for dose calculation) |

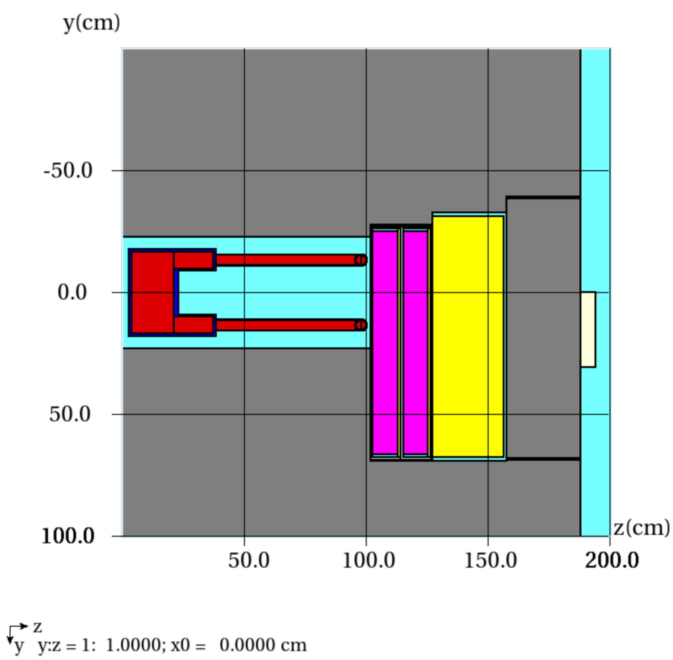


Figure 1: MARS geometry for the source pit and plumbing. The view is a $y - z$ slice at $x = 0$. This is a plane through the DT generator bath and shows the first vertical rise of the plumbing. Up ($+z$) is to the right.

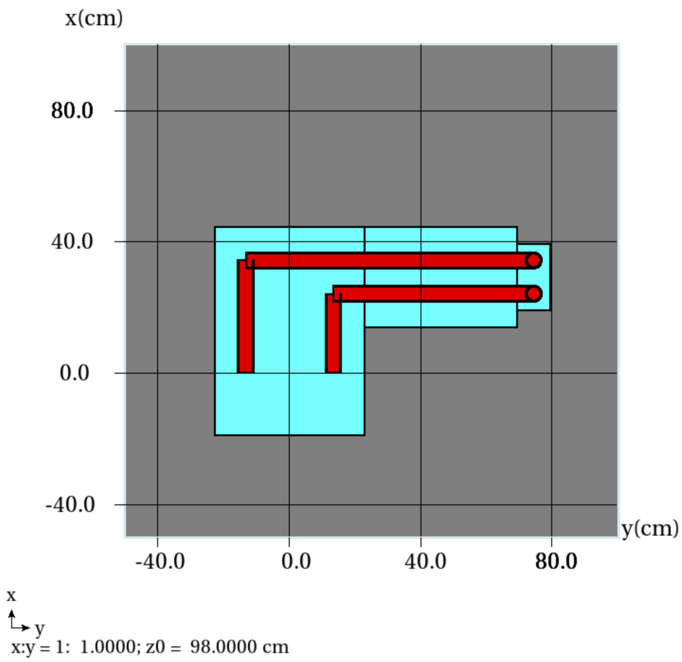


Figure 2: MARS geometry for the source pit and plumbing. The view is an $x-y$ slice at $z = 98$ cm. This is just below the lead shielding and shows the horizontal run of plumbing to the pipe chase notch. The actual centerline of the pipes is at $z$ =97.79 cm. Note that $z$ is pointing into the paper, that is, the view is from the bottom looking up.

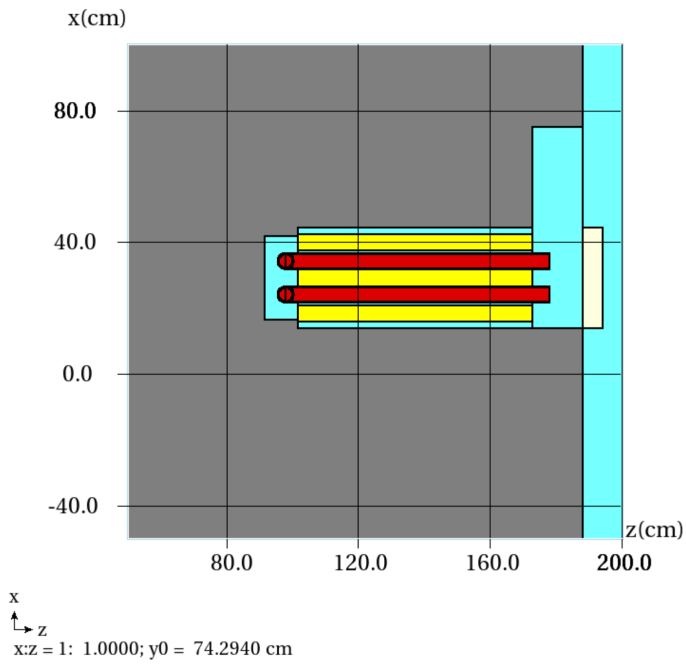


Figure 3: MARS geometry for the source pit and plumbing. The view is an $x-z$ slice at $y = 74.294$ cm. This is in the pipe chase and shows the pipes rising to the floor trench. Up $(+z)$ is to the right.

