ORNL/TM-2024/3282

REDUCED GEOMETRY FOR THE NB5 VELOCITY SELECTOR SHIELDING BOX

Kyle B Grammer

February 15, 2024

OAK RIDGE National Laboratory

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Neutron Technologies Division

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Oak Ridge, TN 37831
managed by
UT-BATTELLE LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

DEPENDENT SOURCE VERIFICATION FOR THE NB5 BEAMLINE

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	REV 0	REV 1	REV 2	REV 3
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LIST OF ABBREVIATIONS

CGH Cold Guide Hall

HFIR High Flux Isotope Reactor

NB5 neutron beamline 5

ABSTRACT

This report details the reduced NB5 velocity selector shielding box that has been isolated from the complete HFIR CGH model in order to speed up detailed calculations of the velocity selector shielding. This shielding model is intended for outsourcing shielding optimization calculations.

1. INTRODUCTION

This report discusses the reduced geometry of the NB5 velocity selector box and the nearby geometry relevant to this box. The rest of the geometry in the Cold Guide Hall (CGH) at the High Flux Isotope Reactor (HFIR) has been removed except for a floor and surrounding air. This geometry can be used with the S3 source from the report ORNL/TM-2024/3274 [2] for MCNP 6.2 [3].

The original geometry can be seen in figure 1, which shows the common shielding concrete (brown) and the velocity selector shielding for the neighboring neutron beamline. The reduced geometry removes all of this concrete shielding and the neighboring beamline.

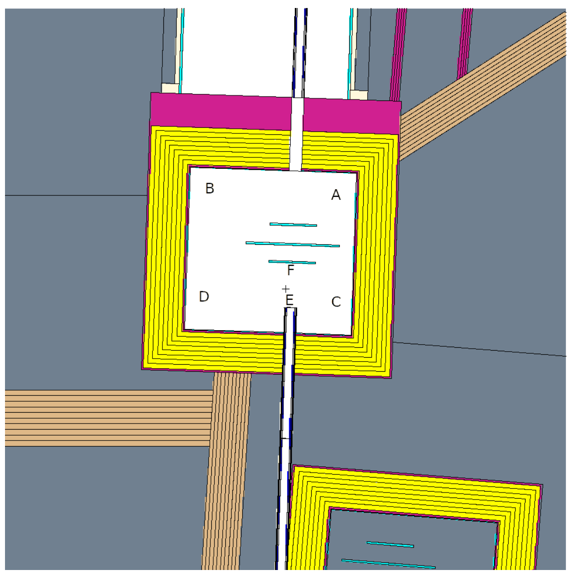

Figure 1. NB5 velocity selector shielding box. Neutrons enter from the guide penetration on the bottom. The adjacent NB4 velocity selector shielding is seen at the bottom.

The annotations in this figure are the same as in the source verification report (ORNL/TM-2024/3274 [2]) and these points will be used for verification purposes to establish that this geometry adequately represents the interior of the velocity selector shielding box.

- **Point A.** The downstream beam right corner after the velocity selector, at (-107.5, 0, 3502.5).
- **Point B.** The downstream beam left corner after the velocity selector, at (-37.5, 0, 3502.5).
- **Point C.** The upstream beam left corner before the velocity selector, at (-107.5, 0, 3442.5).
- **Point D.** The upstream beam right corner before the velocity selector, at (-37.5, 0, 3442.5).
- **Point E.** The end of the last guide segment at the beam window, at (-82.5, 0, 3442.5).
- **Point F.** The first boron carbide plate, representing the shutter, at (-82.5, 0, 3462.5).

1.1 REDUCED GEOMETRY FOR COMPARISON

The reduced geometry has also been constructed for simulating the NB5 velocity selector shielding without the rest of the HFIR CGH. A calculation with this geometry is also compared to the result of the calculation suite to verify that it adequately represents the region of the NB5 velocity selector shielding. The horizontal slice (fig. 2) contains the last guide segment, the velocity selector, and the first collimator box after the velocity selector along with a single guide segment inside it. The vertical slice (fig. 3) shows just the shielding volume and the floor. This geometry has been used for a test calculation using S3 in order to verify that it is consistent and the dose maps can be found at figures 9 and 10 and should be compared to figures 7 and 8 (the S0 calculation from [2]).

