Division of Compensation Analysis and Support Technical Information Bulletin	Document Number: DCAS-TIB-0010 Effective Date: 06/18/2010 Revision No. 3
Best Estimate External Dose Reconstruction for Glovebox Workers	**Page 1 of 39**
Approval: Signature on file J.W. Neton, Associate Director for Science **Date: 06/18/2010**	**Supersedes: Rev. 02**

RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
5/18/2005	5/18/2005	1	Updated document to provide methodology and guidance on applying correction factors to glovebox workers for over and under estimation of dose.
12/30/2005	12/30/2005	02	Modified to provide best estimate approach.
06/18/2010	6/18/2010	03	Revised to expand the purpose section; clarified the use of ATTILA for geometric analysis only; standardized tables and graphs; and discussed organs affected by the process. Document number changed to reflect official name change from OCAS to DCAS. Incorporated SC&A review comments.

1.0 Purpose

The purpose of this technical information bulletin (TIB) is to provide guidance on dose reconstructions for glovebox workers. This TIB discusses the special exposure characteristics that may be encountered by energy employees who work with gloveboxes and provides special dose correction factors or modifiers that should be applied to affected energy employee's dose. It should be noted that throughout this technical information bulletin, the term glovebox is used, however, in the early years of the Atomic Energy Commission (AEC) facilities; these types of units were commonly called dry boxes as their original intent was to isolate radioactive materials. Throughout this report these terms should be considered equivalent.
A general approach for computation of a torso correction factor will be considered for a single glovebox using a radiation transport modeling software called ATTILA. Geometry is the variable of concern.

2.0 Special Exposure Considerations

Geometry deserves special consideration when conducting dose reconstructions for glovebox workers. Therefore the dose reconstructions affected by this TIB are those for cancers of the stomach, liver, bladder, prostate, ovaries, testes, genitalia, or other cancers that appear in the region of those organs. The degree of underestimation is dependent on the distance between the radiological source (exposure geometry), the materials used to construct the glovebox (attenuation or shielding), and the relative duration (time) that an energy employee conducted work in the glovebox. In general, very little is known about the duration of the exposure which is typically dependent upon the specific duties of the energy employee.

2.1 Exposure Geometry

Exposure geometry is a special consideration in dose reconstruction of energy employees who primarily worked in gloveboxes. An underestimation of the dose could occur if the energy employee wore his/her dosimeter on the lapel and not the center area of the chest or on the waist. This underestimation could result due to the difference in relative distance between the external radiation source, the organ of interest, and the dosimeter. Only organs in the lower torso are affected, since design of the glovebox places these organs closer to the radiological source than the dosimeter. The dose to lung is considered to have been reasonably approximated by the dosimeter at least to within the dosimeter uncertainty and the dose to the face and head would have been slightly lower than the dose measured by the dosimeter worn on the lapel.

2.2 Glovebox design

Low energy photons have a relatively low penetrating power and are easily attenuated. As a result, the design of the glovebox is an important consideration in accurately estimating the low energy photon dose. A review of the literature indicates that the design of gloveboxes varied widely.[1, 2] In some instances almost fully metal gloveboxes were used with only a small area for viewing (Figure 1), other gloveboxes had relatively large viewing areas (Figure 2-4), and others had a combination of multiple viewing areas with, in some designs, an opening that coincides with the center of the lower torso (Figure 5).