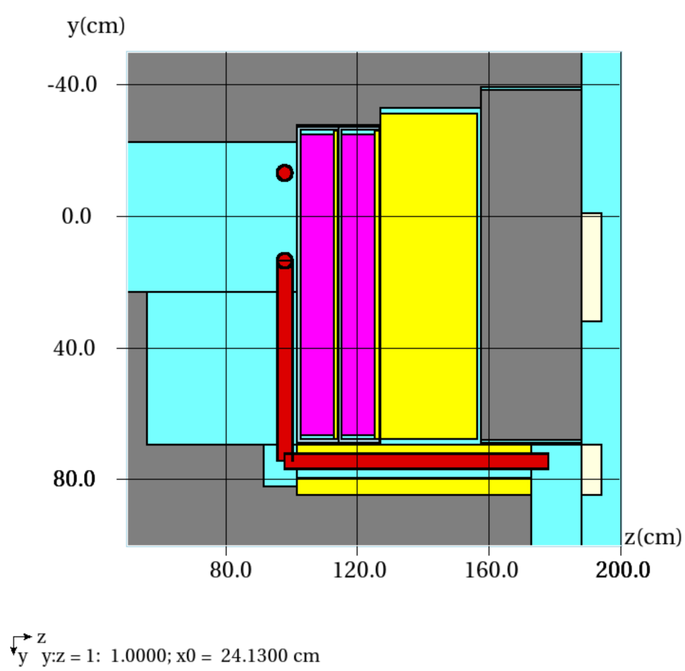


Figure 4: MARS geometry for the source pit and plumbing. The view is a $y-z$ slice at $x = 24.13$ cm. This is a plane through the second vertical rise of the pipe to the detector. The pipe chase and notch are visible. Up $(+z)$ is to the right.

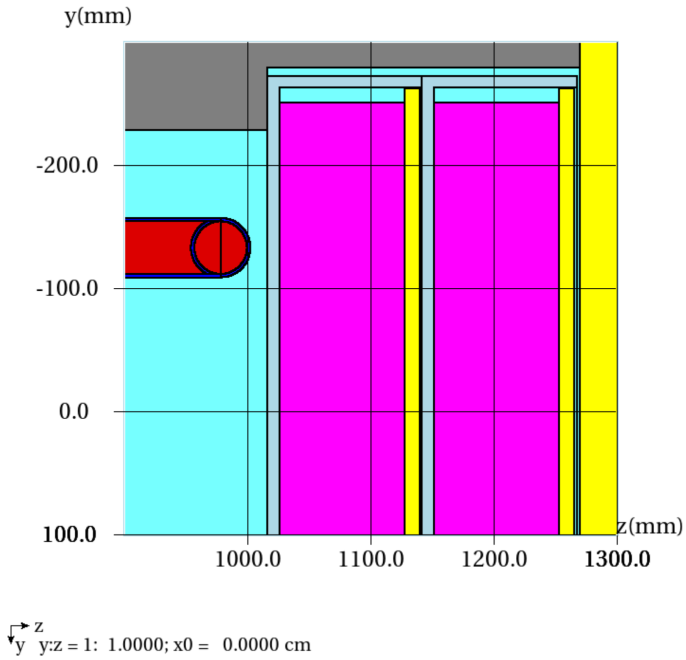


Figure 5: MARS geometry for the source pit and plumbing. The view is a $y - z$ slice at $x = 0$. This is an exploded view of a portion of Fig. 1 showing the stainless steel pipe and the steel frame holding the lead.

## 1.2 Dose results

The dose from the operating neutron generator is calculated using MARS for the geometry described in Sec. 1.1. The calculation is performed by simulating $4 \times 10^7$ primary neutrons emitted isotropically (as expected) from the DT generator. Figs. 6–8 show the resulting dose rate maps at floor level in the Mu2e hall. The total dose rate has a maximum value of 3.6 mrem/hr, scanning over volumes of dimension $6 \times 6 \times 2$ cm$^3$. These rates are for a DT generator operating at full capacity ($10^9$ $n$/s).

In addition to the maps in Figs. 6–8, the dose rate is estimated by placing tissue-equivalent volumes on the floor of the Mu2e hall. These may be seen as the small circular and rectangular outlines on Fig. 6, centered over the concrete plug and over the pipe chase, respectively. The dose rate is found to be $1.65 \pm 0.05$ mrem/hr in the circular tissue (20 cm radius by 6 cm thickness), and $1.38 \pm 0.06$ mrem/hr above the pipe chase (tissue volume 12 inches by 6 inches by 6 cm thick, matching the pipe chase).