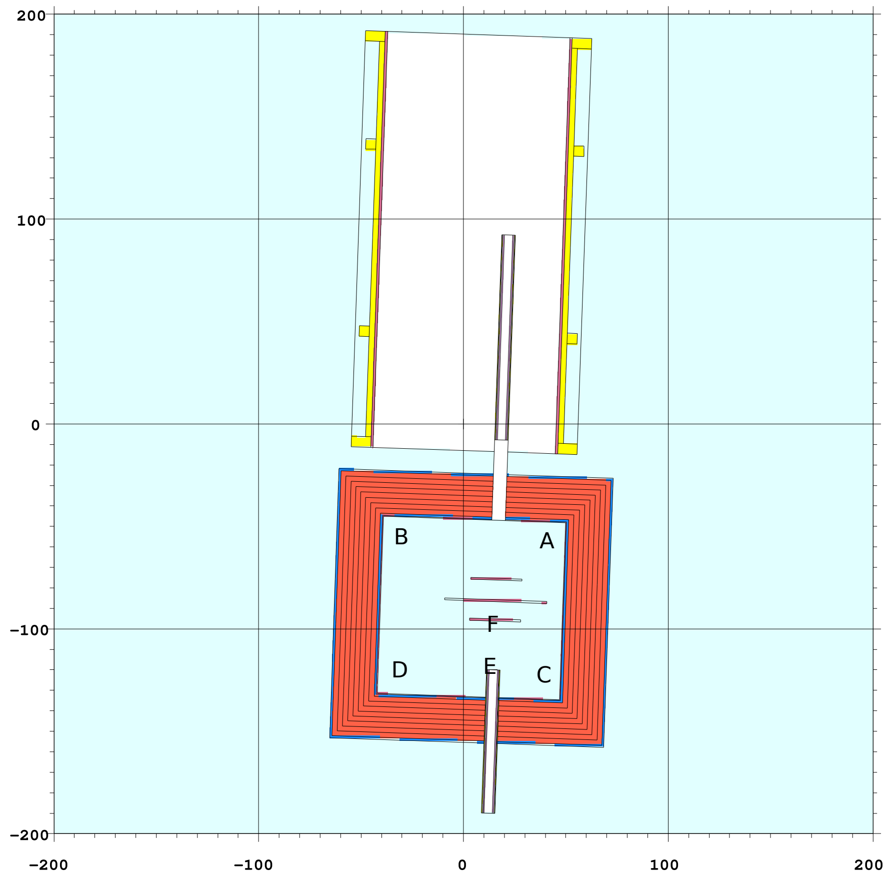

Figure 2. Horizontal slice through the NB5 velocity selector shielding box for the reduced configuration.

1.2 REDUCED GEOMETRY WITH REALISTIC VELOCITY SELECTOR

The realistic velocity selector geometry replaces the placeholder geometry of the velocity selector itself with a representative geometry for the velocity selector and its housing and removes the boron carbide shutter plates from the interior of the shielding box. This is the geometry intended for calculations and optimization of the velocity selector shielding box materials. The configuration of the guides and downstream collimator vessel is representative of the to-be-built geometry in this configuration (figs. 4 and 5).

The velocity selector contains a 25 cm long rotor that exposes absorbing material to the neutron beam. The inner radius of the absorber is 8.5 cm and the outer radius is 14.5 cm (fig. 6). The center shaft is comprised

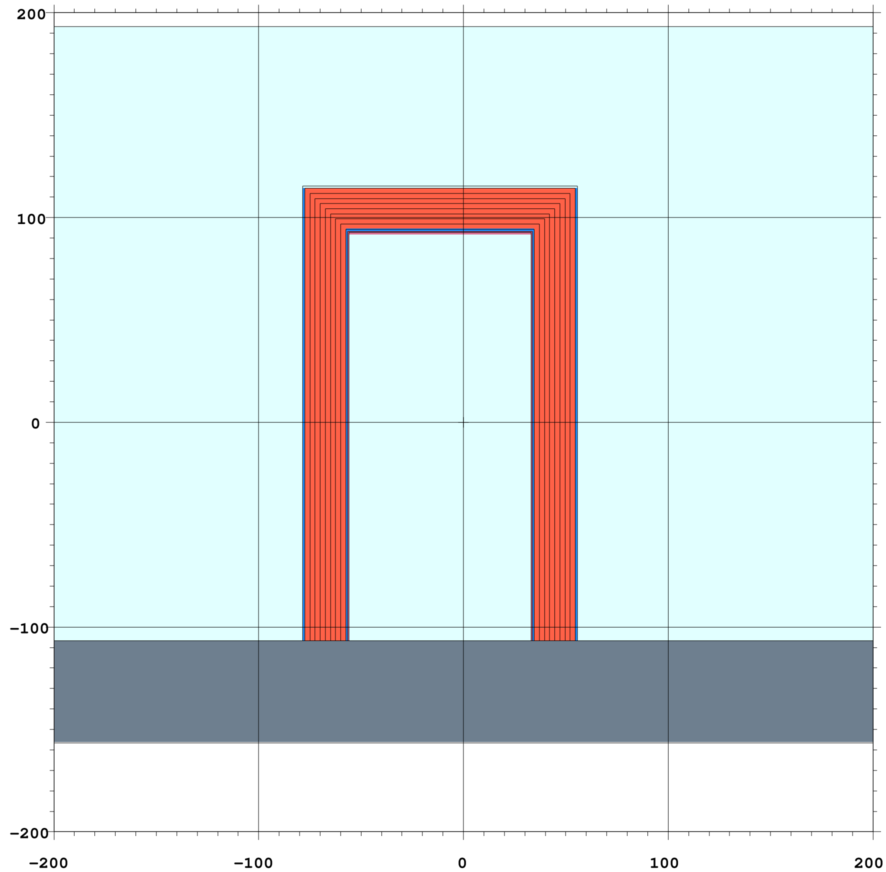

Figure 3. Vertical slice through the NB5 velocity selector shielding box for the reduced configuration.

