

Residual Dose Rates at AP30 Slow Resonant Extraction Region

MARS Simulation for mu2e

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The slow resonant extraction system located beneath the AP30 service building is expected to become activated due to beam losses which are part of the extraction process. The radiation dose rates here are based upon the extraction region model reported in mu2e-doc.db 3615-v3 and are valid only for that model.

Introduction

It is necessary to understand residual dose rates in the slow resonant extraction region for various purposes including design of beam pipe connections, ALARA planning, and radiation damage for materials. The model used for the extraction region is documented in mu2e-doc 3615-v3. Residual dose is required for various surfaces and components including:

- Concrete floor beneath extraction region (H)
- Aisle shield inner wall(H)
- Aisle shield marble(H)
- Bottom of the steel shelves (7) (H)
- Septum flanges (4) (O)
- Septum C channels (2) (O)
- Septum vessels (2) (O)

The source of the results for the above are indicated as coming from histograms (H) or the MARS.OUT file (O). The MARS.OUT and histogram results are reportedly separately, below.

MARS.OUT Results

Since multiple MARS.OUT files cannot be readily combined statistically, a single run is required to get radiation/cooling time tables. The simulation reported here was set up with 250,000 incident particles which required a run time of about 4 hours on the grid. A particle beam model for the slow resonant extraction channel developed by V. Nagaslaev was used in the simulation. The results are normalized to an 8 kW, 8 GeV beam loss calculated to be 1.25%. The model described in mu2e-doc 3615-v3 was used with the following modifications:

- Reduced RSEC to 510 cm to reduce the model volume
- Subroutine mfill was commented out.
- Created additional material ID numbers to resolve component residual dose rates on the septa, ELAM, c-magnet, D2Q3, and D2Q4, and D2Q5.

The devices, new material ID numbers, materials, and contact dose rate results for the condition “30 days irradiation, 1 day cooling time” are summarized in Table 1.

Table 1: Summary of contact radiation dose rates on selected components of the slow resonant extraction system. Additional irradiation and cooling times are given in the referenced Table.

Device	Material ID	material	Residual dose 30 day irradiation, 1 day cooling (mrem/hr)	Table reference for additional irradiation and cooling times
ESS-1 US flange	19	Stainless steel	55	Table 4
ESS-1 vessel	23	Aluminum	373	Table 8
ESS-1 DS flange	20	Stainless steel	793	Table 5
ESS-1 C channel	9	Aluminum	1150	Table 3
D2Q3	28	iron	219	Table 13
ESS-2 US flange	21	Stainless steel	167	Table 6
ESS-2 vessel	24	Aluminum	253	Table 9
ESS-2 DS flange	22	Stainless steel	653	Table 7
ESS-2 C channel	25	Aluminum	761	Table 10
D2Q4	29	Iron	166	Table 14
ELAM	26	Iron	868	Table 11
D2Q5	30	Iron	90	Table 15
C magnet	27	iron	49	Table 12

MARS Histogram Results

Histograms results for surfaces are all normalized to 8 kW, 1.25% beam loss. Figures 1, 2, and 4 are GUI images of the MARS model. The remaining figures shown are histograms of residual dose rate in units of mrem per hour. Table 2 shows a summary of the peak dose rates found for each of the surfaces.

The histogram file (XYZHIS.INP) used for the run is:

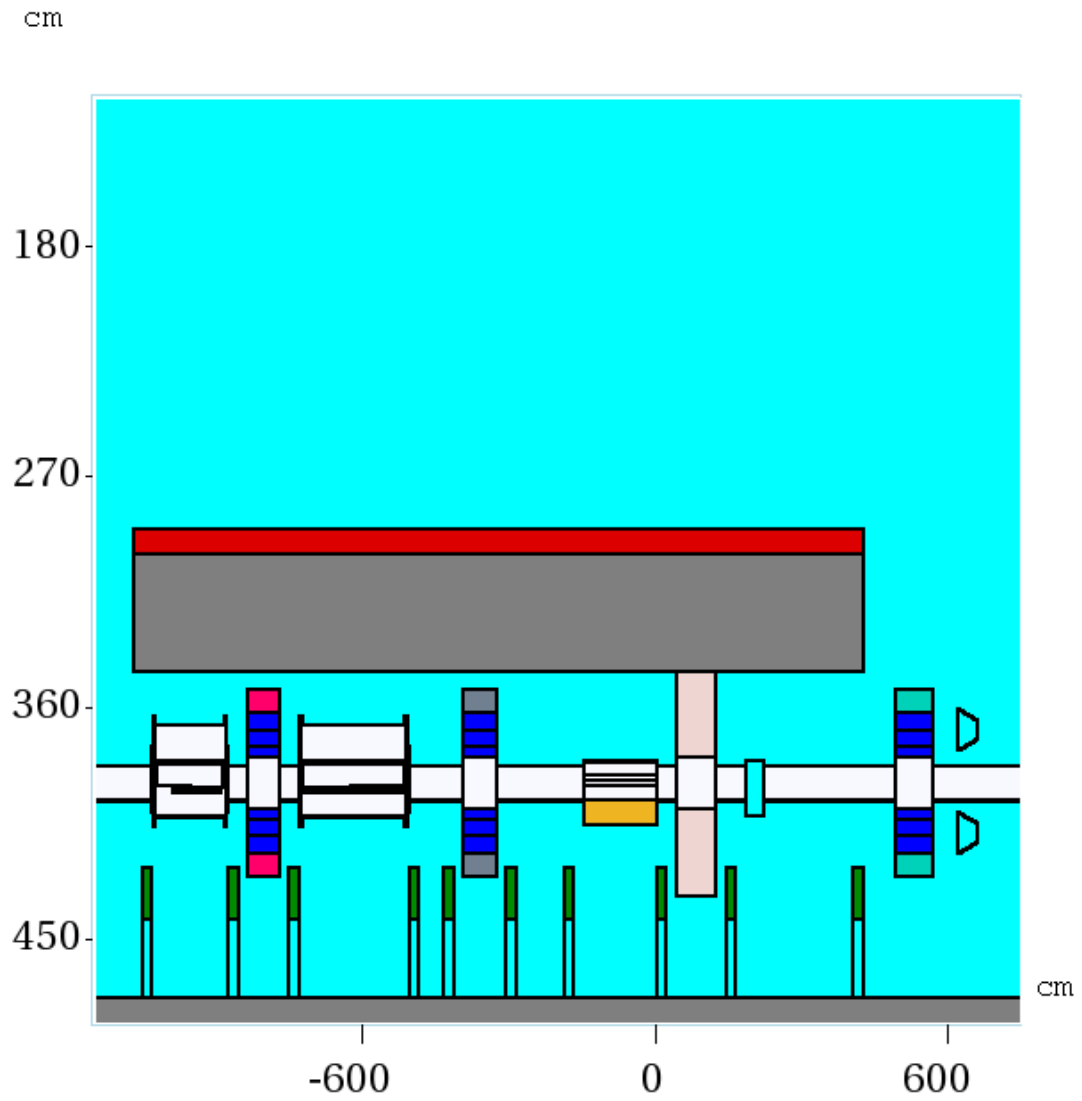
```

AP30 Extraction model
! extraction region contact dose rates
xyz -83.83 -76.2 127.8245 472.381 -1100. 700. 1 20 100 tunnel_floor
DRE
xyz -76.2 106.68 337.5 345.12 -1070.28 419.579 12 1 100 aisle_concrete_inner
DRE
xyz -76.2 106.68 289.875 299.4 -1070.28 419.579 12 1 100 marble_shield
DRE
xyz 31.59 36.67 350.461 472.381 -1034.72 -878.867 1 10 10 ESS-1_shelf
DRE
xyz 46.36 51.44 350.461 472.381 -858.547 -755.367 1 10 10 D2Q3_shelf
DRE
xyz 31.59 36.67 350.461 472.381 -735.047 -509.111 1 10 10 ESS-2_shelf
DRE
xyz 46.36 51.44 350.461 472.381 -417.896 -310.581 1 10 10 D2Q4_shelf
DRE
xyz 30.12 35.2 350.461 472.381 -172.32 -4.5916 1 10 10 ELAM_shelf
DRE
xyz 53.98 59.06 350.461 472.381 17.7284 139.6484 1 10 10 D2Q5_shelf
DRE
xyz 65.67 70.75 350.461 472.381 159.9684 399.2592 1 10 10 cmag_shelf
DRE
Stop

```

Table 2: Summary of peak residual radiation dose rates for histogram surfaces

Surface	Peak residual dose rate (mrem/hr)	Figure
Concrete floor	10	3
Aisle shield, Delivery Ring side	30	5
Aisle shield, marble surface	1.6	6
ESS-1 shelf	280	7
D2Q3 shelf	270	8
ESS-2 shelf	240	9
D2Q4 shelf	170	10
ELAM shelf	200	11
D2Q5 shelf	40	12
C-magnet shelf	32	13



$\begin{matrix} \rightarrow z \\ \downarrow y \end{matrix}$
 $y:z = 1:5.243e+00$

Figure 1: Plan view of extraction system model. Devices shown are ESS-1, D2Q3, ESS-2, D2Q4, ELAM, D2Q5, c-magnet (partial), and D2Q6. The c-magnet is out of plane in this view. The gray region is the tunnel aisle shield and the adjacent red bar indicates the marble exterior of the aisle shield. Green regions indicate the in-tunnel shield support columns.