Raising the neutron generator by five inches increases the dose at floor level by 10-20%. If the HDPE in the pipe chase is removed, the dose over the pipe chase is between 5 and 10 mrem/hr.

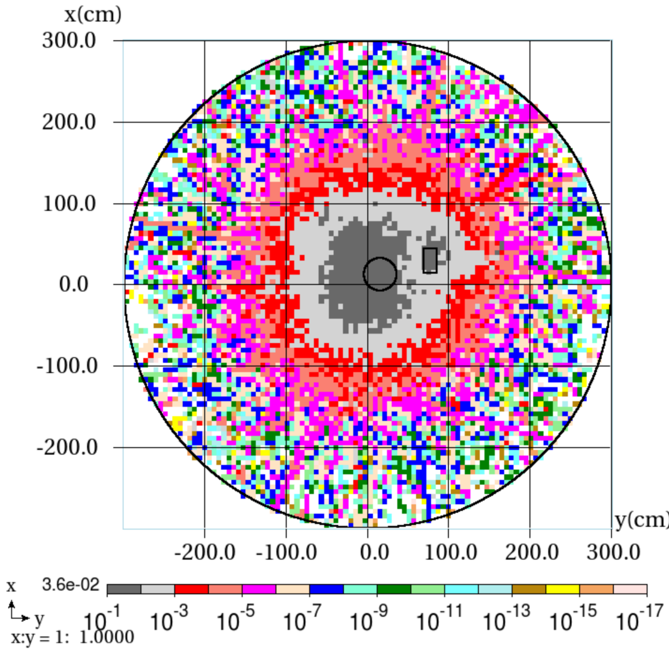


Figure 6: MARS-calculated total dose rate in the $x-y$ plane at floor level ($z = 189$ cm) in the Mu2e hall, over the DT generator pit and pipe chase. Dose units are mSv/hr. The maximum dose is 0.036 mSv/hr, or 3.6 mrem/hr.

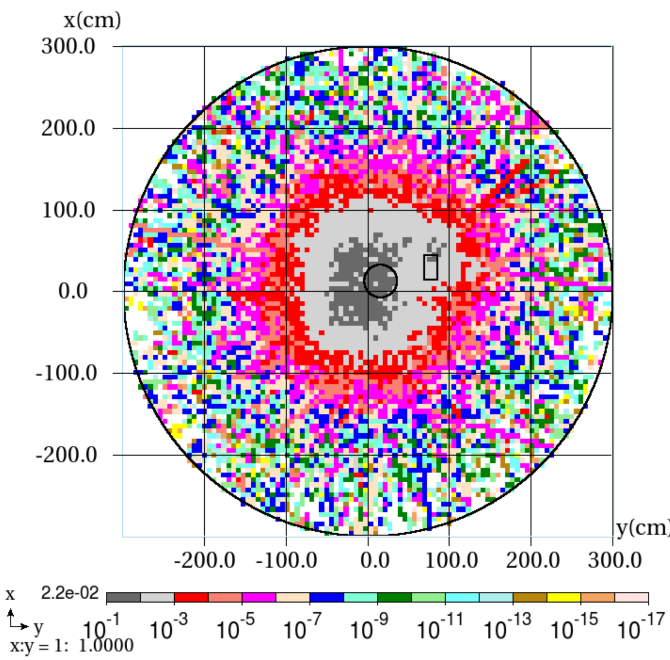


Figure 7: MARS-calculated neutron dose rate in the $x - y$ plane at floor level ($z = 189$ cm) in the Mu2e hall, over the DT generator pit and pipe chase. Dose units are mSv/hr.

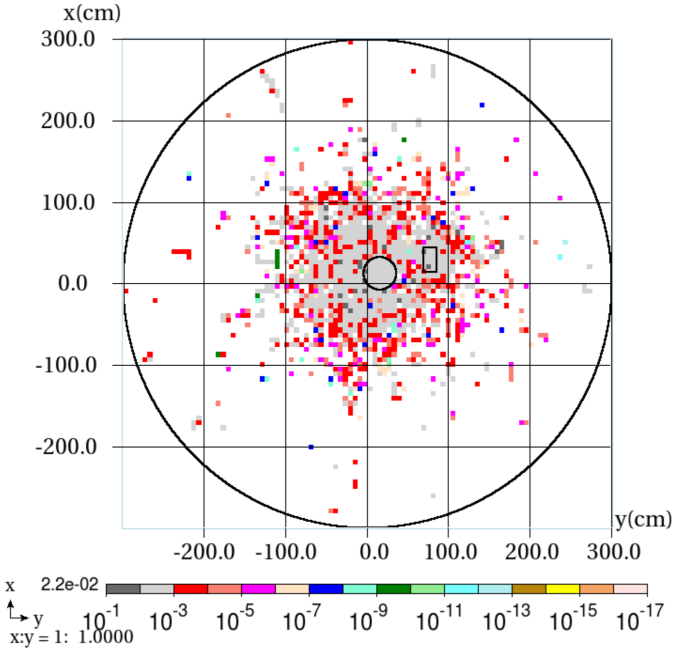


Figure 8: MARS-calculated electron dose rate in the $x - y$ plane at floor level ($z = 189$ cm) in the Mu2e hall, over the DT generator pit and pipe chase. Dose units are mSv/hr.