of aluminum. The absorber is surrounded by a vacuum jacket with 30.1 cm length and 16.5 cm radius and it is contained inside a housing of aluminum with thickness of 5 mm. The velocity selector is offset from the neutron beamline and exposes a boron containing material to the neutron beam. This material is a homogenized mixture of carbon fiber, epoxy, and boron-10 based on estimates that the blades are 70% carbon fiber and 30% epoxy [1] and comprised of a mixture of carbon, hydrogen, and oxygen with trace amounts of chlorine. Marketing literature states that the absorber coating is boron-10 with an areal density of 35 g/m^2. The density of the blades is approximately 1.65 g/cm^3, therefore the velocity selector material is diluted to 0.068413 g/cm^3 by estimating the ratio of the total blade volume to the vacuum volume. The housing of the velocity selector is made of 5 mm thick aluminum. There is a 0.5 mm window along the neutron path.

Table 1. Average neutron and photon dose rates in mrem/hr at 6 points inside the velocity selector box for S0 and the reduced geometry using S3 (RS3) [2]

ID	X	Z	Neutron S0	Photon S0	Neutron RS3	Photon RS3
A	-107.5	3502.5	2.84e-01	9.67e+02	5.79e-01	9.68e+02
B	-37.5	3502.5	1.35e+01	6.22e+02	1.54e+01	6.21e+02
C	-107.5	3442.5	3.23e+02	4.29e+03	3.39e+02	4.37e+03
D	-37.5	3442.5	7.66e+01	1.26e+03	7.32e+01	1.27e+03
E	-82.5	3442.5	5.94e+05	7.45e+04	5.92e+05	7.42e+04
F	-82.5	3462.5	3.15e+05	7.92e+04	3.13e+05	7.89e+04

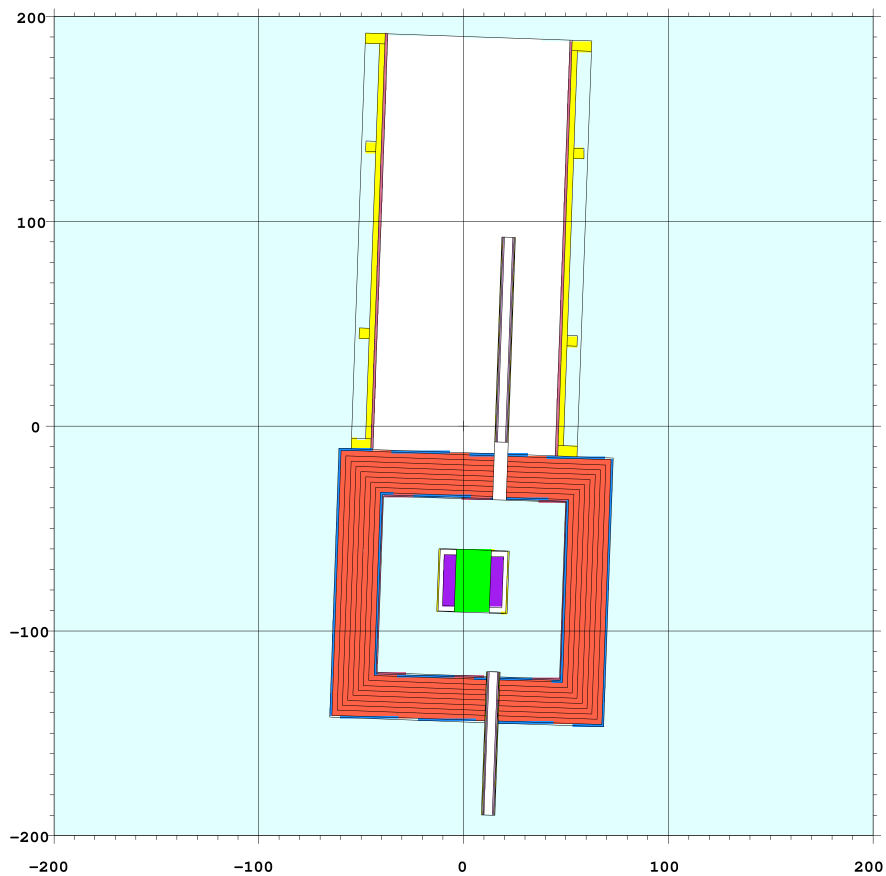

Figure 4. Horizontal slice through the NB5 velocity selector shielding box for the realistic configuration calculation configuration.