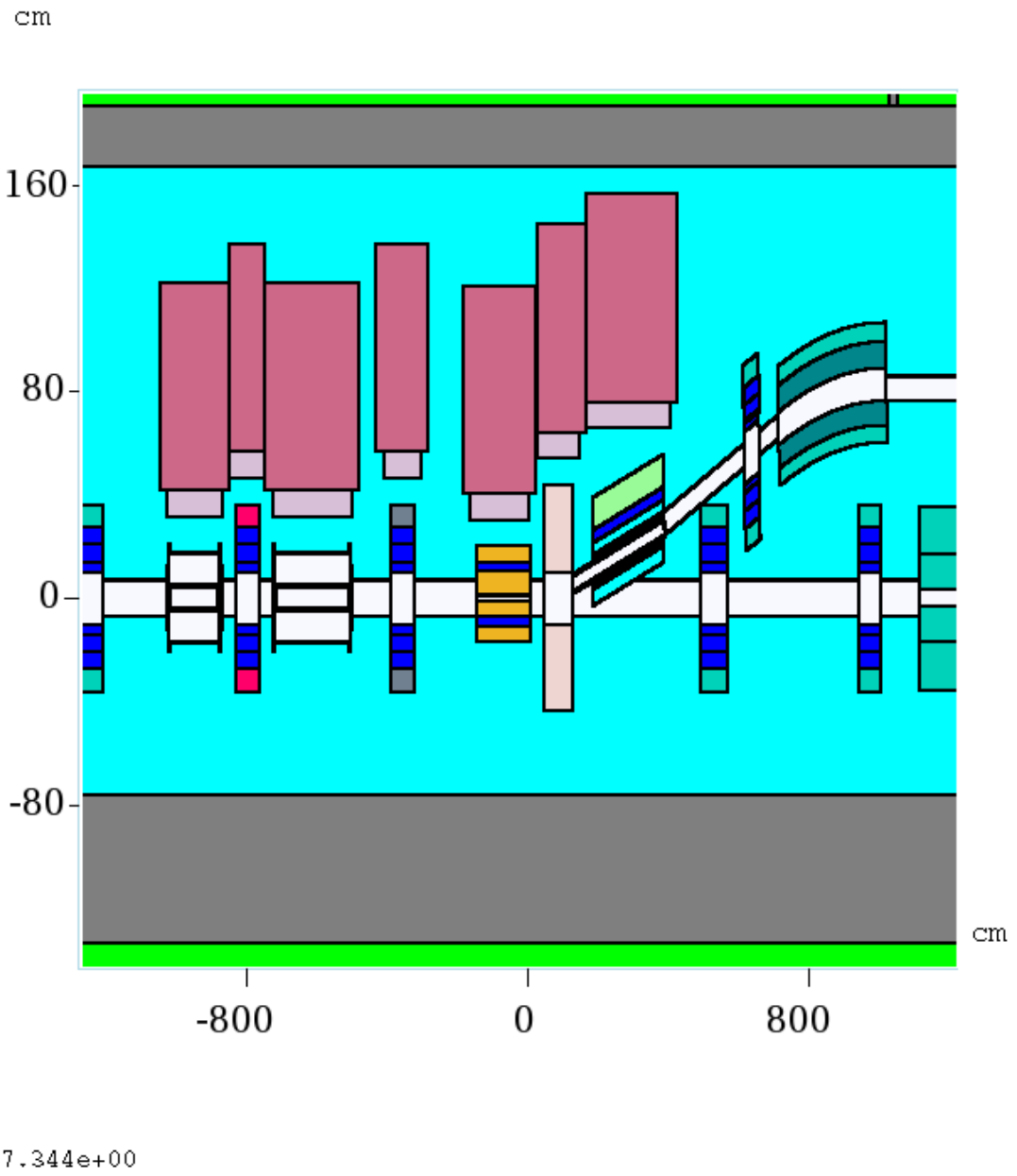


Figure 2: Elevation view of extraction region here shows D2Q2, ESS-1, D2Q3, ESS-2, D2Q4, ELAM, D2Q5, D2Q6, D2Q7 and B207 in the circulating aperture. The c-magnet, Q901, and EDWA are shown in the extraction orbit. The steel shelved and steel shielding are shown in shades of magenta.

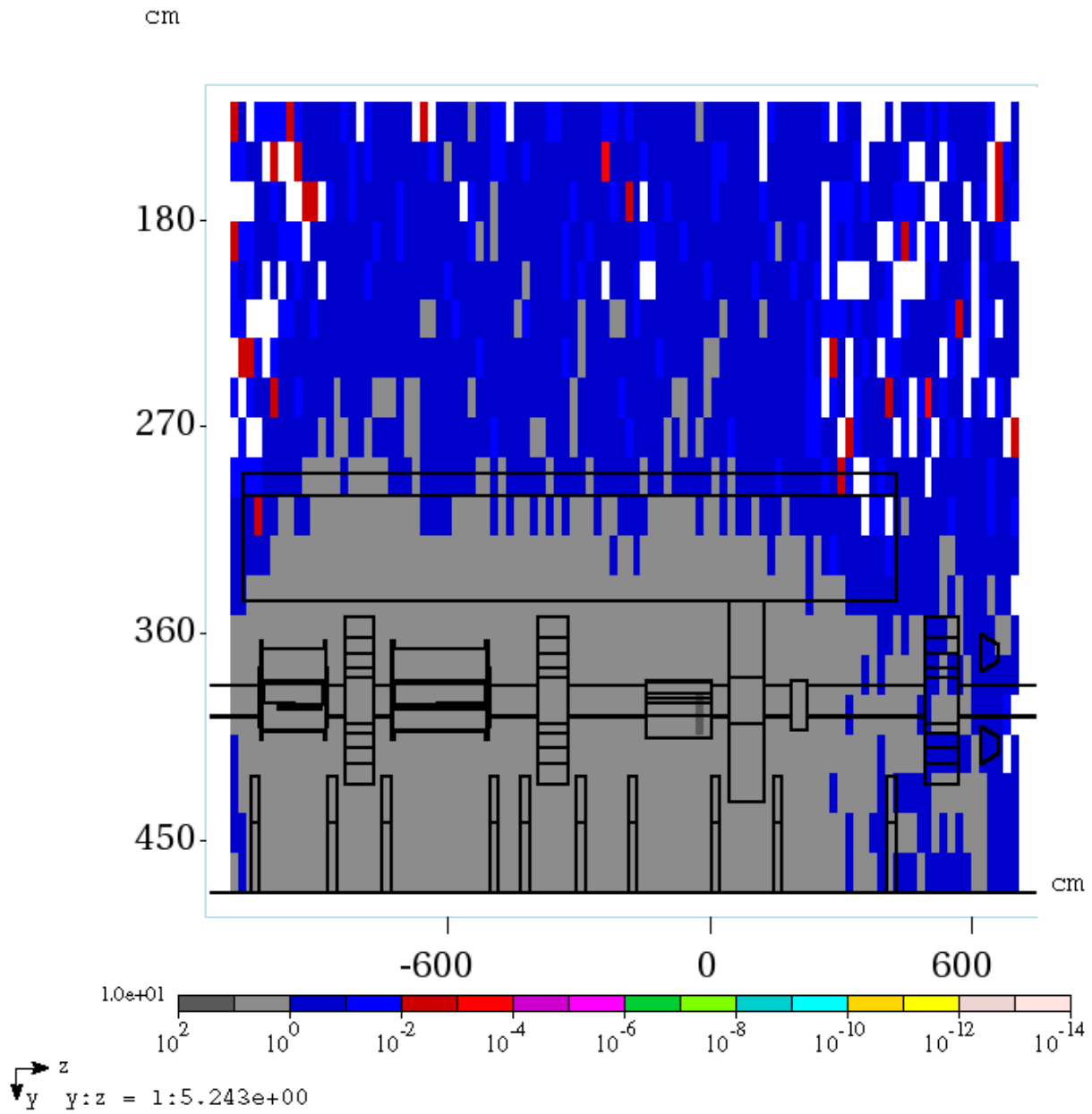


Figure 3: Histogram of concrete floor residual dose rate in units of mrem per hour

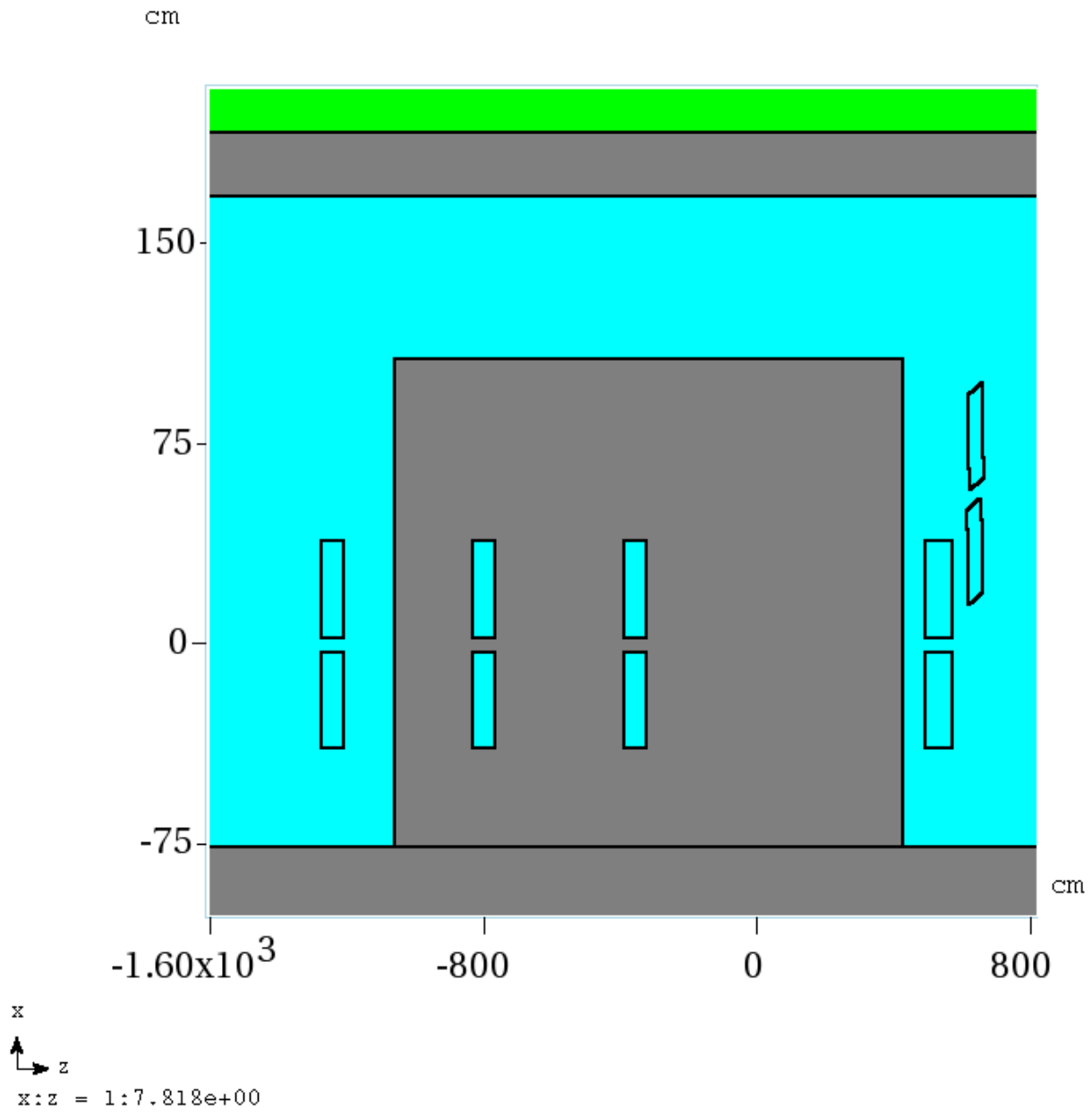


Figure 4: Elevation view of the aisle shield wall adjacent to the extraction region