### 1.3 Acceptance test dose results

When we first take delivery of the DT generator, an acceptance test will be performed in the Mu2e hall. We have computed the dose rates expected from the one-time accptance test geometry. The acceptance test geometry is the same as described in section 1.1 except for the following changes:

- The source is relocated to $(x, y, z) = (29.21, -17.78, 66.04)$ cm$^3$ in MARS coordinates;
- The FC-770 is eliminated;
- The FC-770 reservoir is eliminated;
- The piping is eliminated.

The relocation of the source is intended to make it easier to place neutron detectors (e.g., foils) in a way that they can be extracted via the pipe chase.

In this configuration the dose rate in the tissue sample over the concrete plug is $2.68 \pm 0.07$ mrem/hr and over the pipe chase is $4.25 \pm 0.11$ mrem/hr. Fig. 9 shows the floor level dose (in $6 \times 6 \times 2$ cm$^2$ cells) for the acceptance test configuration. The maximum dose rate is 6.5 mrem/hr.

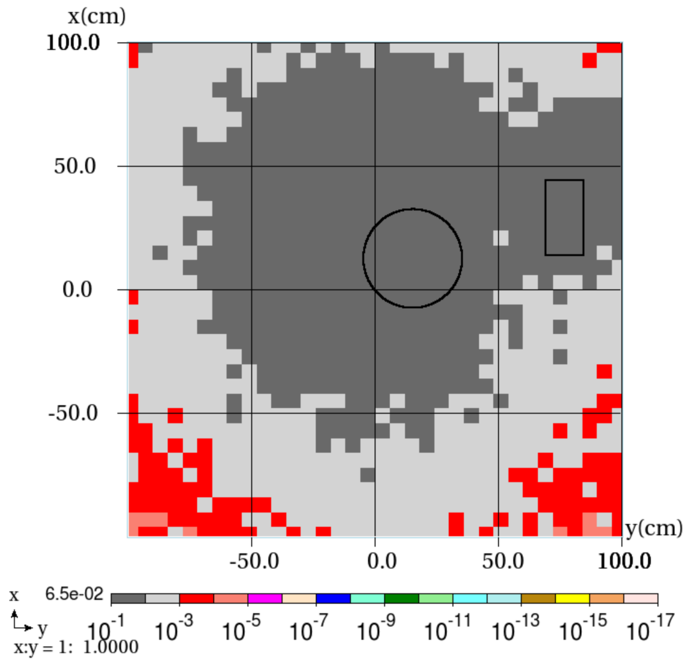


Figure 9: MARS-calculated total dose rate for the acceptance test configuration in the $x - y$ plane at floor level ($z$ = 189 cm) in the Mu2e hall, over the DT generator pit and pipe chase. Dose rate units are mSv/hr. The maximum dose rate is 0.065 mSv/hr, or 6.5 mrem/hr.

## 2 Radiation dose in plumbing

While the calibration system, including the DT generator, is in operation, activated fluid (FC-770) flows through pipes in the trenches from the pit in equipment alcove 3 to the detector. The half-life for decay is 7.13 s, with beta and gamma rays emitted. Dexu Lin has calculated the dose rate in DocDB-16124. The result is that the maximum total dose rate at a distance of one foot from the pipe is less than 1.6 mrem/hour. This is calculated assuming one meter length of fluid in the pipe is concentrated as a point source one foot away from the tissue.

## 3 Dose from leak of activated fluid

We consider radioactivity in the Mu2e hall from possible FC-770 leaks during operation of the calibration system. To get the worst case, we consider a catastrophic scenario in which a pipe is broken due to earthquake motion while the calibration system is in operation with the neutron generator at full capacity ($10^9$ $n$/s), and suppose that none of the shutdown mechanisms operate until the FC-770 is fully expelled from the system. For the worst-case (from the radiation perspective), we assume the break is at the exit from the neutron generator pit and that the pipe breaks completely. This is a highly implausible (and otherwise deadly) scenario, but we are looking for an upper bound here. The time scale for all of the

FC-770 to be dumped is then around 40 s with a flow rate 30 times larger than a California standard (`https://appliance-standards.org/product/faucets`) kitchen faucet.

The viscosity of FC-770 is slightly less than water, at 0.8 centistokes at 25°C (3M MSDS for FC-770). Its relative evaporation rate is medium, at 1.0 [BUOAC=1] (ibid.). On this scale, water is slow at 0.3 and acetone is fast at 5.6 (`http://www.ilpi.com/msds/ref/evaporationrate.html`). The FC-770 will flow like water and seek low points while evaporating gradually, but faster than water. For a worst case estimate, we neglect these effects here. We note that the evaporation time scale is long compared with the half-life, and airborne radiation is not an issue.