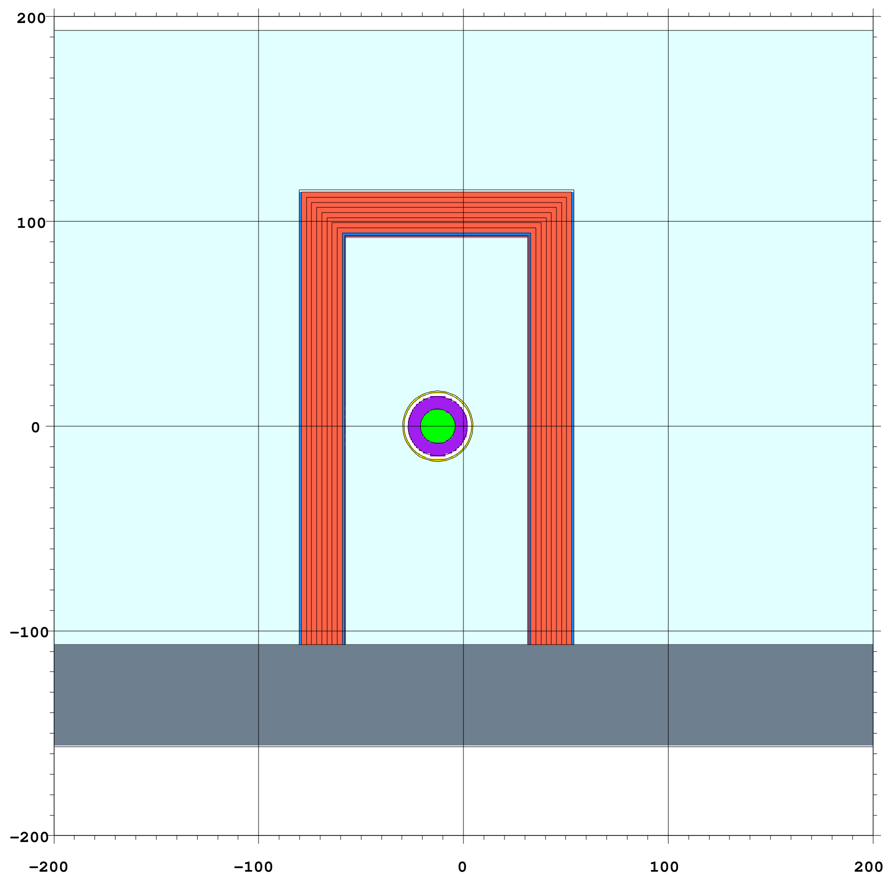

Figure 5. Vertical slice through the NB5 velocity selector shielding box for the realistic configuration calculation configuration.

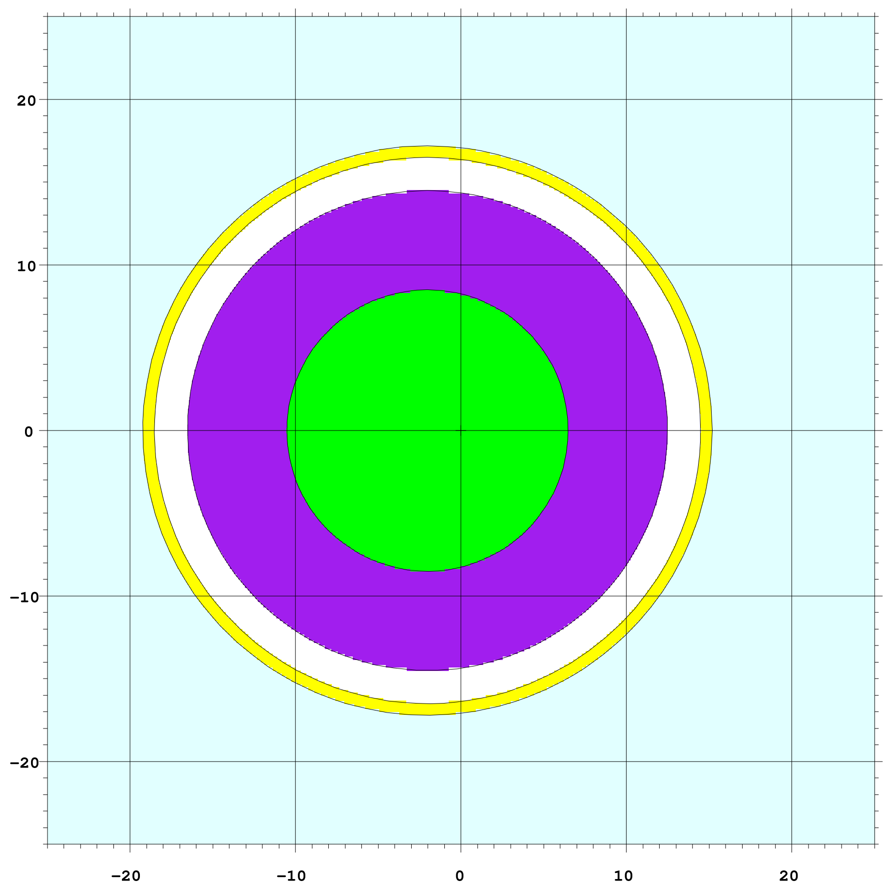

Figure 6. Vertical slice through the NB5 velocity selector showing the absorber, center shaft, vacuum jacket, and housing.

2. SUMMARY

The table 1 indicates that dose calculations due to neutrons reaching the interior of the NB5 velocity selector shielding box can be performed with the tabulated S3 source [2] at the end of cell 30228, which is the last cell entering the box. Because there is good agreement for the reduced geometry and the S0 calculation for points A through F and for the lines along and perpendicular to the beam, the tabulated source and reduced geometry is acceptable for velocity selector shielding box calculations.

The appendix B contains a list of materials that should remain unchanged as the model evolves. They include aluminum structures, the velocity selector, and the neutron guides. Additionally, appendix C contains a list of cells that should remain unchanged. In particular, the velocity selector, guides, and collimator vessel should not be changed. Appendix D contains the neutron and photon dose functions that should be used.