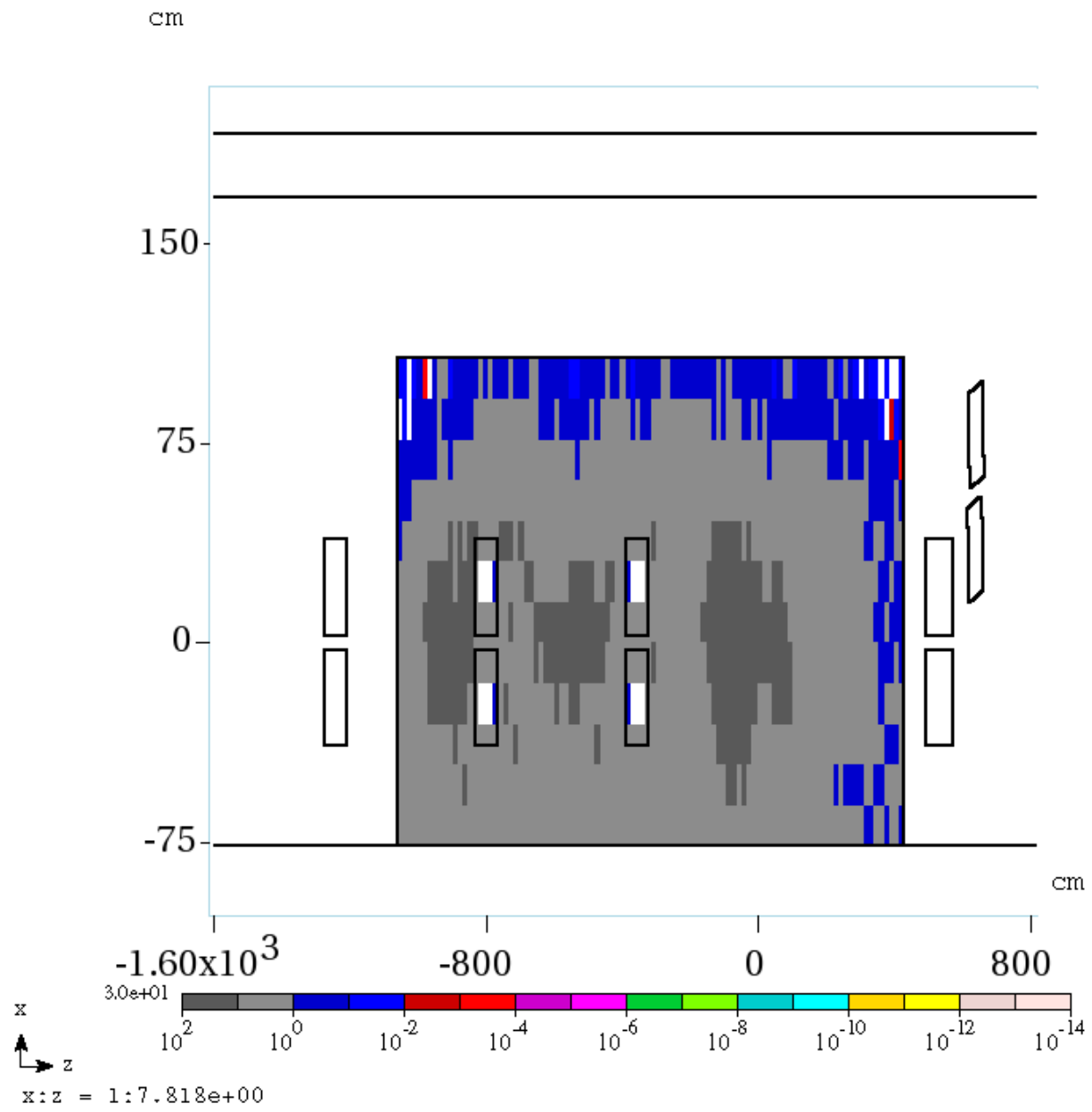


Figure 5: Histogram of shield wall on the Delivery Ring side of the wall

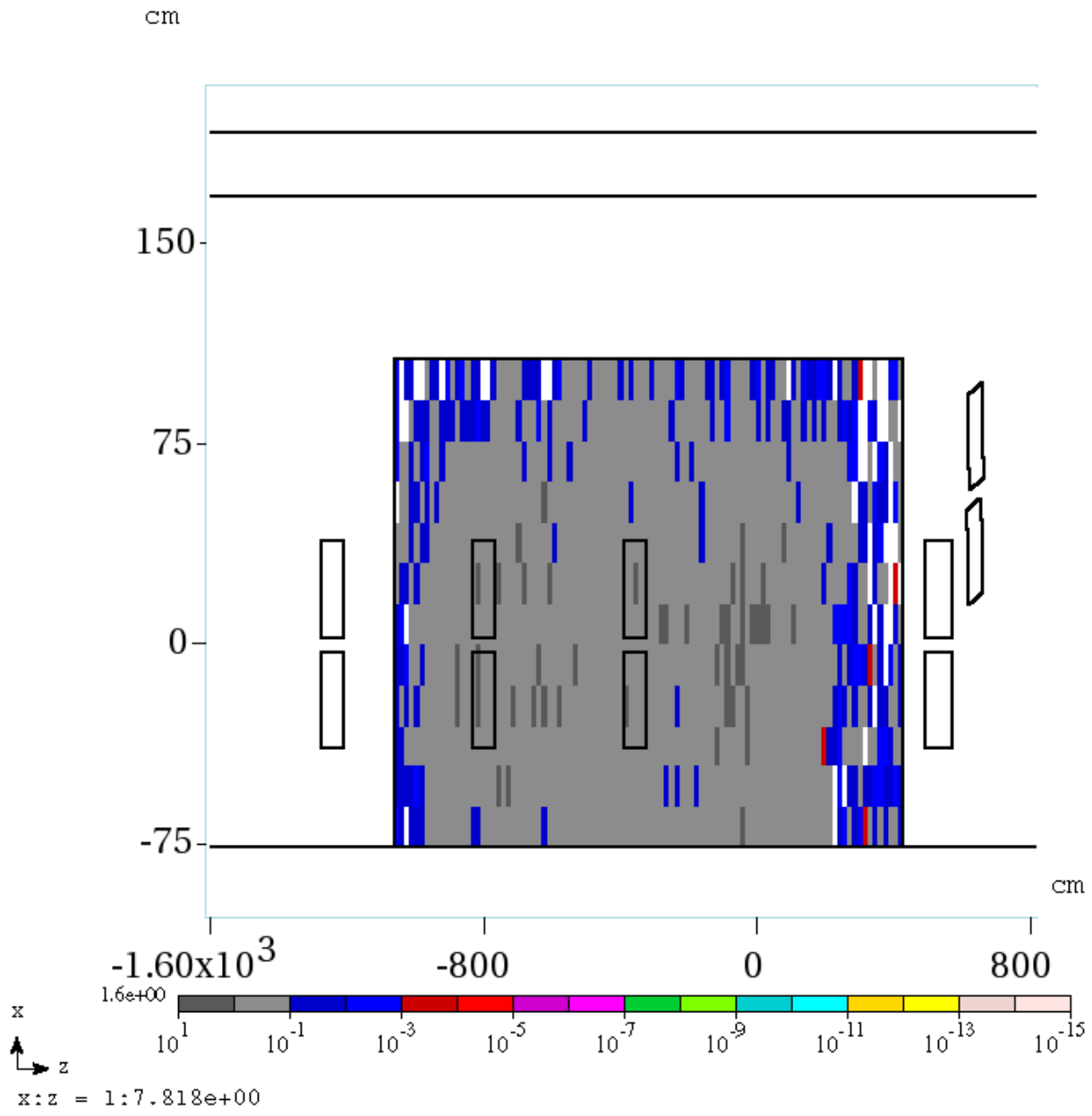


Figure 6: Histogram of shield wall on aisle side of the wall

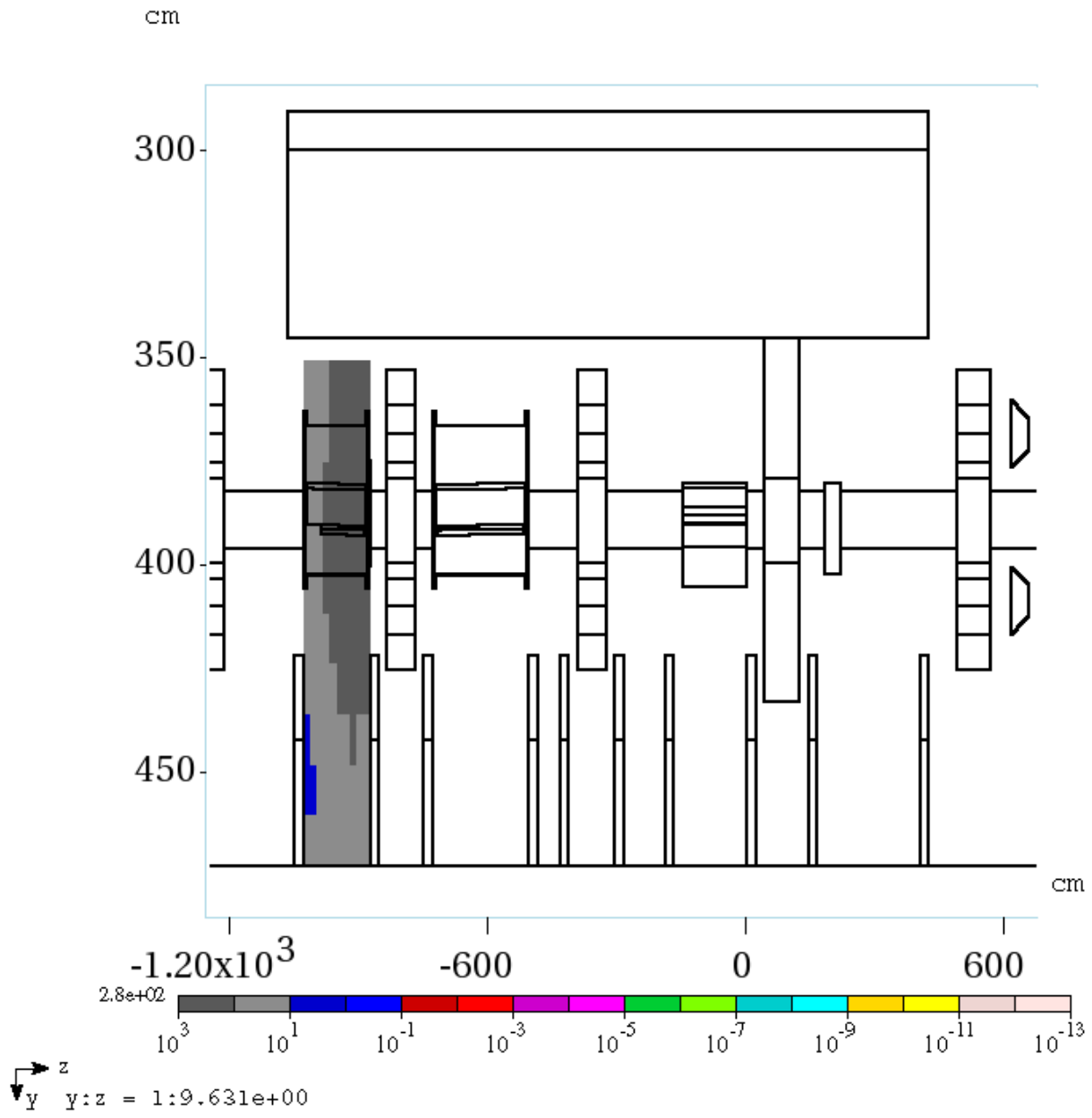


Figure 7: Histogram of the residual dose rate on the bottom side of the ESS-1 shelf