The radioactivity in the activated FC-770 decays with a half-life of $T_{1/2} = 7$ s (mean lifetime $\tau = 10.3$ s). This is short compared with the time of the spill, thus we consider the activation as a function of time. The maximum dose rate occurs at the time all of the fluid is dumped, approximating the flow as abruptly changing from a constant to zero. Call this time $T$. The number of activated $^{16}N$ in the dumped fluid at time $t$ is then:

$$N_{16}(t) = \rho_{16} c_{\rm pump} \tau \begin{cases} \left(1 - e^{-t/\tau}\right), & 0 < t < T \\ \left(e^{T/\tau} - 1\right) e^{-t/\tau}, & t > T, \end{cases} \tag{1}$$

where $\rho_{16}$ is the number density of $^{16}N$ in the activation bath and $c_{\rm pump}$ is the pump capacity (volume/s). The parameters and computed quantities are summarized in Table 2.

Table 2: Parameters and derived quantities used in the calculation of dose from a catastrophic leak.

| Parameter | Symbol | Value | Units |
|---|---|---|---|
| Pump capacity | $c_{\rm pump}$ | $3.5 \times 10^{-3}$ | $m^3 s^{-1}$ |
| Volume of liquid | V | 134 | $m^3$ |
| Time for dump | $T$ | 39 | s |
| $^{16}$N lifetime | $\tau$ | 10.3 | s |
| Density of $^{16}$N | $\rho_{16}$ | $6.5 \times 10^{9}$ | $m^{-3}$ |
| Total energy of radiation | $E_{\max}$ | $1.4 \times 10^{-3}$ | J |

Nitrogen-16 decays essentially 100% via beta transitions to various levels of $^{16}O$. The excited oxygen levels decay to the ground state via emission of gamma rays, notably a line at 6.1 MeV, which is the one we use for crystal calibration. The decay scheme is shown in Fig. 10. The total energy available is $Q = 10.4$ MeV. We'll ignore energy lost in neutrinos and conservatively use 10.4 MeV as the energy lost to radiation in $^{16}N$ decays, in a mix of gammas and electrons. If we do this, the total energy in the radiation from our extreme dump is

$$E_{\rm dump} = QV\rho_{16} = 0.0014 \text{ J}. \tag{2}$$

Note that if this energy could somehow all be absorbed in 1 kg of tissue, the total integrated dose would be 1.4 mGy.

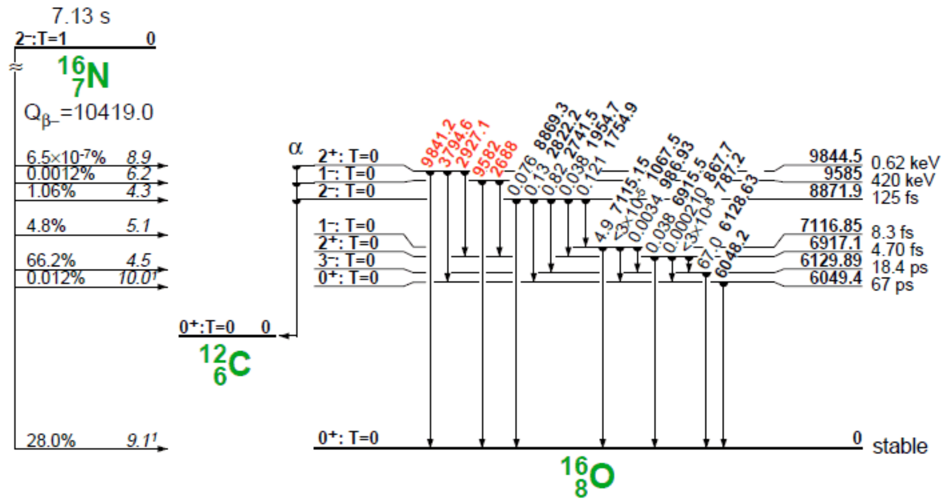


Figure 10: Level and decay scheme for nitrogen-16 (from `https://www.nuclear-power.net/nuclear-power-plant/nuclear-reactor/nuclear-instrumentation/nitrogen-16-power-monitoring/`).

As a function of time, the rate of energy radiated is given by

$$\frac{dE}{dt} = \frac{Q}{\tau} N_{16}(t). \tag{3}$$

The time distribution of the radiated energy is shown in Fig. 11. Again, if all of the energy were being absorbed in one kilogram of tissue, the left scale could be read as in units of Gy/hr. Note that the rate is essentially zero after 100 s, so the duration of any exposure is very short.