The geometry intended for optimization runs is the realistic velocity selector geometry. In this geometry, the upstream face of the collimator vessel should remain fix and should match the external face of the velocity selector shielding box. The interior of the velocity selector shielding will also contain an instrument shutter between the last upstream guide segment and the velocity selector, though this is omitted from the geometry.

3. REFERENCES

[1] D. J. Dorsey, R. Hebner, and W. S. Charlton. “Non-Destructive Evaluation of Carbon Fiber Composite Reinforcement Content”. In: *Journal of Composite Materials* 38.17 (Sept. 2004), pp. 1505–1519. ISSN: 0021-9983. DOI: 10.1177/0021998304043753.

[2] Kyle Grammer. *ALTERNATIVE SOURCE VERIFICATION FOR THE NB5 BEAMLINE*. Tech. rep. ORNL/TM-2024/3274. Sept. 2024.

[3] CJ Werner. “MCNP Users Manual-Code Version 6.2 (Report, LA-UR-17-29981)”. In: *New Mexico: Los Alamos National Laboratory* (2017).

APPENDIX A. DOSE MAPS

APPENDIX A. DOSE MAPS

Dose maps for each configuration are included below.

A.1 SOURCE 0 DOSE MAPS

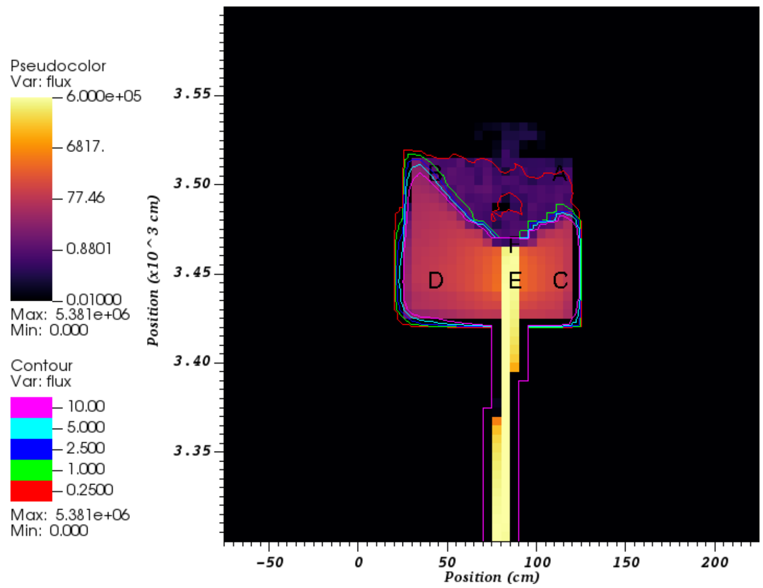

Figure 7. Source 0 neutron dose map. Neutron dose map for the primary moderator source calculation.

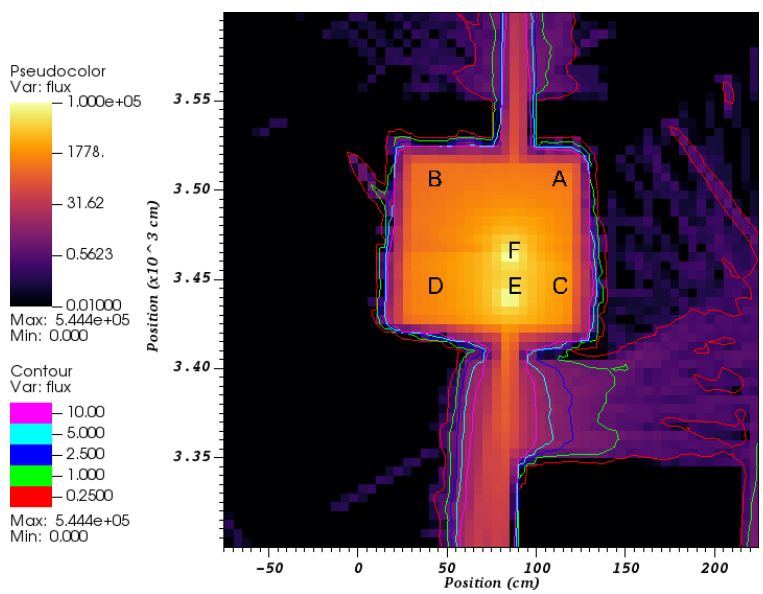

Figure 8. Source 0 photon dose map. Photon dose map for the primary moderator source calculation.