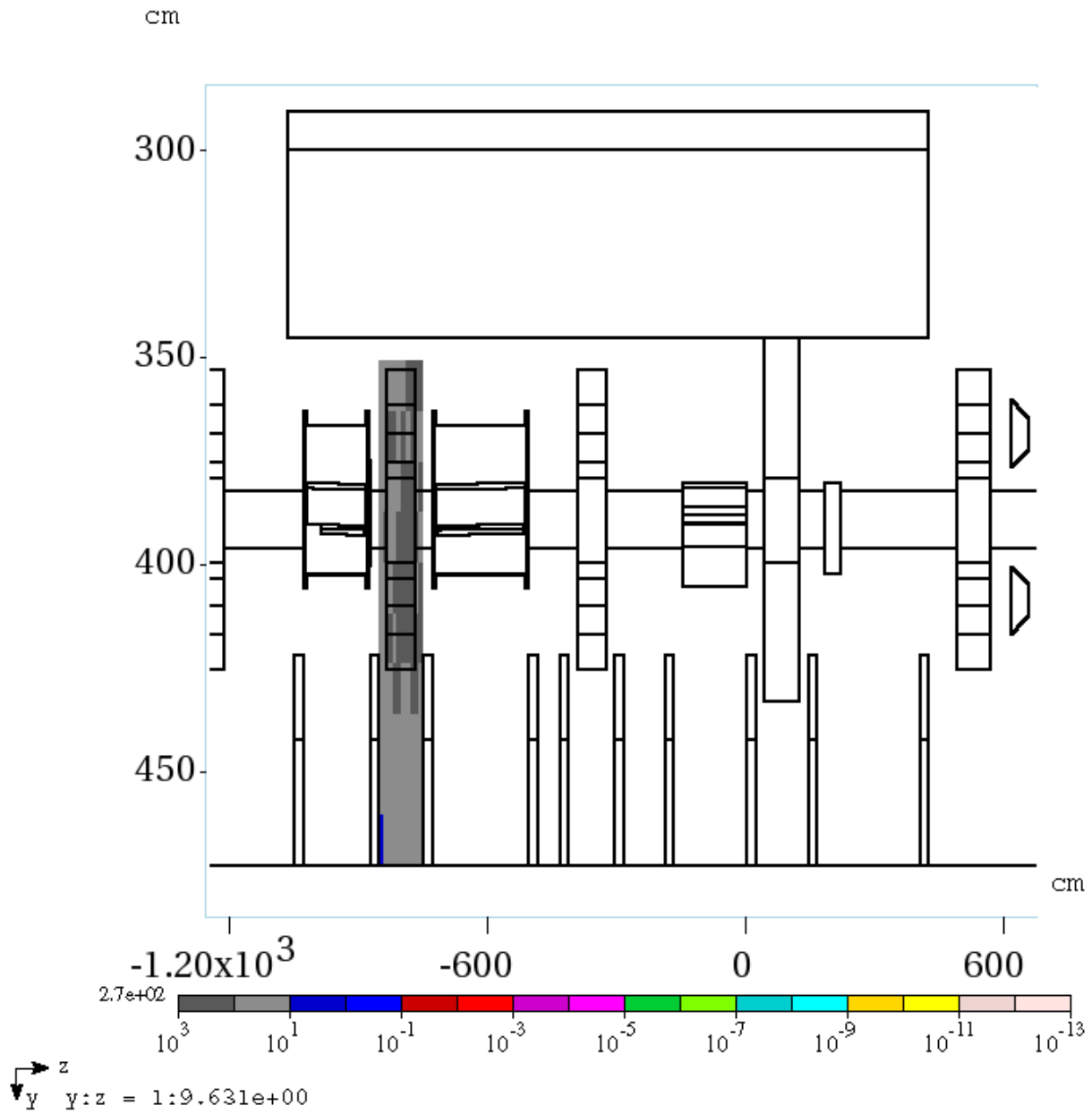


Figure 8: Histogram of the residual dose rate on the bottom side of the D2Q3 shelf

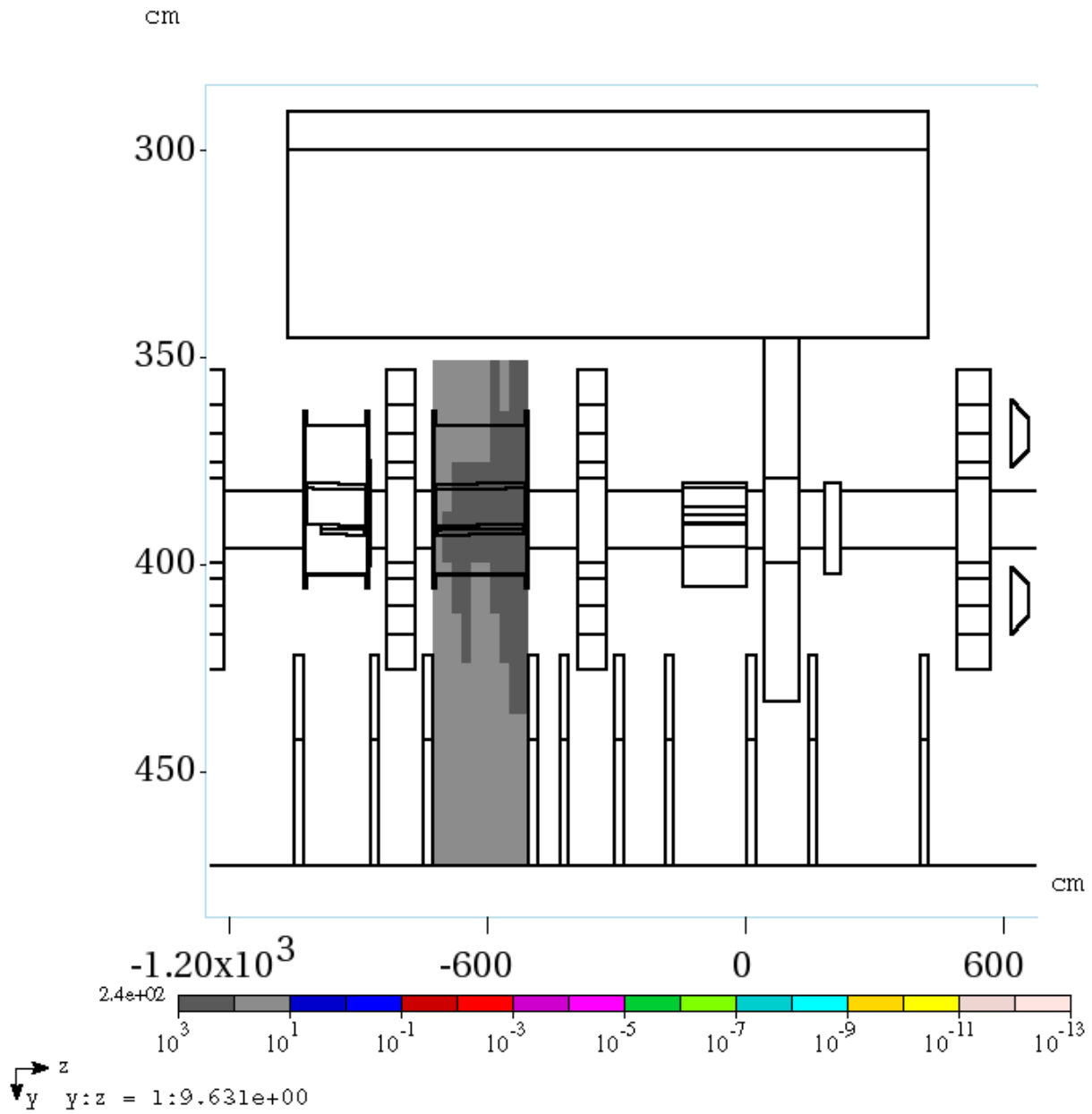


Figure 9: Histogram of the residual dose rate on the bottom side of the ESS-2 shelf

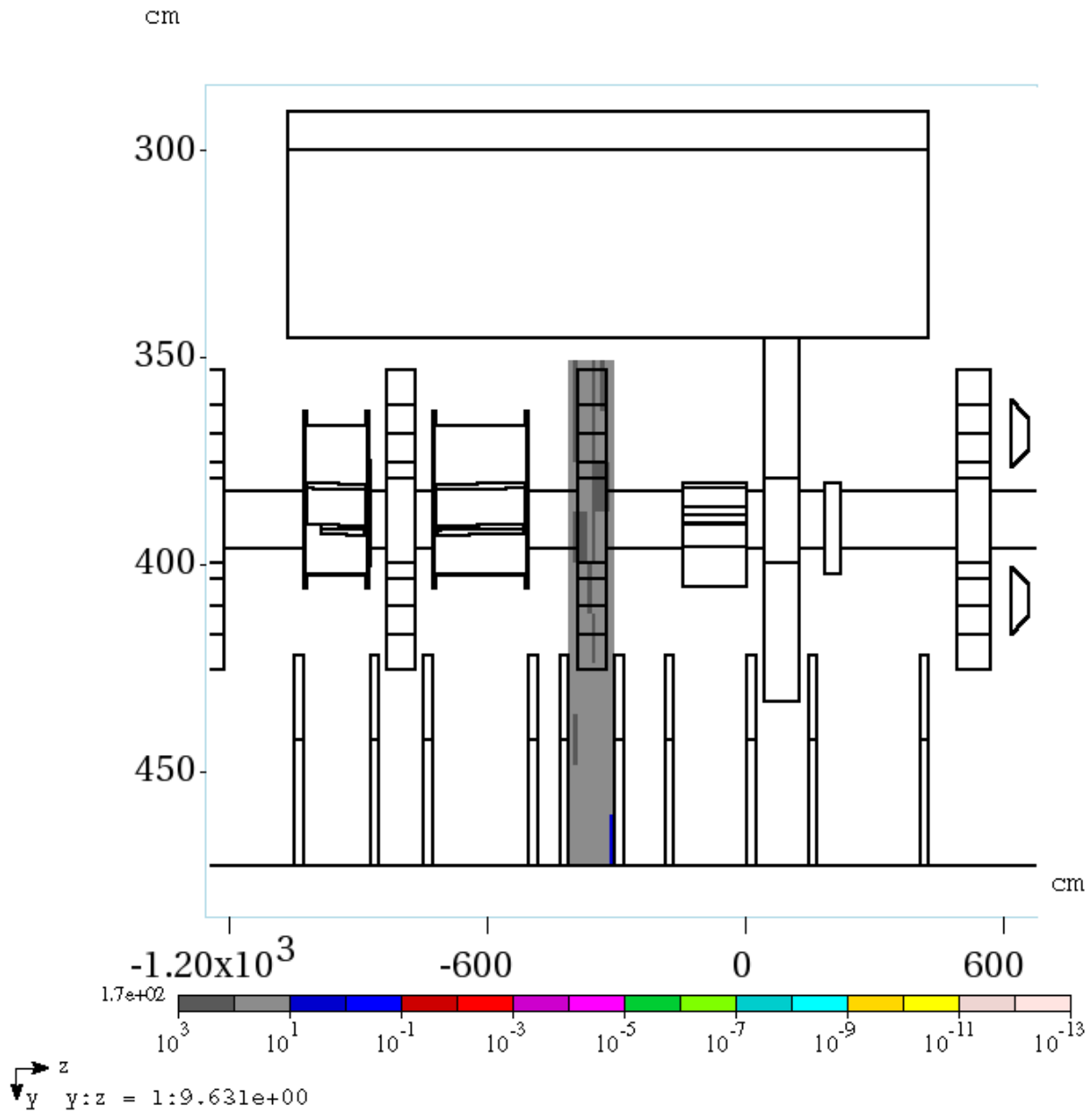


Figure 10: Histogram of the residual dose rate on the bottom side of the D2Q4 shelf