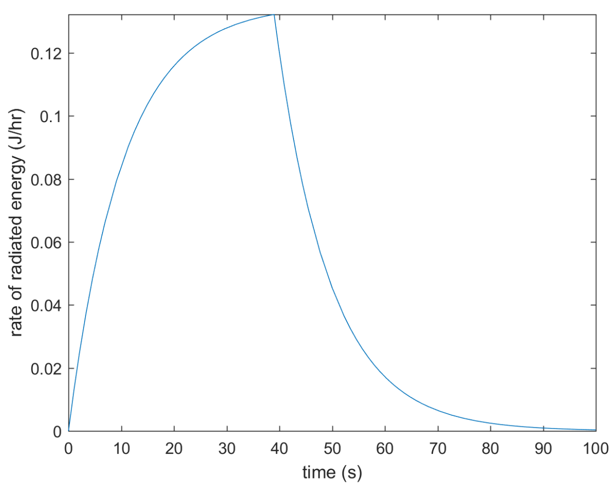


Figure 11: The energy in radiation for an extreme dump of activated FC-770 as a function of time.

We conclude that there is no scenario in which the radioactivity from a spill is of concern.

# A Appendix

## A.1 MARS.INP

```
DT generator 180529, 190718
C 190801 change z_source from 35.56 to 22.86
INDX 3=T 5=T
CTRL 1=1 3=0
C random number seed, comment to get default
C SEED 64217136
NEVT 1000 1
ENRG 0.0143 5=1.0E-12 6=1.5E-6 7=1.5E-6
VARS 4=1.0E9
IPIB 2
INIT 0. 0. 22.86
SMIN 1.E-3 5.
EMST 4=3
LEMS 2=3 3=3 4=3
ZSEC 300.
NHBK 1
NLTR 1
RSEC 300.
C Use NVTRIAL:5=1E8
RZVL 2=200 5=1E9
MATR 'MATER.INP'
STOP

*LENT START

*LENT END

*MCNP START
m1 24000 -0.190000 25055 -0.020000 26000 -0.695000 28000 -0.095000 cond=1
m2 1001 -0.006 6000 -0.030 8016 -0.500 11023 -0.010 13027 -0.030 &
 14000 -0.200 19000 -0.010 20000 -0.200 26000 -0.014
m3 6000 -0.856285 1001 -0.143715
m4 82000 -1.0 cond=1
m5 7014 -0.746 8016 -0.240 18000 -0.013 1001 -0.001 gas=1
m6 1001 -0.006 6000 -0.030 8016 -0.500 11023 -0.010 13027 -0.030 &
 14000 -0.200 19000 -0.010 20000 -0.200 26000 -0.014
m7 7014 -0.746 8016 -0.240 18000 -0.013 1001 -0.001 gas=1
m8 6000 -0.31372 8016 -0.019608 9019 -0.666667
```

```
m9 26000 -1.0 cond=1
m10 1001 -0.10771 6000 -0.12833  7014 -0.034742 8016 -0.72655
*MCNP END
```