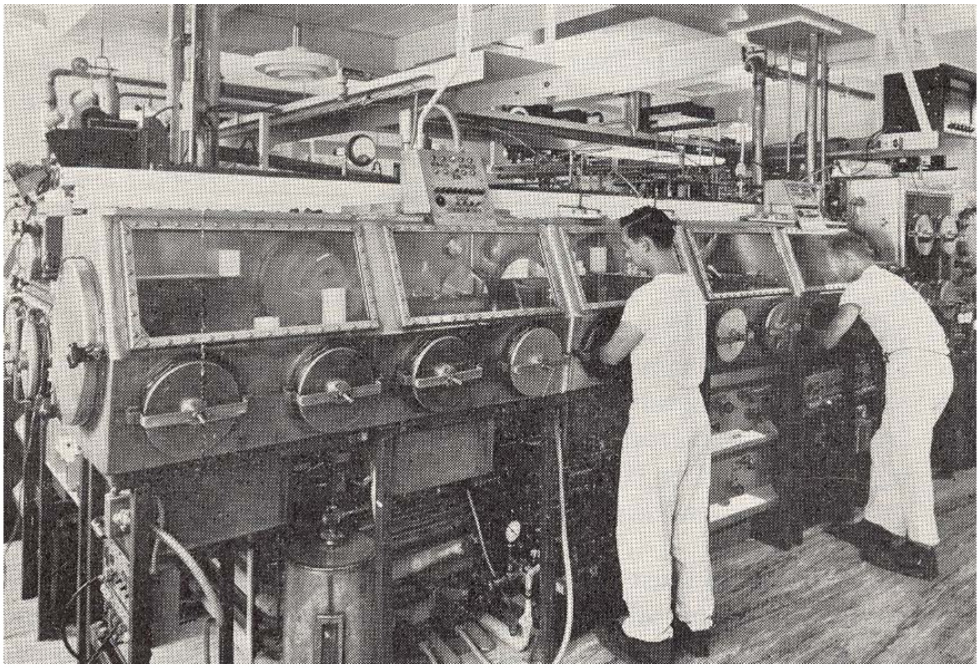

Figure 1 Plutonium gloveboxes at LANL [(1)]

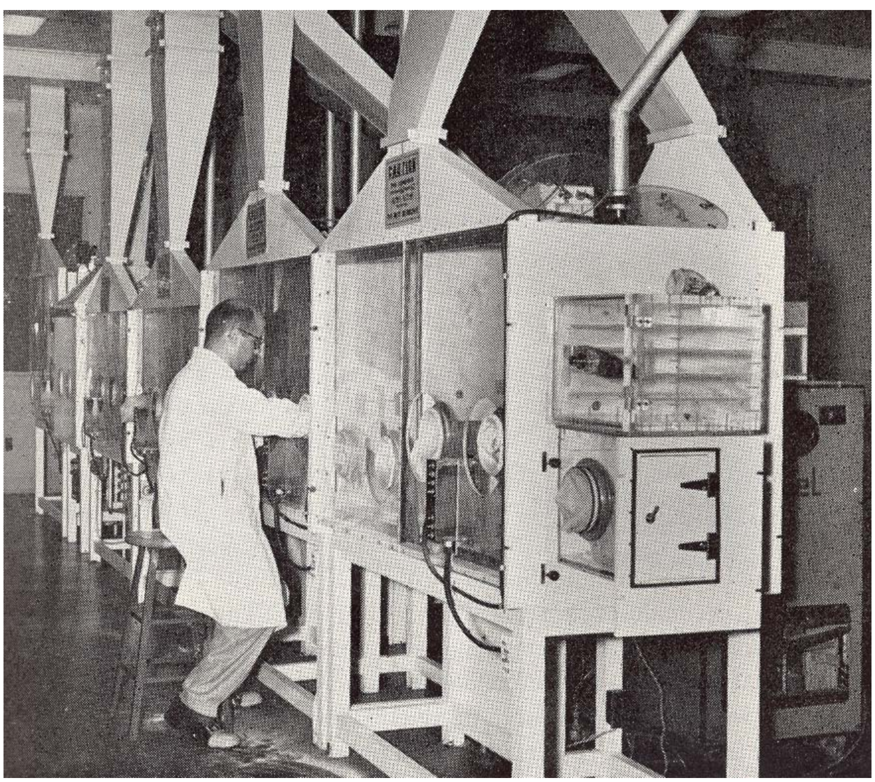

Figure 2 Plutonium gloveboxes at Chalk River [(1)]

Figure 3 Plutonium gloveboxes at Hanford [2]