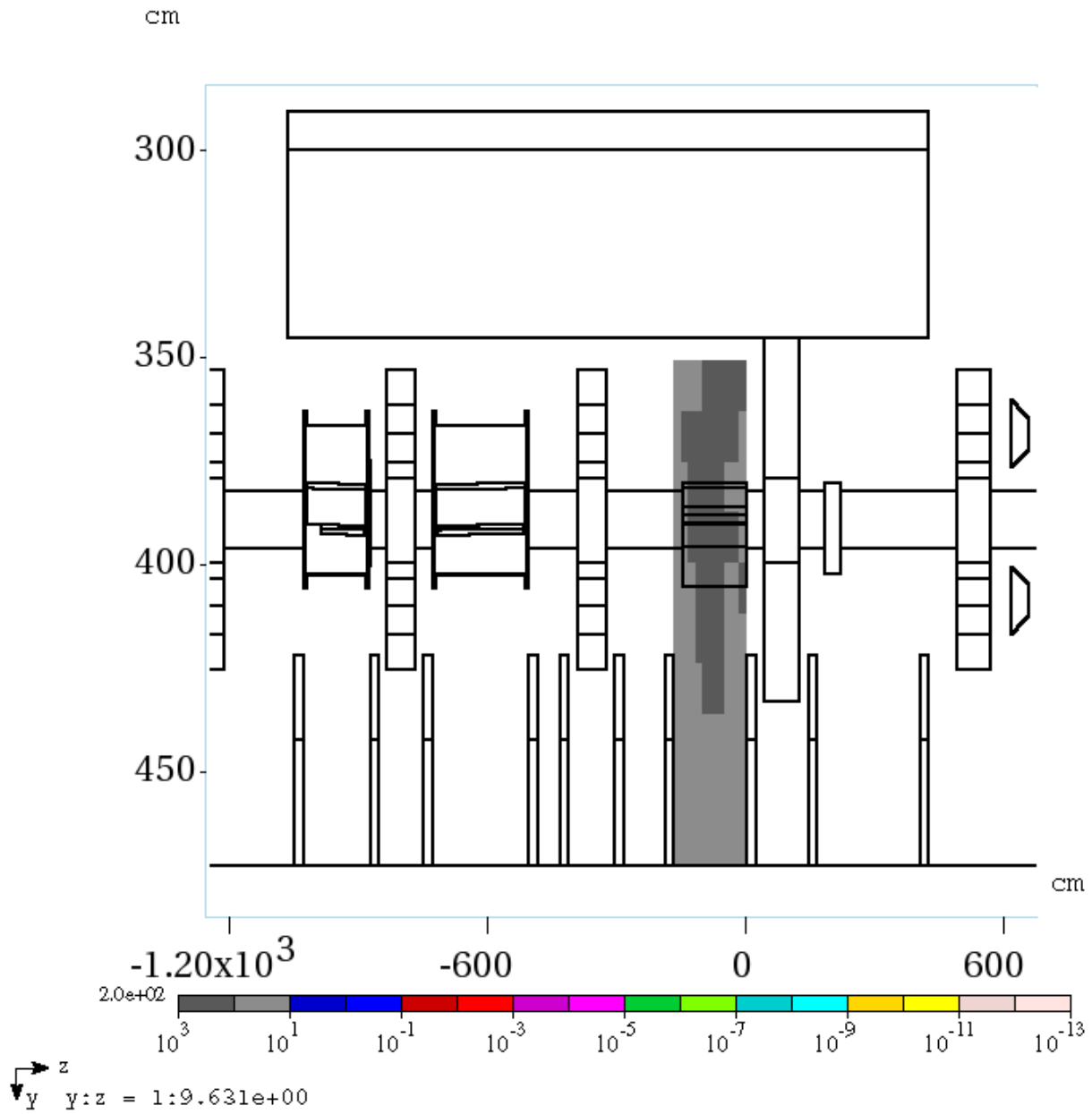


Figure 11: Histogram of the residual dose rate on the bottom side of the ELAM shelf

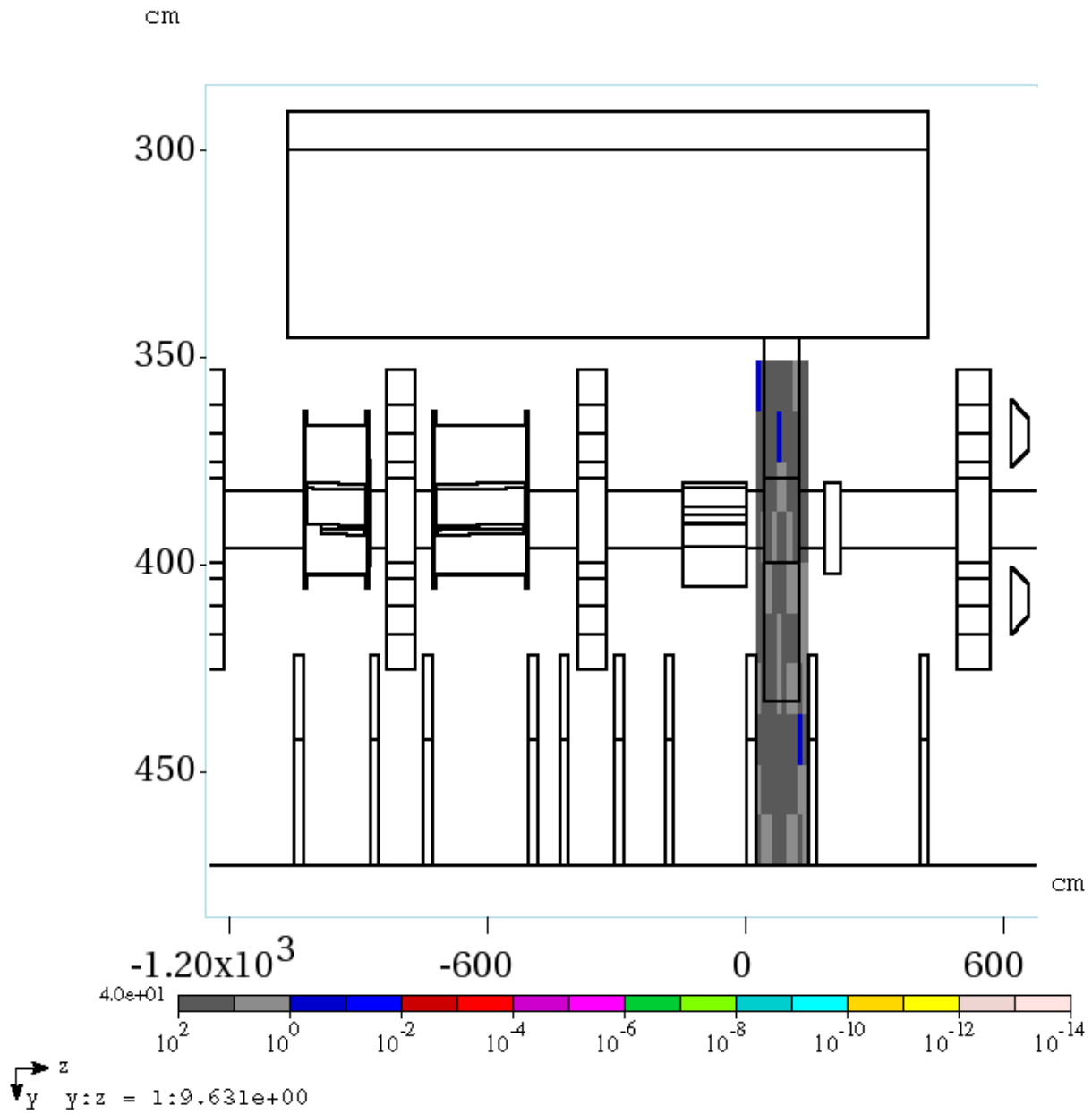


Figure 12: Histogram of the residual dose rate on the bottom side of the D2Q5 shelf

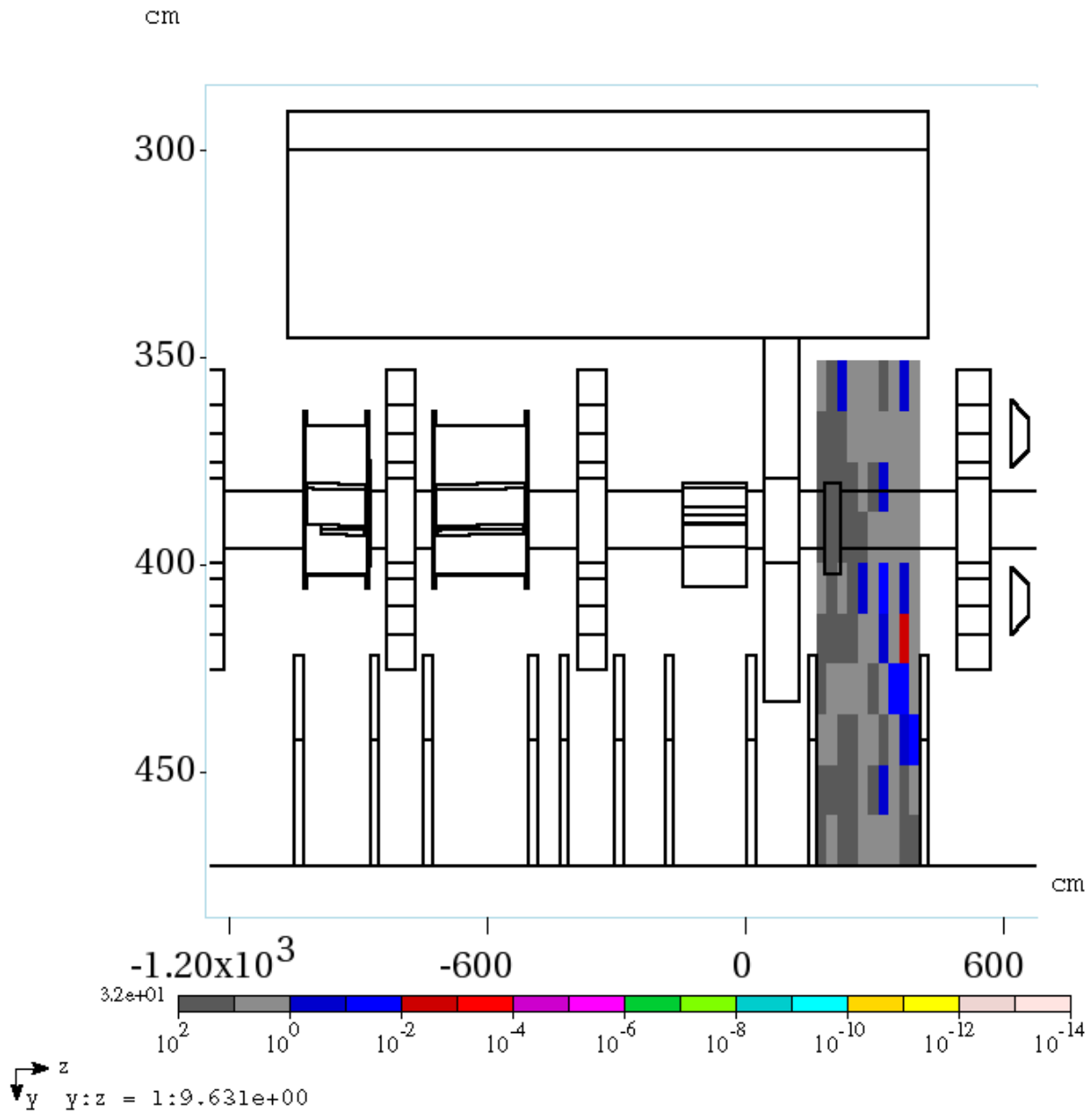


Figure 13: Histogram of the residual dose rate on the bottom side of the C-magnet shelf

Table 3

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 9 VOLUME= 4.81502E+03 CM^3

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0
Tcool	Tcool (sec)						
1sec	1.000E+00	5.935E+01	6.778E+01	7.301E+01	7.934E+01	8.040E+01	8.156E+01
1min	6.000E+01	2.975E+01	3.818E+01	4.326E+01	4.971E+01	5.076E+01	5.193E+01
10min	6.000E+02	2.176E+01	3.014E+01	3.510E+01	4.160E+01	4.264E+01	4.381E+01
0.5hr	1.800E+03	1.787E+01	2.612E+01	3.095E+01	3.740E+01	3.845E+01	3.963E+01
1hr	3.600E+03	1.623E+01	2.429E+01	2.899E+01	3.531E+01	3.636E+01	3.754E+01
2hr	7.200E+03	1.481E+01	2.250E+01	2.698E+01	3.302E+01	3.407E+01	3.525E+01
4hr	1.440E+04	1.273E+01	1.965E+01	2.369E+01	2.917E+01	3.021E+01	3.140E+01
6hr	2.160E+04	1.143E+01	1.780E+01	2.153E+01	2.659E+01	2.763E+01	2.882E+01
12hr	4.320E+04	8.446E+00	1.328E+01	1.611E+01	1.999E+01	2.101E+01	2.221E+01
1day	8.640E+04	4.828E+00	7.599E+00	9.260E+00	1.154E+01	1.254E+01	1.377E+01
2days	1.728E+05	1.590E+00	2.504E+00	3.106E+00	3.951E+00	4.846E+00	6.174E+00
7days	6.048E+05	1.000E-02	1.740E-02	5.735E-02	2.446E-01	7.397E-01	2.459E+00
30d	2.592E+06	3.808E-03	7.610E-03	3.780E-02	2.252E-01	7.043E-01	2.400E+00
0.5yr	1.577E+07	3.345E-03	6.687E-03	3.326E-02	1.984E-01	6.238E-01	2.138E+00
1yr	3.154E+07	2.919E-03	5.836E-03	2.904E-02	1.732E-01	5.452E-01	1.871E+00
2yr	6.307E+07	2.236E-03	4.472E-03	2.225E-02	1.327E-01	4.177E-01	1.433E+00
5yr	1.577E+08	1.006E-03	2.012E-03	1.001E-02	5.972E-02	1.879E-01	6.448E-01
10yr	3.154E+08	2.658E-04	5.315E-04	2.644E-03	1.578E-02	4.966E-02	1.704E-01
20yr	6.307E+08	1.861E-05	3.720E-05	1.851E-04	1.105E-03	3.477E-03	1.193E-02
30yr	9.461E+08	1.351E-06	2.703E-06	1.345E-05	8.023E-05	2.532E-04	8.711E-04