A.2 REDUCED GEOMETRY COMPARISON DOSE MAPS

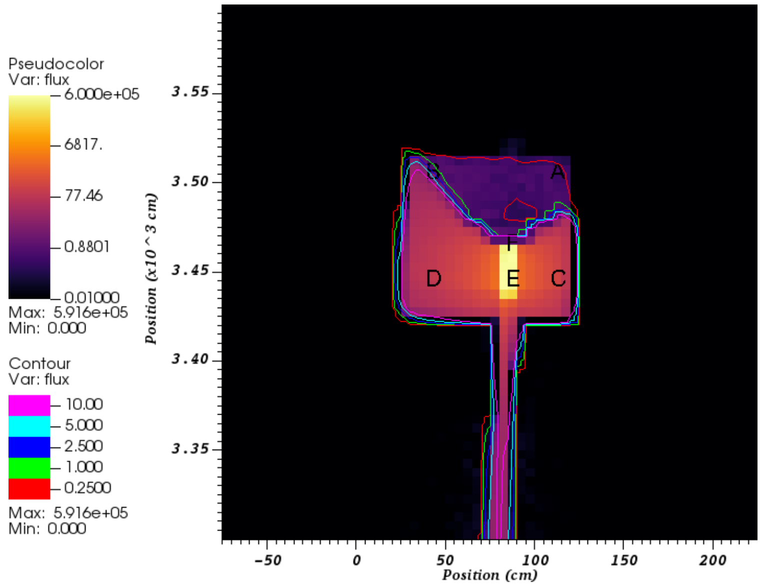

Figure 9. Reduced geometry comparison neutron dose map.

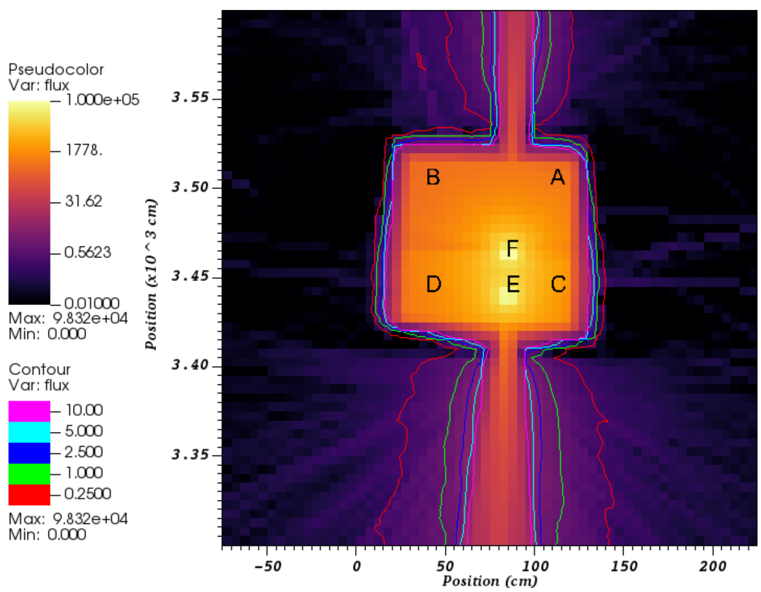

Figure 10. Reduced geometry comparison photon dose map.

A.3 REALISTIC CONFIGURATION DOSE MAPS

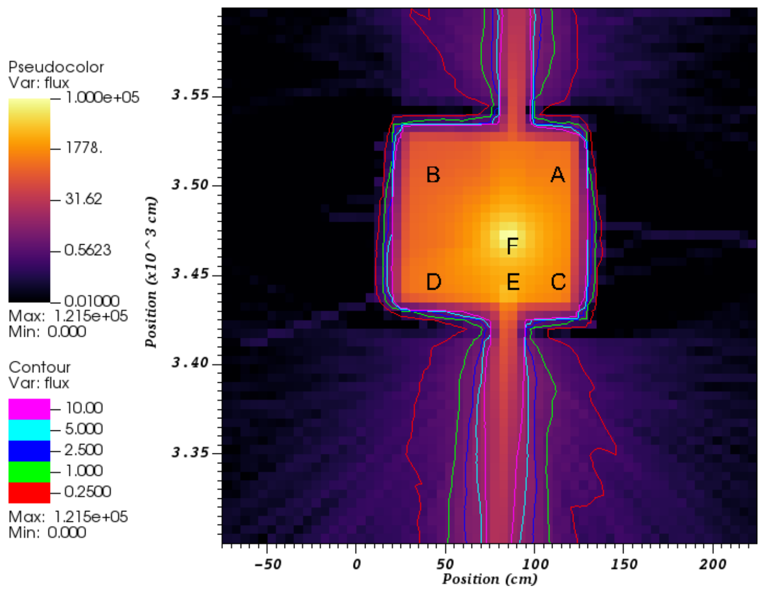

Figure 11. Realistic configuration geometry neutron dose map.

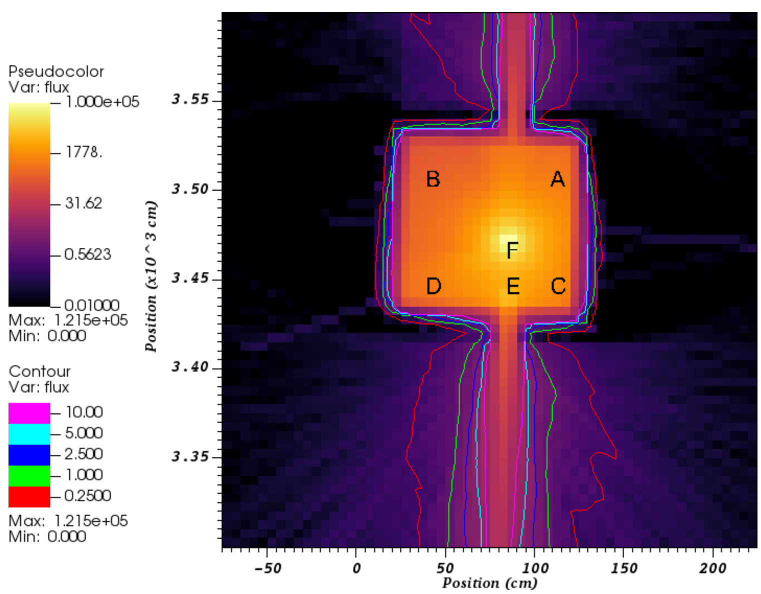

Figure 12. Realistic configuration geometry photon dose map.