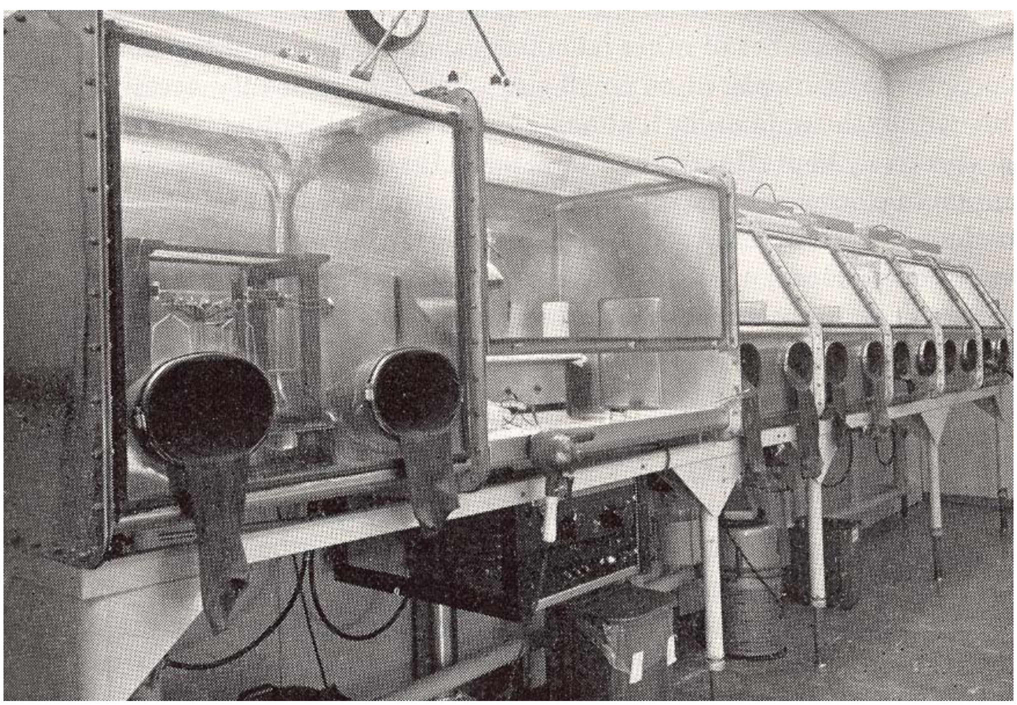

Figure 4 Plutonium gloveboxes at LANL's CMR facility [1]

Figure 5 Other plutonium gloveboxes at Hanford. Note the viewing area in direct line with the lower torso in the center between the gloves. (2)

Since the actual glovebox design is not known for each dose reconstruction scenario, a claimant favorable approach is used by assuming the glovebox had a large viewing face and the worker's lower torso was exposed more by elevation of the simulated worker as shown in the ATTILA figures. This is considered a reasonable but necessary claimant favorable assumption, since identifying the actual glovebox design at each facility (DOE site, building, room, etc.) would be time consuming. In addition, during the course of an energy employee's employment, it is likely that they conducted work in many different types of gloveboxes, thus a time dependent work location correction factor for each glovebox design would be necessary to account for such differences. The effect of this assumption is to overestimate the dose to the lower organs rather than an underestimate.

While the face (viewing area) of a glovebox was typically constructed using a clear polymer type material such as Lucite[3], the sides and bases of gloveboxes are almost always constructed of sturdy materials such as wood, aluminum, and most commonly steel. These materials generally shield an individual worker from side exposure to low energy photons. As a result the low energy photon dose is virtually 100% from the anterior- posterior exposure geometry due to the radiological materials in the specific glovebox where the energy employee conducted his/her work. On the other hand, the intermediate and high energy photon dose would be a combination of the direct work in the glovebox as well as surrounding gloveboxes and process lines.

3.0 Methodology

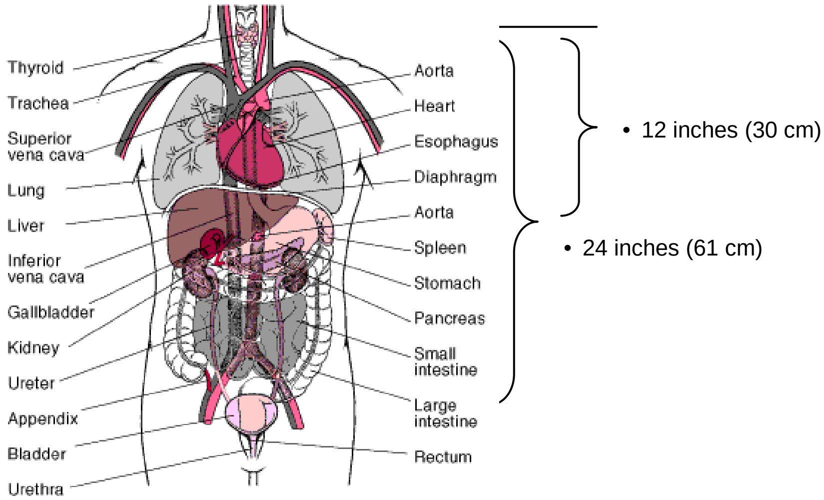

Figure 6 Diagram of Human Torso [4]

In the scenario used to develop a correction factor the radiation source was assumed to be directly in line with the specific organ of interest in the lower portion of the torso. To accurately estimate the underestimate of dose, the actual height of the glovebox and location of the source in relation to the energy employee's organ of interest and the distance to their lapel would be necessary (Figure 6). This analysis Used 24 inches as a reasonable claimant favorable assumption to simplify the calculation. In general, the correction factors for smaller stature workers would be less than those indicated in this technical information bulletin as the 24 inches is based on a moderately tall worker. In some instances, especially in the case of small stature workers, some of the organs could be below the bottom of the glovebox, thus low energy photons are virtually completely shielded (attenuated) and intermediate energy photons more attenuated than those measured on the dosimeter (Note the relative difference in worker stature in Figure 3).

As stated above, an average distance of 24 inches (61 cm) was assumed to be the distance between the lower torso and the lapel. The distance between the radiation source and the lower torso was assumed to vary from 6 inches to 18 inches. These distances were selected as the general range from which a worker could conduct most of their work in the glovebox. A source closer than 6 inches, while technically possible in some glovebox designs, is not very likely given the body location with respect to the glovebox. In some instances (Figure 2) a nearly straight down movement would be needed to position a source 6 inches from the lower torso. On the converse, 18 inches was selected as a reasonable upper distance. While some workers with longer arms might have been able to reach the back of the glovebox, a comfortable working distance for most workers would be between 10-14 inches between the source and the lower torso with a central tendency estimated at approximately 12 inches. This is used as the source distance.