Table 4

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 19 VOLUME= 5.92297E+03 CM^3

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0
Tcool	Tcool (sec)						
1sec	1.000E+00	8.849E-01	9.502E-01	1.160E+00	1.493E+00	1.736E+00	2.074E+00
1min	6.000E+01	8.089E-01	8.742E-01	1.081E+00	1.417E+00	1.659E+00	1.998E+00
10min	6.000E+02	6.322E-01	6.965E-01	8.958E-01	1.239E+00	1.479E+00	1.820E+00
0.5hr	1.800E+03	5.020E-01	5.648E-01	7.557E-01	1.106E+00	1.345E+00	1.687E+00
1hr	3.600E+03	4.016E-01	4.620E-01	6.443E-01	1.002E+00	1.238E+00	1.582E+00
2hr	7.200E+03	2.932E-01	3.498E-01	5.207E-01	8.863E-01	1.121E+00	1.466E+00
4hr	1.440E+04	1.820E-01	2.326E-01	3.903E-01	7.642E-01	9.962E-01	1.346E+00
6hr	2.160E+04	1.323E-01	1.787E-01	3.272E-01	7.030E-01	9.318E-01	1.282E+00
12hr	4.320E+04	6.527E-02	1.041E-01	2.350E-01	6.122E-01	8.341E-01	1.189E+00
1day	8.640E+04	3.884E-02	7.009E-02	1.830E-01	5.506E-01	7.659E-01	1.124E+00
2days	1.728E+05	2.657E-02	4.981E-02	1.449E-01	4.877E-01	6.968E-01	1.055E+00
7days	6.048E+05	1.196E-02	2.337E-02	8.283E-02	3.430E-01	5.319E-01	8.800E-01
30d	2.592E+06	3.716E-03	7.376E-03	3.146E-02	1.590E-01	2.970E-01	5.964E-01
0.5yr	1.577E+07	6.583E-04	1.314E-03	6.316E-03	3.627E-02	8.734E-02	2.304E-01
1yr	3.154E+07	2.751E-04	5.496E-04	2.680E-03	1.564E-02	4.162E-02	1.205E-01
2yr	6.307E+07	9.886E-05	1.976E-04	9.727E-04	5.735E-03	1.621E-02	4.958E-02
5yr	1.577E+08	1.085E-05	2.169E-05	1.072E-04	6.345E-04	1.860E-03	5.933E-03
10yr	3.154E+08	1.618E-06	3.236E-06	1.613E-05	9.643E-05	3.100E-04	1.089E-03
20yr	6.307E+08	5.191E-07	1.038E-06	5.183E-06	3.104E-05	1.014E-04	3.626E-04
30yr	9.461E+08	2.485E-07	4.970E-07	2.482E-06	1.488E-05	4.898E-05	1.764E-04

Table 5

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 20 VOLUME= 5.78851E+03 CM³

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0
Tcool	Tcool (sec)						
1sec	1.000E+00	1.027E+01	1.116E+01	1.428E+01	1.899E+01	2.194E+01	2.576E+01
1min	6.000E+01	9.214E+00	1.010E+01	1.318E+01	1.793E+01	2.087E+01	2.470E+01
10min	6.000E+02	7.038E+00	7.920E+00	1.088E+01	1.574E+01	1.865E+01	2.251E+01
0.5hr	1.800E+03	5.338E+00	6.204E+00	9.038E+00	1.401E+01	1.689E+01	2.077E+01
1hr	3.600E+03	4.080E+00	4.922E+00	7.624E+00	1.270E+01	1.556E+01	1.947E+01
2hr	7.200E+03	2.896E+00	3.699E+00	6.224E+00	1.143E+01	1.426E+01	1.819E+01
4hr	1.440E+04	1.914E+00	2.653E+00	4.973E+00	1.030E+01	1.310E+01	1.706E+01
6hr	2.160E+04	1.481E+00	2.169E+00	4.349E+00	9.712E+00	1.249E+01	1.646E+01
12hr	4.320E+04	8.914E-01	1.478E+00	3.390E+00	8.771E+00	1.150E+01	1.549E+01
1day	8.640E+04	5.870E-01	1.060E+00	2.713E+00	7.928E+00	1.059E+01	1.461E+01
2days	1.728E+05	4.006E-01	7.498E-01	2.136E+00	6.960E+00	9.540E+00	1.355E+01
7days	6.048E+05	1.754E-01	3.422E-01	1.184E+00	4.732E+00	7.026E+00	1.094E+01
30d	2.592E+06	4.818E-02	9.554E-02	3.983E-01	1.960E+00	3.569E+00	6.959E+00
0.5yr	1.577E+07	7.451E-03	1.488E-02	7.175E-02	4.136E-01	1.020E+00	2.748E+00
1yr	3.154E+07	3.347E-03	6.688E-03	3.266E-02	1.909E-01	5.126E-01	1.494E+00
2yr	6.307E+07	1.236E-03	2.471E-03	1.216E-02	7.171E-02	2.023E-01	6.171E-01
5yr	1.577E+08	1.248E-04	2.496E-04	1.232E-03	7.286E-03	2.112E-02	6.647E-02
10yr	3.154E+08	1.396E-05	2.792E-05	1.391E-04	8.314E-04	2.667E-03	9.344E-03
20yr	6.307E+08	5.202E-06	1.040E-05	5.196E-05	3.113E-04	1.023E-03	3.676E-03
30yr	9.461E+08	3.121E-06	6.241E-06	3.118E-05	1.869E-04	6.181E-04	2.236E-03

Table 6

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 21 VOLUME= 5.71910E+03 CM^3

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0
Tcool	Tcool (sec)						
1sec	1.000E+00	2.296E+00	2.486E+00	3.138E+00	4.137E+00	4.787E+00	5.648E+00
1min	6.000E+01	2.072E+00	2.262E+00	2.905E+00	3.912E+00	4.560E+00	5.423E+00
10min	6.000E+02	1.593E+00	1.782E+00	2.401E+00	3.431E+00	4.073E+00	4.942E+00
0.5hr	1.800E+03	1.226E+00	1.410E+00	2.003E+00	3.056E+00	3.693E+00	4.566E+00
1hr	3.600E+03	9.504E-01	1.130E+00	1.695E+00	2.770E+00	3.401E+00	4.280E+00
2hr	7.200E+03	6.809E-01	8.508E-01	1.380E+00	2.480E+00	3.106E+00	3.990E+00
4hr	1.440E+04	4.411E-01	5.962E-01	1.083E+00	2.209E+00	2.828E+00	3.720E+00
6hr	2.160E+04	3.348E-01	4.787E-01	9.361E-01	2.069E+00	2.682E+00	3.576E+00
12hr	4.320E+04	1.905E-01	3.128E-01	7.145E-01	1.852E+00	2.451E+00	3.353E+00
1day	8.640E+04	1.223E-01	2.208E-01	5.679E-01	1.671E+00	2.256E+00	3.164E+00
2days	1.728E+05	8.349E-02	1.563E-01	4.478E-01	1.471E+00	2.037E+00	2.944E+00
7days	6.048E+05	3.681E-02	7.185E-02	2.500E-01	1.009E+00	1.515E+00	2.398E+00
30d	2.592E+06	1.044E-02	2.071E-02	8.687E-02	4.306E-01	7.899E-01	1.554E+00
0.5yr	1.577E+07	1.678E-03	3.352E-03	1.614E-02	9.296E-02	2.277E-01	6.095E-01
1yr	3.154E+07	7.383E-04	1.475E-03	7.200E-03	4.207E-02	1.127E-01	3.278E-01
2yr	6.307E+07	2.706E-04	5.409E-04	2.662E-03	1.569E-02	4.430E-02	1.352E-01
5yr	1.577E+08	2.798E-05	5.594E-05	2.762E-04	1.634E-03	4.752E-03	1.502E-02
10yr	3.154E+08	3.439E-06	6.878E-06	3.427E-05	2.048E-04	6.575E-04	2.306E-03
20yr	6.307E+08	1.217E-06	2.435E-06	1.216E-05	7.282E-05	2.388E-04	8.568E-04
30yr	9.461E+08	6.822E-07	1.364E-06	6.816E-06	4.086E-05	1.349E-04	4.876E-04

Table 7

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 22 VOLUME= 5.88432E+03 CM^3

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0	
Tcool	Tcool (sec)							
1sec	1.000E+00	8.413E+00	9.147E+00	1.172E+01	1.560E+01	1.802E+01	2.115E+01	2.337E+01
1min	6.000E+01	7.547E+00	8.280E+00	1.082E+01	1.473E+01	1.714E+01	2.028E+01	2.251E+01
10min	6.000E+02	5.761E+00	6.487E+00	8.930E+00	1.294E+01	1.532E+01	1.848E+01	2.070E+01
0.5hr	1.800E+03	4.363E+00	5.076E+00	7.413E+00	1.151E+01	1.388E+01	1.705E+01	1.927E+01
1hr	3.600E+03	3.329E+00	4.023E+00	6.252E+00	1.044E+01	1.278E+01	1.598E+01	1.820E+01
2hr	7.200E+03	2.361E+00	3.022E+00	5.105E+00	9.393E+00	1.172E+01	1.493E+01	1.715E+01
4hr	1.440E+04	1.564E+00	2.173E+00	4.086E+00	8.476E+00	1.078E+01	1.402E+01	1.624E+01
6hr	2.160E+04	1.213E+00	1.780E+00	3.577E+00	7.997E+00	1.028E+01	1.353E+01	1.574E+01
12hr	4.320E+04	7.337E-01	1.218E+00	2.794E+00	7.228E+00	9.466E+00	1.274E+01	1.495E+01
1day	8.640E+04	4.843E-01	8.746E-01	2.238E+00	6.534E+00	8.721E+00	1.201E+01	1.422E+01
2days	1.728E+05	3.305E-01	6.186E-01	1.762E+00	5.735E+00	7.853E+00	1.114E+01	1.335E+01
7days	6.048E+05	1.446E-01	2.822E-01	9.752E-01	3.896E+00	5.778E+00	8.982E+00	1.116E+01
30d	2.592E+06	3.961E-02	7.853E-02	3.272E-01	1.609E+00	2.928E+00	5.704E+00	7.762E+00
0.5yr	1.577E+07	6.102E-03	1.219E-02	5.876E-02	3.388E-01	8.364E-01	2.253E+00	3.704E+00
1yr	3.154E+07	2.747E-03	5.488E-03	2.680E-02	1.567E-01	4.208E-01	1.227E+00	2.214E+00
2yr	6.307E+07	1.015E-03	2.030E-03	9.989E-03	5.889E-02	1.661E-01	5.068E-01	9.912E-01
5yr	1.577E+08	1.023E-04	2.045E-04	1.009E-03	5.969E-03	1.729E-02	5.441E-02	1.556E-01
10yr	3.154E+08	1.133E-05	2.265E-05	1.129E-04	6.745E-04	2.163E-03	7.578E-03	4.959E-02
20yr	6.307E+08	4.243E-06	8.487E-06	4.238E-05	2.539E-04	8.344E-04	2.999E-03	2.455E-02
30yr	9.461E+08	2.563E-06	5.126E-06	2.561E-05	1.535E-04	5.077E-04	1.837E-03	1.674E-02