APPENDIX B. MATERIALS

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The following are the materials that should remain fixed within realistic configuration calculations. The material libraries specified below are ENDFB-VII.1 at 293.6 K (`.80c`), `1001.90c` (erratum of ENDFB-VII.1 at 293.6 K), ENDFB-VIII.0 (.00c), ENDFB-VII.0 (`.70c`), ENDFB-VI at 293.6 K (`.60c`), ENDFB-VI.8 at 293.6K (`.62c`), ENDFB-V at 293.6K (`.50c` and `.55c`). All materials should be at room temperature.

B.1 AIR

The air used for the surrounding room air and for the interior of the shielding box should remain with this composition.

```
c air, 50% humid, 298K
c density -0.001177 g/cm3
m38    7014.80c -0.745149381541224
       7015.80c -0.002722252748816
       8016.80c -0.237553531746114
       8017.80c -9.04902333305166E-05
       8018.00c -0.000488170995599
       18040.80c -0.012756770312773
       6000.80c -0.000137681610312
       1001.90c -0.001085161446284
```

B.2 ALUMINUM 6061

Aluminum 6061 is used in the velocity selector housing as well as the downstream collimator box and it should remain as follows.

```
c aluminum 6061, PNNL-15870 Rev2
c density -2.71 g/cm3
m10    12000.62c -0.010000
       13027.80c -0.972000
       14000.60c -0.006000.80c
       22000.62c -0.000876
       24000.50c -0.001950
       25055.80c -0.000876
       26000.80c -0.004088
       29000.50c -0.002750
       30000.70c -0.001460
mt10       al27.12t
```

B.3 BOROFLOAT GLASS

Borofloat glass is the substrate of the guide cells upstream and downstream of the velocity selector and should remain as follows.

```
c borofloat glass
c density -2.2 g/cm3
m13    5010.80c 0.052
       5011.80c 0.208
       8016.80c 1.30
       11023.80c 0.08
       13027.80c 0.04
       14000.60c 0.81
```

B.4 BORON CARBIDE

Boron carbide is used in the downstream collimator box.

```
c boron carbide
c density -2.52 g/cm3
m15    6000.80c -0.21739
       5010.80c -0.144221
       5011.80c -0.638271
```

B.5 CONCRETE

Barytes concrete used for the building floor.

```
c barytes concrete
c density -3.11 g/cm3
m6     1001.90c 1.681e-2
       5010.80c 3.378e-4
       5011.80c 1.368e-3
       8016.80c 4.195e-2
       11023.80c 3.193e-4
       12000.62c 1.549e-4
       13027.80c 7.534e-4
       14000.60c 1.260e-3
       16032.80c 5.401e-3
       20000.62c 3.273e-3
       22000.62c 1.336e-4
       25055.80c 1.713e-4
       26000.55c 6.875e-4
       56138.80c 5.394e-3
```

B.6 VELOCITY SELECTOR MATERIAL

The velocity selector material is a boron loaded absorber.

```
c velocity selector material - diluted
c density -0.068413 g/cm3
m40    6000.80c -8.3834
       1001.90c -0.113815
       8016.80c -0.2606
       17035.80c -0.18063
       17037.80c -0.19075
       5010.80c -1.0922
```

APPENDIX C. CELLS THAT SHOULD REMAIN STATIC

APPENDIX C. CELLS THAT SHOULD REMAIN STATIC

The materials of the following cells should remain static. In some cases, the dimensions should never change (guide pieces, collimator vessel, and the velocity selector), but in other cases new shielding pieces will be cut from cells (such as building air). The surface definitions for these cells should not be altered.

Table 2. Cells that should remain static in all configurations

Cell(s)	Material number	Material	Density (g/cm^3)	Function
300-323	9	al 6061	2.71	Collimator vessel shell
324	0	vacuum	n/a	Collimator vessel vacuum
325	38	air	0.001177	Air surrounding collimator vessel
326	15	B4C	2.52	Boron carbide in collimator vessel
9990	6	concrete	3.11	Building floor
9991	38	air	0.001177	Building air
30228	0	vacuum	n/a	Guide segment interior
30229	13	glass	2.2	Guide segment glass
30230	0	vacuum	n/a	Guide segment vacuum jacket
30231	9	al 6061	2.71	Guide segment casing
30236	9	al 6061	2.71	Guide segment window
30237	0	vacuum	n/a	Guide segment interior
30238	13	glass	2.2	Guide segment glass
30239	0	vacuum	n/a	Guide segment vacuum jacket
30240	9	al 6061	2.71	Guide segment casing
35237	38	air	0.001177	Air inside velocity selector
35249	0	vacuum	n/a	Downstream guide penetration
36050	40	absorber	0.068413	Velocity selector
36051	10	al 6061	1.355	Velocity selector shaft
36052	0	vacuum	n/a	Velocity selector vacuum
36053	9	al 6061	2.71	Velocity selector casing
36054	0	vacuum	n/a	Velocity selector window