At source distances greater than 48 inches, the relative difference between the dose to the lower torso and the lapel is less than 25% (factor 1.25) which is typically within the uncertainty of the dosimeter measurement. Thus the intermediate and high energy photon dose to the lower torso is approximately equal to the dose measured by the dosimeter on the lapel.

A model to determine the best-estimate correction factor for lower torso exposure to a glovebox worker was developed using modeling software called ATTILA. It is a multi-group deterministic radiation transport environment that can directly use Computer Aided Design (CAD) data and model complex geometry efficiently and accurately to solve large 3-D problems. Attila can solve neutron and photon transport equations and accounts for the same transport effects as Monte Carlo but is faster. Attila directly solves the differential form of the Boltzmann transport equation. A mesh is generated consisting of discrete points in space in the entire domain of the model. The transport equation is then solved for flux as a function of angle, energy and particle type, at every mesh point. Interpolation between mesh points is also performed.

The Attilla model's geometry and flux contours can be seen in Figure 7. The makeup of the glovebox is a stainless steel top, bottom and sides with a Lucite front face. This was deemed a more conservative, i.e. claimant favorable, design compared to boxes with partial stainless steel front faces. The human figure also provides for more of the lower torso to be exposed above the table top, again to be conservative.

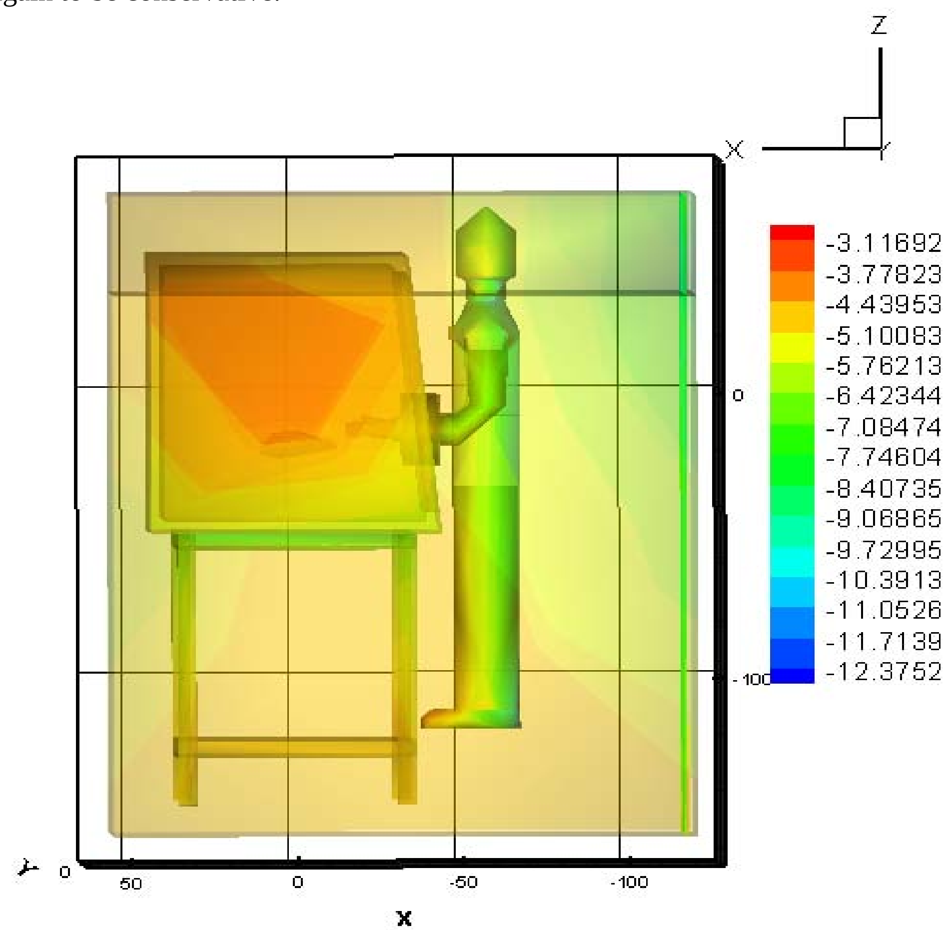

Figure 7 ATTILA model geometry and flux contours.

3.1 Data analysis

ATTILA calculates photon flux at all mesh points in the domain of the problem. In order to avoid selection bias from a single-point calculation, data was extracted at 30 points each in the regions A and B on a plane perpendicular to the x-axis corresponding to the surface of the body (Figure 8). Flux distributions for each region were then determined by CRYSTAL BALL software. The flux data from region A and B follow a lognormal distribution. The regions A and B correspond to upper torso and lower torso respectively.