Table 8

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 23 VOLUME= 3.82943E+03 CM^3

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0
Tcool	Tcool (sec)						
1sec	1.000E+00	1.789E+01	2.062E+01	2.231E+01	2.435E+01	2.463E+01	2.493E+01
1min	6.000E+01	9.750E+00	1.248E+01	1.412E+01	1.620E+01	1.647E+01	1.678E+01
10min	6.000E+02	6.910E+00	9.623E+00	1.122E+01	1.332E+01	1.359E+01	1.390E+01
0.5hr	1.800E+03	5.632E+00	8.301E+00	9.859E+00	1.194E+01	1.221E+01	1.252E+01
1hr	3.600E+03	5.126E+00	7.733E+00	9.249E+00	1.129E+01	1.156E+01	1.187E+01
2hr	7.200E+03	4.707E+00	7.195E+00	8.639E+00	1.059E+01	1.086E+01	1.117E+01
4hr	1.440E+04	4.080E+00	6.321E+00	7.623E+00	9.389E+00	9.662E+00	9.973E+00
6hr	2.160E+04	3.681E+00	5.746E+00	6.945E+00	8.577E+00	8.849E+00	9.160E+00
12hr	4.320E+04	2.733E+00	4.297E+00	5.210E+00	6.456E+00	6.724E+00	7.038E+00
1day	8.640E+04	1.563E+00	2.460E+00	2.993E+00	3.723E+00	3.984E+00	4.305E+00
2days	1.728E+05	5.147E-01	8.104E-01	1.000E+00	1.265E+00	1.499E+00	1.847E+00
7days	6.048E+05	2.996E-03	5.149E-03	1.572E-02	6.487E-02	1.943E-01	6.441E-01
30d	2.592E+06	9.959E-04	1.990E-03	9.887E-03	5.890E-02	1.842E-01	6.278E-01
0.5yr	1.577E+07	8.748E-04	1.749E-03	8.699E-03	5.189E-02	1.632E-01	5.593E-01
1yr	3.154E+07	7.635E-04	1.526E-03	7.594E-03	4.531E-02	1.426E-01	4.892E-01
2yr	6.307E+07	5.847E-04	1.170E-03	5.818E-03	3.471E-02	1.092E-01	3.748E-01
5yr	1.577E+08	2.631E-04	5.261E-04	2.618E-03	1.562E-02	4.915E-02	1.686E-01
10yr	3.154E+08	6.951E-05	1.390E-04	6.916E-04	4.127E-03	1.299E-02	4.457E-02
20yr	6.307E+08	4.867E-06	9.729E-06	4.841E-05	2.889E-04	9.094E-04	3.121E-03
30yr	9.461E+08	3.536E-07	7.072E-07	3.519E-06	2.099E-05	6.625E-05	2.280E-04

Table 9

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 24 VOLUME= 5.80061E+03 CM^3

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0
Tcool	Tcool (sec)						
1sec	1.000E+00	1.273E+01	1.459E+01	1.573E+01	1.712E+01	1.734E+01	1.758E+01
1min	6.000E+01	6.562E+00	8.414E+00	9.528E+00	1.094E+01	1.116E+01	1.140E+01
10min	6.000E+02	4.749E+00	6.590E+00	7.679E+00	9.104E+00	9.318E+00	9.559E+00
0.5hr	1.800E+03	3.890E+00	5.702E+00	6.762E+00	8.176E+00	8.392E+00	8.635E+00
1hr	3.600E+03	3.536E+00	5.306E+00	6.337E+00	7.724E+00	7.939E+00	8.181E+00
2hr	7.200E+03	3.233E+00	4.921E+00	5.904E+00	7.231E+00	7.446E+00	7.689E+00
4hr	1.440E+04	2.787E+00	4.308E+00	5.193E+00	6.395E+00	6.609E+00	6.854E+00
6hr	2.160E+04	2.506E+00	3.907E+00	4.723E+00	5.834E+00	6.047E+00	6.291E+00
12hr	4.320E+04	1.855E+00	2.916E+00	3.538E+00	4.387E+00	4.597E+00	4.844E+00
1day	8.640E+04	1.061E+00	1.669E+00	2.033E+00	2.532E+00	2.737E+00	2.989E+00
2days	1.728E+05	3.493E-01	5.500E-01	6.811E-01	8.647E-01	1.049E+00	1.321E+00
7days	6.048E+05	2.141E-03	3.711E-03	1.194E-02	5.044E-02	1.521E-01	5.053E-01
30d	2.592E+06	7.820E-04	1.563E-03	7.764E-03	4.625E-02	1.446E-01	4.930E-01
0.5yr	1.577E+07	6.869E-04	1.373E-03	6.831E-03	4.075E-02	1.281E-01	4.392E-01
1yr	3.154E+07	5.995E-04	1.199E-03	5.963E-03	3.558E-02	1.120E-01	3.842E-01
2yr	6.307E+07	4.592E-04	9.184E-04	4.569E-03	2.726E-02	8.578E-02	2.943E-01
5yr	1.577E+08	2.066E-04	4.131E-04	2.055E-03	1.226E-02	3.859E-02	1.324E-01
10yr	3.154E+08	5.458E-05	1.092E-04	5.431E-04	3.241E-03	1.020E-02	3.499E-02
20yr	6.307E+08	3.821E-06	7.639E-06	3.801E-05	2.269E-04	7.141E-04	2.451E-03
30yr	9.461E+08	2.775E-07	5.551E-07	2.762E-06	1.648E-05	5.200E-05	1.789E-04

Table 10

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 25 VOLUME= 7.22598E+03 CM^3

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0	
Tcool	Tcool (sec)							
1sec	1.000E+00	4.156E+01	4.711E+01	5.057E+01	5.473E+01	5.556E+01	5.645E+01	6.232E+01
1min	6.000E+01	1.934E+01	2.489E+01	2.824E+01	3.250E+01	3.331E+01	3.422E+01	4.006E+01
10min	6.000E+02	1.457E+01	2.008E+01	2.336E+01	2.764E+01	2.846E+01	2.936E+01	3.520E+01
0.5hr	1.800E+03	1.205E+01	1.747E+01	2.067E+01	2.492E+01	2.573E+01	2.665E+01	3.248E+01
1hr	3.600E+03	1.093E+01	1.623E+01	1.933E+01	2.350E+01	2.431E+01	2.523E+01	3.106E+01
2hr	7.200E+03	9.909E+00	1.497E+01	1.793E+01	2.191E+01	2.273E+01	2.364E+01	2.946E+01
4hr	1.440E+04	8.451E+00	1.300E+01	1.567E+01	1.929E+01	2.010E+01	2.102E+01	2.686E+01
6hr	2.160E+04	7.551E+00	1.174E+01	1.420E+01	1.755E+01	1.835E+01	1.928E+01	2.510E+01
12hr	4.320E+04	5.558E+00	8.734E+00	1.061E+01	1.317E+01	1.397E+01	1.490E+01	2.071E+01
1day	8.640E+04	3.174E+00	4.997E+00	6.100E+00	7.616E+00	8.390E+00	9.344E+00	1.513E+01
2days	1.728E+05	1.046E+00	1.647E+00	2.053E+00	2.625E+00	3.321E+00	4.352E+00	1.011E+01
7days	6.048E+05	7.040E-03	1.237E-02	4.316E-02	1.883E-01	5.728E-01	1.909E+00	7.637E+00
30d	2.592E+06	2.957E-03	5.911E-03	2.936E-02	1.749E-01	5.470E-01	1.864E+00	7.499E+00
0.5yr	1.577E+07	2.598E-03	5.194E-03	2.583E-02	1.541E-01	4.846E-01	1.661E+00	6.707E+00
1yr	3.154E+07	2.267E-03	4.533E-03	2.255E-02	1.346E-01	4.235E-01	1.453E+00	5.875E+00
2yr	6.307E+07	1.737E-03	3.474E-03	1.728E-02	1.031E-01	3.244E-01	1.113E+00	4.511E+00
5yr	1.577E+08	7.813E-04	1.562E-03	7.774E-03	4.639E-02	1.460E-01	5.008E-01	2.042E+00
10yr	3.154E+08	2.064E-04	4.128E-04	2.054E-03	1.226E-02	3.857E-02	1.324E-01	5.455E-01
20yr	6.307E+08	1.445E-05	2.889E-05	1.438E-04	8.580E-04	2.701E-03	9.268E-03	3.923E-02
30yr	9.461E+08	1.049E-06	2.099E-06	1.044E-05	6.229E-05	1.966E-04	6.764E-04	3.115E-03

Table 11

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 26 VOLUME= 1.08177E+05 CM^3

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0
Tcool	Tcool (sec)						
1sec	1.000E+00	1.492E+01	1.587E+01	1.943E+01	2.445E+01	2.783E+01	3.663E+01
1min	6.000E+01	1.360E+01	1.454E+01	1.806E+01	2.313E+01	2.648E+01	3.530E+01
10min	6.000E+02	1.081E+01	1.174E+01	1.515E+01	2.032E+01	2.365E+01	3.249E+01
0.5hr	1.800E+03	8.279E+00	9.189E+00	1.245E+01	1.775E+01	2.104E+01	2.991E+01
1hr	3.600E+03	6.303E+00	7.179E+00	1.027E+01	1.571E+01	1.897E+01	2.787E+01
2hr	7.200E+03	4.381E+00	5.201E+00	8.073E+00	1.369E+01	1.690E+01	2.584E+01
4hr	1.440E+04	2.664E+00	3.405E+00	6.012E+00	1.183E+01	1.500E+01	2.401E+01
6hr	2.160E+04	1.914E+00	2.590E+00	5.012E+00	1.090E+01	1.402E+01	2.303E+01
12hr	4.320E+04	9.461E-01	1.516E+00	3.606E+00	9.579E+00	1.262E+01	2.169E+01
1day	8.640E+04	5.704E-01	1.041E+00	2.839E+00	8.680E+00	1.165E+01	2.075E+01
2days	1.728E+05	4.115E-01	7.814E-01	2.309E+00	7.730E+00	1.062E+01	1.971E+01
7days	6.048E+05	2.080E-01	4.060E-01	1.355E+00	5.190E+00	7.801E+00	1.676E+01
30d	2.592E+06	4.774E-02	9.456E-02	3.886E-01	1.876E+00	3.727E+00	7.829E+00
0.5yr	1.577E+07	9.052E-03	1.809E-02	8.840E-02	5.171E-01	1.401E+00	4.095E+00
1yr	3.154E+07	5.319E-03	1.063E-02	5.223E-02	3.074E-01	8.568E-01	2.580E+00
2yr	6.307E+07	2.248E-03	4.495E-03	2.213E-02	1.305E-01	3.682E-01	1.123E+00
5yr	1.577E+08	2.014E-04	4.025E-04	1.983E-03	1.171E-02	3.320E-02	1.019E-01
10yr	3.154E+08	7.434E-06	1.486E-05	7.380E-05	4.393E-04	1.361E-03	4.593E-03
20yr	6.307E+08	3.208E-06	6.419E-06	3.209E-05	1.924E-04	6.392E-04	2.324E-03
30yr	9.461E+08	2.763E-06	5.525E-06	2.762E-05	1.657E-04	5.505E-04	2.002E-03