APPENDIX D. DOSE CONVERSION FUNCTIONS

APPENDIX D. DOSE CONVERSION FUNCTIONS

The following list is the energy and coefficient list to convert neutron flux to dose into mrem/hr.

```
c      energy   neutron ftd into mrem/hr
mshmf1 0.00        3.2700E-03
4.1400E-07  3.2700E-03
1.1200E-06  4.4620E-03
3.0600E-06  4.9090E-03
1.0700E-05  5.3200E-03
3.7300E-05  5.5730E-03
1.0100E-04  5.6070E-03
2.1400E-04  5.5250E-03
4.5400E-04  5.4040E-03
1.5800E-03  5.2660E-03
3.3500E-03  5.3020E-03
1.5000E-02  6.2700E-03
2.1900E-02  7.7770E-03
2.4200E-02  8.5530E-03
3.1800E-02  9.3970E-03
5.2500E-02  1.1830E-02
1.1100E-01  1.8640E-02
1.5800E-01  2.7440E-02
2.4700E-01  3.7850E-02
3.6800E-01  5.1870E-02
4.9800E-01  6.5810E-02
6.0800E-01  7.6820E-02
7.4300E-01  8.6120E-02
8.2100E-01  9.3110E-02
1.1100E+00  1.0270E-01
1.4200E+00  1.1510E-01
1.8300E+00  1.2570E-01
2.2300E+00  1.3430E-01
2.3500E+00  1.3860E-01
2.4700E+00  1.4030E-01
3.0100E+00  1.4430E-01
3.6800E+00  1.4990E-01
4.9700E+00  1.5570E-01
6.0600E+00  1.6020E-01
7.4100E+00  1.6290E-01
8.6100E+00  1.6470E-01
1.0000E+01  1.6580E-01
1.2200E+01  1.6670E-01
1.4200E+01  1.6720E-01
1.4900E+01  1.6730E-01
1.6900E+01  1.6730E-01
1.9600E+01  1.6720E-01
2.5000E+01  1.6670E-01
3.0000E+01  1.6600E-01
```

```
4.0000E+01  1.6490E-01
5.0000E+01  1.6310E-01
6.0000E+01  1.6200E-01
7.0000E+01  1.6370E-01
8.0000E+01  1.6530E-01
1.0000E+02  1.6560E-01
1.2000E+02  1.6440E-01
1.4000E+02  1.6980E-01
1.5000E+02  1.7370E-01
1.6000E+02  1.7630E-01
1.8000E+02  1.8010E-01
2.0000E+02  1.8510E-01
2.2500E+02  1.9060E-01
2.5000E+02  1.9670E-01
2.7500E+02  2.0270E-01
3.0000E+02  2.0870E-01
3.2500E+02  2.1470E-01
3.5000E+02  2.2060E-01
3.7500E+02  2.2640E-01
4.0000E+02  2.3220E-01
4.5000E+02  2.4090E-01
5.0000E+02  2.5230E-01
5.5000E+02  2.6350E-01
6.0000E+02  2.7460E-01
6.5000E+02  2.8550E-01
7.0000E+02  2.9630E-01
7.5000E+02  3.0690E-01
8.0000E+02  3.1730E-01
8.5000E+02  3.2760E-01
9.0000E+02  3.3760E-01
9.5000E+02  3.4750E-01
1.0000E+03  3.5720E-01
1.1000E+03  3.7140E-01
1.2000E+03  3.8980E-01
1.3000E+03  4.0750E-01
1.4000E+03  4.2450E-01
1.5500E+03  4.4480E-01
1.7000E+03  4.6790E-01
1.8500E+03  4.8970E-01
2.0000E+03  5.1030E-01
c
```

The following list is the energy and coefficient list to convert photon flux to dose into mrem/hr.

```
c      energy   gamma ftd into mrem/hr
mshmf2  1.00E-01   2.8000E-04
2.00E-01   2.8510E-04
4.00E-01   5.3710E-04
1.00E+00   1.2710E-03
```

```
1.50E+00   2.1070E-03
2.00E+00   2.7200E-03
2.50E+00   3.2500E-03
3.00E+00   3.7300E-03
3.50E+00   4.3660E-03
4.00E+00   4.3660E-03
4.50E+00   5.1600E-03
5.00E+00   5.1600E-03
5.50E+00   5.9170E-03
6.00E+00   5.9170E-03
6.50E+00   6.6630E-03
7.00E+00   6.6630E-03
7.50E+00   7.3840E-03
8.00E+00   7.3840E-03
1.00E+01   8.4660E-03
1.20E+01   9.9400E-03
1.40E+01   1.1430E-02
2.00E+01   1.4440E-02
1.00E+03   1.4440E-02
c
```