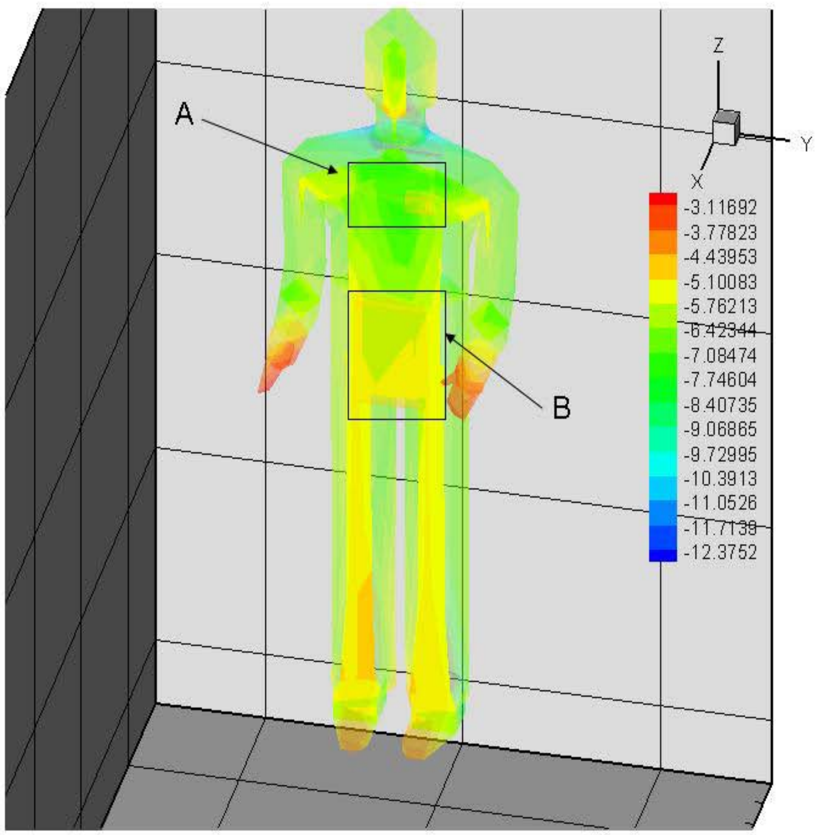

Figure 8 Data point selection regions. Various colors signify relative magnitude of flux across a selected plane on the x-axis.

Ratios between flux distributions in regions B and A formed another set of data for analysis by CRYSTAL BALL software.

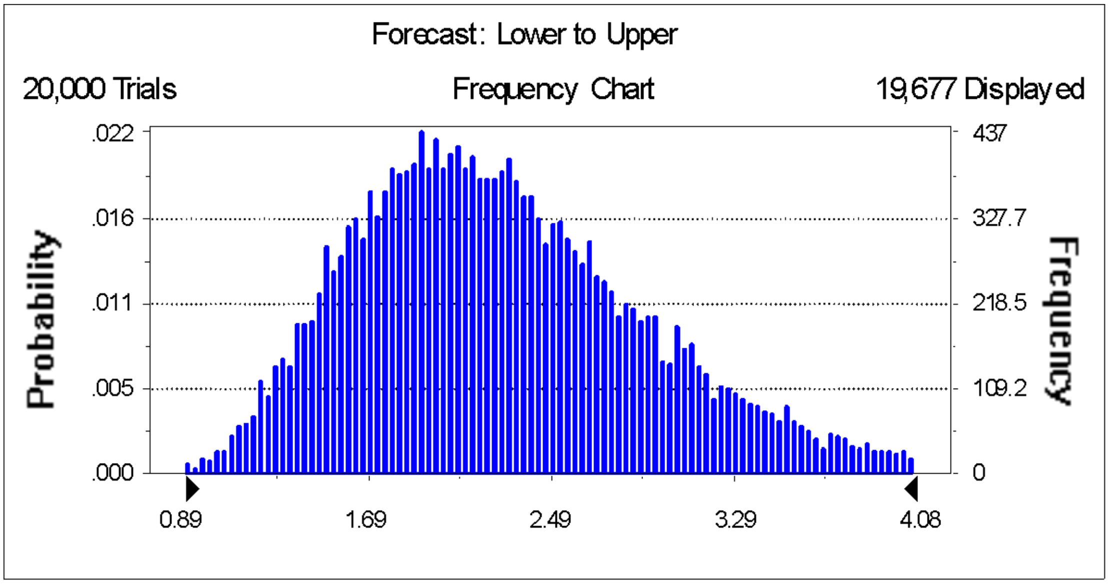

Figure 9 Distribution of lower torso to upper torso ratios

3.2 Results

An effort has been made to include the uncertainty of the dosimeter in the glovebox correction factor. There are two situations concerning such uncertainty, one where the combination of dosimeter reading and organ DCF is a constant and the other where that value is a normal distribution with+/-30% standard deviation.