## A.2 GEOM.INP

```
DT generator nominal configuration190724
!completely checked and updated, including notch 190724 fcp
!pipes added 180716 fcp
!190729 fcp lower bath and source, source at 9 inches instead of 14
!190801 fcp revised notch to as-cut dimensions

!tissue at floor level - cylinder centered on concrete cover
tissCC 2 0 10 12.7 15.24 187.96 0.0 20. 6.
!tissue at floor level - rectangle centered on pipe chase
tissPC 1 0 10 29.21 76.835 187.96 15.24 7.62 6.

!shield plug components
conclid 1 0 2 12.7 14.605 157.48 46.6625 53.34 30.48

conclidv 1 0 5 12.7 14.605 157.48 46.99 53.975 30.48

polylid 1 0 3 12.7 18.0975 127 40.64 49.53 29.21

polylidv 1 0 5 12.7 18.0975 127 41.91 51.1175 30.48

polytop 1 0 3 12.7 20.6375 125.2601 34.2138 46.9138 1.27

leadlidt 1 0 4 12.7 20.6375 115.1001 33.02 45.72 10.16

leadairt 1 0 5 12.7 20.6375 115.1001 34.29 46.99 11.5951

FEfratop 1 0 9 12.7 20.6375 114.1476 35.2425 47.9425 12.5476

polybot 1 0 3 12.7 20.6375 112.7125 34.2138 46.9138 1.27

leadlidb 1 0 4 12.7 20.6375 102.5525 33.02 45.72 10.16

leadairb 1 0 5 12.7 20.6375 102.5525 34.29 46.99 11.5951

FEfrabot 1 0 9 12.7 20.6375 101.6 35.2425 47.9425 12.5476

leadlidv 1 0 5 12.7 20.6375 101.6 36.83 48.5775 25.4

!HDPE in pipe chase, captured behind pipes
```

```
pcHDPE 1 0 3 29.21 81.915 101.6 14.605 2.54 71.12
! HPDE in pipe chase (beside and between pipes)
pcHDPEl 1 0 3 18.415 74.295 101.6 2.54 2.54 71.12
!(inches)      7.25 29.75 40 1 1. 28
pcHDPEm 1 0 3 29.21 74.295 101.6 2.54 2.54 71.12
!(inches)     11.5 29.75 40 1 1. 28
pcHDPEr 1 0 3 40.005 74.295 101.6 2.54 2.54 71.12
!(inches)     15.75 29.75 40 1 1. 28
! HDPE in pipe chase (outside plumbing)
pcHDPEo 1 0 3 29.21 70.485 101.6 14.605 1.27 71.12
!(inches)    11.5 27.75 40 5.75 0.5 28


!fluid irradiation tank
Fside 2 0 8 0 0 20.955 9.8425 16.8275 16.1925


Fbot 2 0 8 0 0 3.4925 0 16.8275 17.4625

ssside 2 0 1 0 0 22.86 8.89 17.78 15.24

ssbot 2 0 1 0 0 2.54 0 17.78 20.32

!pipes
pumpz2 2 0 1 0 -13.335 38.1 2.13614 2.413 59.69
!high pumpz2 2 0 1 0 -13.335 50.8 2.13614 2.413 46.99
!(inches)        0 -5.25 20 0.841 0.95 18.5
pumpz 2 0 1 34.29 74.295 97.79 2.13614 2.413 80.01
diskz2 2 0 1 0 13.335 38.1 2.13614 2.413 59.69
!high diskz2 2 0 1 0 13.335 50.8 2.13614 2.413 46.99
!(inches)0 5.25 20 18.5

diskz 2 0 1 24.13 74.295 97.79 2.13614 2.413 80.01
pumpx 2 1 1 0.0 -13.335 97.79 2.13614 2.413 34.29
diskx 2 1 1 0.0 13.335 97.79 2.13614 2.413 24.13
TR1 0.0 0.0 0.0 0.0 90.0 0.0

pumpy 2 2 1 34.29 -13.335 97.79 2.13614 2.413 87.63

disky 2 2 1 24.13 13.335 97.79 2.13614 2.413 60.96
TR2 0.0 0.0 0.0 -90.0 0.0 0.0
FCpz2 2 0 8 0 -13.335 38.1 0 2.13614 59.69
! high FCpz2 2 0 8 0 -13.335 50.8 0 2.13614 46.99
!(inches) 0 -5.25 20 0.841 18.5
FCpz 2 0 8 34.29 74.295 97.79 0 2.13614 80.01
```

```
FCpy 2 2 8 34.29 -13.335 97.79 0 2.13614 87.63
FCpx 2 1 8 0 -13.335 97.79 0 2.13614 34.29
FCdz2 2 0 8 0 13.335 38.1 0 2.13614 59.69
!high FCdz2 2 0 8 0 13.335 50.8 0 2.13614 46.99
!(inches) 0 5.25 20 18.5
FCdz 2 0 8 24.13 74.295 97.79 0 2.13614 80.01

FCdy 2 2 8 24.13 13.335 97.79 0 2.13614 60.96
FCdx 2 1 8 0 13.335 97.79 0 2.13614 24.13

!trench (but don't start with TR)
atrconc 1 0 2 59.69 114.935 172.72 15.24 15.24 15.24

btrench 1 0 5 44.45 99.695 172.72 30.48 30.48 15.24

notch 1 0 5 29.21 75.565 91.44 12.7 6.35 10.16
!(inches) 11.5 29.75 36 5 2.5 4


pipechas 1 0 5 29.21 76.835 101.6 15.24 7.62 86.36
Lshelf 1 0 5 29.21 46.0375 55.88 15.24 23.1775 45.72
!(inches) 11.5 18.125 22 6 9.125 18

dtvoid 1 0 5 12.7 0 0 31.75 22.86 101.6

concworl 2 0 6 0 0 0 0 300 187.96

atmosph 2 0 7 0 0 187.96 0 300 112.04


STOP
```

## A.3 MATER.INP

```
DT generator 180529

1 'STST'
2 'CONC'
3 'CH2'
4 'PB'
5 'AIR'
6 'CONC'
7 'AIR'
8 'Fluorinert' 1.78 3
```

```
 12.0107 6.00000 0.31372549
 15.9994 8.00000 0.019607843
 18.998 9.00000 0.666666667
9 'FE'
10 'TISS'

STOP
```