Table 12

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 27 VOLUME= 2.57223E+05 CM^3

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0
Tcool	Tcool (sec)						
1sec	1.000E+00	8.726E-01	9.274E-01	1.129E+00	1.413E+00	1.607E+00	2.113E+00
1min	6.000E+01	7.975E-01	8.521E-01	1.051E+00	1.338E+00	1.531E+00	2.038E+00
10min	6.000E+02	6.387E-01	6.925E-01	8.853E-01	1.178E+00	1.369E+00	1.878E+00
0.5hr	1.800E+03	4.932E-01	5.457E-01	7.301E-01	1.030E+00	1.219E+00	1.730E+00
1hr	3.600E+03	3.784E-01	4.288E-01	6.040E-01	9.119E-01	1.099E+00	1.611E+00
2hr	7.200E+03	2.646E-01	3.116E-01	4.743E-01	7.919E-01	9.762E-01	1.491E+00
4hr	1.440E+04	1.599E-01	2.021E-01	3.499E-01	6.790E-01	8.609E-01	1.380E+00
6hr	2.160E+04	1.139E-01	1.524E-01	2.896E-01	6.225E-01	8.017E-01	1.321E+00
12hr	4.320E+04	5.461E-02	8.689E-02	2.053E-01	5.432E-01	7.174E-01	1.240E+00
1day	8.640E+04	3.227E-02	5.887E-02	1.606E-01	4.913E-01	6.608E-01	1.185E+00
2days	1.728E+05	2.326E-02	4.416E-02	1.306E-01	4.376E-01	6.028E-01	1.126E+00
7days	6.048E+05	1.176E-02	2.297E-02	7.670E-02	2.941E-01	4.433E-01	9.599E-01
30d	2.592E+06	2.713E-03	5.374E-03	2.211E-02	1.069E-01	2.130E-01	6.993E-01
0.5yr	1.577E+07	5.211E-04	1.041E-03	5.089E-03	2.977E-02	8.074E-02	4.138E-01
1yr	3.154E+07	3.068E-04	6.131E-04	3.013E-03	1.773E-02	4.943E-02	2.679E-01
2yr	6.307E+07	1.298E-04	2.595E-04	1.278E-03	7.536E-03	2.126E-02	1.190E-01
5yr	1.577E+08	1.162E-05	2.323E-05	1.145E-04	6.756E-04	1.916E-03	1.216E-02
10yr	3.154E+08	4.242E-07	8.483E-07	4.211E-06	2.506E-05	7.758E-05	1.702E-03
20yr	6.307E+08	1.812E-07	3.625E-07	1.812E-06	1.087E-05	3.610E-05	1.277E-03
30yr	9.461E+08	1.560E-07	3.120E-07	1.560E-06	9.356E-06	3.109E-05	1.106E-03

Table 13

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 28 VOLUME= 1.56782E+05 CM^3

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0
Tcool	Tcool (sec)						
1sec	1.000E+00	3.901E+00	4.145E+00	5.043E+00	6.310E+00	7.173E+00	8.235E+00
1min	6.000E+01	3.566E+00	3.810E+00	4.697E+00	5.975E+00	6.835E+00	7.901E+00
10min	6.000E+02	2.858E+00	3.098E+00	3.957E+00	5.262E+00	6.113E+00	7.187E+00
0.5hr	1.800E+03	2.209E+00	2.443E+00	3.265E+00	4.602E+00	5.444E+00	6.527E+00
1hr	3.600E+03	1.695E+00	1.920E+00	2.702E+00	4.073E+00	4.907E+00	5.998E+00
2hr	7.200E+03	1.186E+00	1.396E+00	2.121E+00	3.537E+00	4.359E+00	5.460E+00
4hr	1.440E+04	7.163E-01	9.045E-01	1.563E+00	3.030E+00	3.842E+00	4.959E+00
6hr	2.160E+04	5.102E-01	6.815E-01	1.293E+00	2.777E+00	3.576E+00	4.697E+00
12hr	4.320E+04	2.438E-01	3.877E-01	9.154E-01	2.421E+00	3.198E+00	4.336E+00
1day	8.640E+04	1.438E-01	2.623E-01	7.158E-01	2.190E+00	2.946E+00	4.094E+00
2days	1.728E+05	1.036E-01	1.968E-01	5.820E-01	1.950E+00	2.687E+00	3.834E+00
7days	6.048E+05	5.242E-02	1.024E-01	3.418E-01	1.311E+00	1.976E+00	3.105E+00
30d	2.592E+06	1.210E-02	2.396E-02	9.859E-02	4.767E-01	9.500E-01	2.005E+00
0.5yr	1.577E+07	2.326E-03	4.648E-03	2.272E-02	1.329E-01	3.604E-01	1.054E+00
1yr	3.154E+07	1.370E-03	2.737E-03	1.345E-02	7.916E-02	2.207E-01	6.648E-01
2yr	6.307E+07	5.796E-04	1.159E-03	5.705E-03	3.365E-02	9.492E-02	2.896E-01
5yr	1.577E+08	5.189E-05	1.037E-04	5.110E-04	3.016E-03	8.554E-03	2.624E-02
10yr	3.154E+08	1.892E-06	3.783E-06	1.878E-05	1.118E-04	3.460E-04	1.166E-03
20yr	6.307E+08	8.072E-07	1.615E-06	8.073E-06	4.842E-05	1.608E-04	5.847E-04
30yr	9.461E+08	6.951E-07	1.390E-06	6.949E-06	4.168E-05	1.385E-04	5.038E-04

Table 14

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 29 VOLUME= 1.56782E+05 CM^3

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0	
Tcool	Tcool (sec)							
1sec	1.000E+00	2.978E+00	3.164E+00	3.846E+00	4.809E+00	5.466E+00	6.275E+00	7.188E+00
1min	6.000E+01	2.723E+00	2.909E+00	3.583E+00	4.554E+00	5.209E+00	6.021E+00	6.934E+00
10min	6.000E+02	2.184E+00	2.367E+00	3.020E+00	4.012E+00	4.660E+00	5.478E+00	6.391E+00
0.5hr	1.800E+03	1.690E+00	1.868E+00	2.493E+00	3.509E+00	4.151E+00	4.975E+00	5.887E+00
1hr	3.600E+03	1.298E+00	1.470E+00	2.064E+00	3.106E+00	3.741E+00	4.572E+00	5.483E+00
2hr	7.200E+03	9.092E-01	1.069E+00	1.620E+00	2.696E+00	3.322E+00	4.161E+00	5.072E+00
4hr	1.440E+04	5.485E-01	6.917E-01	1.192E+00	2.307E+00	2.925E+00	3.776E+00	4.689E+00
6hr	2.160E+04	3.903E-01	5.206E-01	9.857E-01	2.113E+00	2.722E+00	3.575E+00	4.486E+00
12hr	4.320E+04	1.858E-01	2.951E-01	6.963E-01	1.841E+00	2.432E+00	3.299E+00	4.209E+00
1day	8.640E+04	1.093E-01	1.993E-01	5.440E-01	1.664E+00	2.239E+00	3.114E+00	4.023E+00
2days	1.728E+05	7.875E-02	1.495E-01	4.423E-01	1.482E+00	2.043E+00	2.917E+00	3.824E+00
7days	6.048E+05	3.984E-02	7.778E-02	2.598E-01	9.966E-01	1.503E+00	2.363E+00	3.260E+00
30d	2.592E+06	9.199E-03	1.822E-02	7.498E-02	3.626E-01	7.230E-01	1.527E+00	2.377E+00
0.5yr	1.577E+07	1.772E-03	3.541E-03	1.731E-02	1.012E-01	2.746E-01	8.030E-01	1.408E+00
1yr	3.154E+07	1.044E-03	2.086E-03	1.025E-02	6.031E-02	1.682E-01	5.065E-01	9.113E-01
2yr	6.307E+07	4.417E-04	8.829E-04	4.347E-03	2.564E-02	7.233E-02	2.207E-01	4.048E-01
5yr	1.577E+08	3.954E-05	7.903E-05	3.894E-04	2.298E-03	6.518E-03	2.000E-02	4.136E-02
10yr	3.154E+08	1.440E-06	2.879E-06	1.429E-05	8.505E-05	2.632E-04	8.873E-04	5.764E-03
20yr	6.307E+08	6.133E-07	1.227E-06	6.134E-06	3.679E-05	1.222E-04	4.443E-04	4.324E-03
30yr	9.461E+08	5.281E-07	1.056E-06	5.280E-06	3.167E-05	1.052E-04	3.828E-04	3.744E-03

Table 15

RESIDUAL DOSE RATE (mSv/hr) IN A TISSUE-EQUIVALENT BODY ON CONTACT WITH MATERIAL IM = 30 VOLUME= 4.64016E+05 CM^3

AT AINT = 6.250E+12 P/SEC

IRRADIATION TIME (day) =	0.5	1.0	5.0	30.0	100.0	365.0	7300.0
Tcool	Tcool (sec)						
1sec	1.000E+00	1.695E+00	1.799E+00	2.169E+00	2.691E+00	3.055E+00	4.013E+00
1min	6.000E+01	1.557E+00	1.660E+00	2.026E+00	2.553E+00	2.916E+00	3.875E+00
10min	6.000E+02	1.261E+00	1.364E+00	1.718E+00	2.255E+00	2.615E+00	3.577E+00
0.5hr	1.800E+03	9.870E-01	1.086E+00	1.426E+00	1.976E+00	2.332E+00	3.297E+00
1hr	3.600E+03	7.661E-01	8.614E-01	1.184E+00	1.749E+00	2.101E+00	3.069E+00
2hr	7.200E+03	5.406E-01	6.289E-01	9.282E-01	1.511E+00	1.858E+00	2.831E+00
4hr	1.440E+04	3.234E-01	4.019E-01	6.741E-01	1.278E+00	1.621E+00	2.603E+00
6hr	2.160E+04	2.278E-01	2.989E-01	5.517E-01	1.163E+00	1.499E+00	2.481E+00
12hr	4.320E+04	1.038E-01	1.631E-01	3.811E-01	1.002E+00	1.327E+00	2.317E+00
1day	8.640E+04	5.926E-02	1.080E-01	2.948E-01	9.027E-01	1.219E+00	2.214E+00
2days	1.728E+05	4.261E-02	8.093E-02	2.396E-01	8.042E-01	1.112E+00	2.106E+00
7days	6.048E+05	2.158E-02	4.215E-02	1.409E-01	5.417E-01	8.202E-01	1.800E+00
30d	2.592E+06	5.020E-03	9.945E-03	4.100E-02	1.987E-01	3.980E-01	1.321E+00
0.5yr	1.577E+07	9.860E-04	1.970E-03	9.632E-03	5.635E-02	1.530E-01	7.857E-01
1yr	3.154E+07	5.824E-04	1.164E-03	5.719E-03	3.366E-02	9.389E-02	5.090E-01
2yr	6.307E+07	2.468E-04	4.935E-04	2.430E-03	1.433E-02	4.043E-02	2.261E-01
5yr	1.577E+08	2.209E-05	4.415E-05	2.175E-04	1.284E-03	3.641E-03	1.117E-02
10yr	3.154E+08	7.907E-07	1.581E-06	7.847E-06	4.670E-05	1.443E-04	4.859E-04
20yr	6.307E+08	3.315E-07	6.632E-07	3.315E-06	1.988E-05	6.604E-05	2.401E-04
30yr	9.461E+08	2.854E-07	5.708E-07	2.853E-06	1.712E-05	5.687E-05	2.023E-04