3.2.1 Geometric mean and standard deviation when dosimeter uncertainty constant

The resulting distribution of ratios from ATTILA was determined to be lognormal (Figure 9) with a geometric mean of 2.19 and a geometric standard deviation of 1.34. This mean and standard deviation will be applied to the dosimeter reading for deep dose when dosimeter correction factor is considered constant, i.e. equal to 1.3.

3.2.2 Geometric Mean and standard deviation when dosimeter uncertainty is a distribution

The resultant geometric mean and standard deviation for the distribution produced (Figure 10) by CRYSTAL BALL when the lower-to-upper-torso distribution in Figure 9 is combined to a truncated normal dosimeter uncertainty distribution (only positive values are considered) is 2.3 and 1.13 respectively. This produces a glovebox correction factor that includes a dosimeter distribution uncertainty and is used when the dosimeter uncertainty of +/-30% needs to be considered.

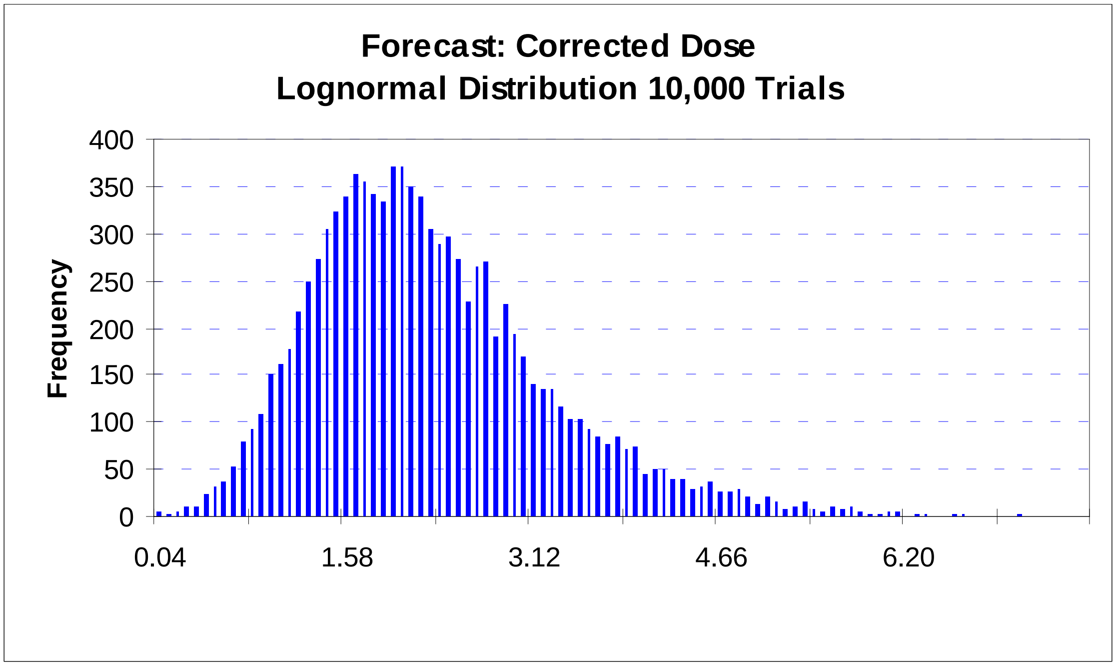

Figure 10 Combined distribution of lower-to-upper-torso ratio and dosimeter uncertainty

3.3 Reasonable Claimant Favorable Assumptions

Listed below are several claimant favorable assumptions used in the development of this methodology that could result in an overestimate of the actual dose.

- Claimant favorable glovebox design
- Direct line of sight to lower torso with Lucite as shielding
- Distance from lower torso to lapel based on tall workers

Obtaining data for precise evaluation of these parameters requires extensive time and research for each nuclear facility and in some instances the information cannot be obtained (e.g. facility has undergone D&D or other significant modification over time).

4.0 Applicability to Neutron Doses

The high energy photon correction factors described above may also be appropriate to measured neutron dose and potentially to some applications using neutron to photon (n-p) ratios. An evaluation of the applicability to neutron dose requires a site specific evaluation.

When a neutron to photon ratio method is used to estimate the neutron dose, it is important to know the general location of the photon and the neutron dosimeter. In the case of the Savannah River neutron to photon (n-p) ratios, the ratio was developed from joint measurement data of the TLD typically worn on the lapel and the neutron dosimeter (belly button dosimeter) worn around the waist. In this instance, the correction factor should not be applied since the measured neutron dose is a good representation of the dose to the lower torso. In later years, however, when the dosimeter combined photon and neutron TLD elements, a correction factor would need to be applied.