## A.4 XYZHIS.INP

```
 XYZ histo test with histo list  05-APR-2016

xyz -300. 300. -1.0 1.0 0. 300. 100 1 100 XZ-scan at |y|<1.0
DET DEG DEN

xyz -0.4 0.4 -300. 300. 0. 300. 1 100 100 YZ-scan at |x|<0.4
DET

xyz -28.81 29.61 -300. 300. 0. 300. 1 100 100 YZ-scan at |x-29.21|<0.4
DET

xyz -300. 300. -300. 300. 187.96 189.96 100 100 1 XY-scan at z=187.96
DET DEG DEN DEE DEP

xyz -300. 300. -300. 300. 187.96 300 100 100 1 XY-scan at z>187.96
DET DEG DEN

stop

FLP FLP>0.05 FLP>0.17 FLP>1. FLP>1.3 FLP>1.5 FLP>2.7
stop

STA DRE FLT FLP FLN FLN>0.02 FLK FLM>0.1 FLG FLE DAB DPA
DET DET>0.02 DEP DEN DEK DEM DEG DEE
PDT PDP PDN PDK PDM PDG PDE DPH HYD HEL TRI

xyz -0.4 0.4  -10. 10.  0. 50. 1 20 50 YZ-scan_at_|x|<0.4
PDT>0.1 DAB>0.1 DPA>0.1

xyz -5. 5.  -5. 5.  10. 12. 50 50 1 XY-scan_at_z=10-12cm
DRE DRE>0.1 HYD HEL TRI

xyz 0. 5. 2. 7. 10. 15. 1 1 1 Spectrum-1_in_a_5x5x5_cm_cube
SPP SPN SPK SPM SPG SPE
```

```
stop

! Comment on (NX NY NZ) binning priority:
!  1 1 5 means XZ (or XS)
!  1 2 5 means YZ (or YS)
!  2 1 5 means XZ (or XS)


! XYZ X1 X2 Y1 Y2 Z1 Z2 NX NY NZ TEXT
! Histo types (1-40):
C STA- star density               E>30 MeV (cm^-3 s^-1)
C DRE- residual dose on contact            (mSv/hr)
C FLT- total flux of hadrons       E>ETFT   (cm^-2 s^-1)
C FLP- flux of protons             E>ETFH   (cm^-2 s^-1)
C FLN- flux of neutrons            E>ETFN   (cm^-2 s^-1)
C FLK- flux of pions/kaons         E>ETFH   (cm^-2 s^-1)
C FLM- flux of muons               E>ETFM   (cm^-2 s^-1)
C FLG- flux of photons             E>ETFG   (cm^-2 s^-1)
C FLE- flux of e-e+                E>ETFE   (cm^-2 s^-1)
C DAB- absorbed dose                        (Gy/yr)  at 2.e7 s/yr
C
C All DPA histograms are generated with the IPNRT control parameter of DPAC card:
C IPNRT=1 "original" NRT; IPNRT=2 with Nordlund correction; IPNRT=3 (default) with S
C
C DPA- DPA, total (recoil+NIEL+neut+EMS)    (DPA/yr) at 2.e7 s/yr
C DPH*- DPA, NIEL hadrons and muons         (DPA/yr) at 2.e7 s/yr ! temporary disabl
C DPN- DPA, neutrons at E < 14 MeV          (DPA/yr) at 2.e7 s/yr
C DPE- DPA, EMS                             (DPA/yr) at 2.e7 s/yr
C HYD- Hydrogen gas capture                 (cm^-3 s^-1)
C HEL- Helium gas capture                   (cm^-3 s^-1)
C TRI- Tritium gas capture                  (cm^-3 s^-1)
C EQ1- 1-MeV(Si) equivalent neutron fluence (cm^-2 s^-1)
C
C DET- FTD prompt effective dose (default), total    (mSv/hr)
C DEP- FTD prompt effective dose (default), proton   (mSv/hr)
C DEN- FTD prompt effective dose (default), neutron  (mSv/hr)
C DEK- FTD prompt effective dose (default), pi/K     (mSv/hr)
C DEM- FTD prompt effective dose (default), muon     (mSv/hr)
C DEG- FTD prompt effective dose (default), photon   (mSv/hr)
C DEE- FTD prompt effective dose (default), e+e-     (mSv/hr)
C
C PDT- power density, total                 (mW/g or Gy/s)
C PDV- power density, total                 (mW/cm$^3$)
C PDP- power density, proton                (mW/g or Gy/s)
C PDN- power density, neutron               (mW/g or Gy/s)
```

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C PDK- power density, pion/kaon             (mW/g or Gy/s)
C PDM- power density, muon                  (mW/g or Gy/s)
C PDG- power density, photon                (mW/g or Gy/s)
C PDE- power density, e-e+                  (mW/g or Gy/s)
C
C DLT*- instantaneous temperature rise (degC or degK) per AINT (ppp) ! temporary dis
C
C Default cutoff energy is used for spectra:
C
C SPP- proton    energy spectrum            (GeV^-1 cm^-2 s^-1)
C SPN- neutron   energy spectrum            (GeV^-1 cm^-2 s^-1)
C SPK- pion/kaon energy spectrum            (GeV^-1 cm^-2 s^-1)
C SPM- muon      energy spectrum            (GeV^-1 cm^-2 s^-1)
C SPG- photon    energy spectrum            (GeV^-1 cm^-2 s^-1)
C SPE- e+e-      energy spectrum            (GeV^-1 cm^-2 s^-1)
C
! In any run: Sum_detectors (Sum_types) =< nof_histmax (=300, default)
```