However at other facilities, if the NTA film dosimeter was worn on the lapel and a ratio was determined based on a photon dosimeter also worn on the lapel, then the correction factor should be applied. The most efficient method for doing so would be to apply the correction factor to the photon dose before applying the neutron to photon ratio.

5.0 Summary

This Technical Information Bulletin provides guidance for dose reconstruction to organs located in the lower torso. The correction factors for best-estimate of dose provided in Table 1 respectively are for photons emanating from gloveboxes and measured using a dosimeter worn on the lapel. The factors should be applied for all photon energies and doses recorded either as the shielded element of the dosimeter or as the deep dose. The choice of factor will depend on whether the 30% dosimeter uncertainty is to be folded in or not.

Table 1: Lower torso **best-estimate** dose and/or exposure rate correction factors for glovebox work.

Dosimeter Uncertainty Constant	Distribution	Geometric Mean	Geometric Standard Deviation
Yes	Lognormal	2.19	1.34
No	Lognormal	2.3	1.13

6.0 References

1. A. S. Coffinberry and W. N. Miner, The Metal Plutonium, The University of Chicago Press, Chicago, Illinois, 1961.

2. Office of Environmental Management, (1997) U.S. Department of Energy. Linking Legacies: Connecting the Cold War Nuclear Weapons Production Processes to Their Environmental Consequences, DOE/EM-0319, U.S. Department of Energy, Washington D.C.

3. Watson, E. C. (1959) A Film Technique for Measuring the Exposure Dose from Plutonium, *Health Physics*, Vol. 2 pp. 207.

4. Merck (2004), The Merck Manual – Second Home edition, illustration obtained at the following website. http://www.merck.com/mrkshared/mmanual_home2/fg/fg001_1.jsp

5 Grove Engineering (2002), Microshield Program version 5 User Manual, Rockville Maryland.

6. Decisioneering Inc. (2000), Crystal Ball 2000 User Manual, Denver Colorado.

7. 42 C.F.R pt 82, *Methods for Radiation Dose Reconstruction Under the Energy Employee Occupational Illness Compensation Program Act of 2000*; Final Rule, Federal Register/Vol.67, No. 85/Thursday, May 2, 2002, p 22314.

8. NIOSH, (2002) External Dose Reconstruction Implementation Guideline, Rev 1, OCAS-IG-001, National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support, Cincinnati, Ohio.

9. McGhee and Wareing. (2004) Attila™ Version 4: User's Manual, Radion Technologies Los Alamos, NM

Appendix A

Verification of ATTILA model using wrist and lapel monitoring data from the Rocky Flats Plant

Wrist and whole body exposure data from the Rocky Flats Plant (RFP) were collected and used as a means to validate the use of ATTILA in modeling flux distributions. The ratio of wrist to whole body exposure was determined and then compared to a calculated value based on modeling. Exposure data from approximately 960 claims submitted to the EEOICPA program were analyzed. The claims include glovebox and non glovebox workers. The data were separated into two distinct periods at RFP: 1953-1969 and 1977-2001. In order to calculate a ratio of wrist dose to whole-body gamma dose at RFP, the neutron dose component must be subtracted from the reported penetrating dose quantity. The ability to do this is dictated by the availability of independent neutron dose data. For the period 1953-1969 this data was available from the Neutron Dose Reconstruction Project (NDRP). The analysis of this period was restricted to employees who had their dose reconstructed under the NDRP study and who are also EEOICPA claimants. For the years 1977-2001, the neutron data is separately reported in the records provided by DOE. The analysis of this period was not limited to those employees who had their dose reconstructed under the NDRP study. Additional analysis assumptions are shown below:

- Annual, quarter, and cycle data were compared – the maximum value was used
- Dose data from 1970 was excluded due to issues discussed in NDRP report
- Analysis performed excluding deep dose < 30 mrem and then < 100 mrem to determine potential variability due to badge doses near LOD
- Excluded extremity values <= 0

For completeness, an analysis was also done on the NDRP data for the years 1971-1997.

In all cases, the resulting analysis of wrist to whole-body ratios fit lognormal distributions. The results are tabulated below in Table 2. For comparison, the NDRP protocol reported a wrist to whole-body ratio of 2.5 based on1957 data.

Table A1 Wrist to badge ratio geometric means and standard deviations for Rocky Flats workers.

Population	GM	GSD
NDRP (1953-1969) [Excluding < 30 mrem]	2.44	2.68
NDRP (1953-1969) [Excluding < 100 mrem]	2.42	2.54
All (1977 – 2001) [Excluding < 30 mrem]	2.72	2.18
All (1977 – 2001) [Excluding <100 mrem]	3.08	2.14
NDRP (1971-1997) [Excluding < 30 mrem]	2.24	2.28
NDRP (1971-1997) [Excluding < 100 mrem]	2.37	2.77

From ATTILA, flux distributions in regions A and C were combined to form a ratio between wrist and upper torso (Figure A1). This formed the basis of a data set to be analyzed by CRYSTAL BALL software. The wrist-to-upper-torso ratio distribution was lognormal with geometric mean of 2.64 and a geometric standard deviation of 3.13. (FigureA2).

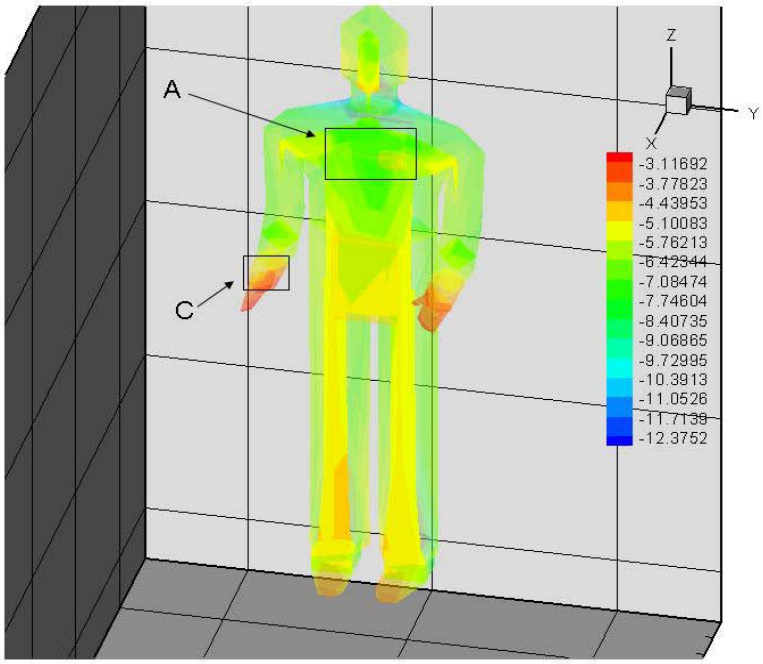

Figure A1 Data point selection regions. Various colors signify relative magnitude of flux across a selected plane on the x-axis.

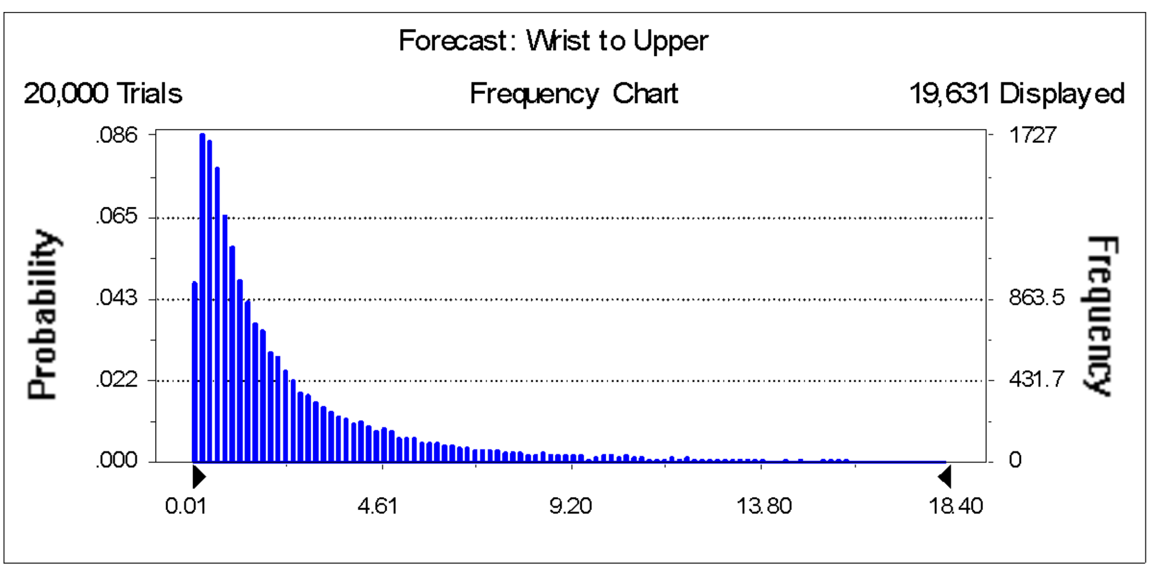

Figure A2 Distribution of wrist to upper torso ratios

This is in agreement with the RFP wrist-to-body-ratio geometric means and standard deviations in Table A1. Based on this analysis, it can be concluded that the ATTILA software is capable of producing reasonable and realistic results.

Appendix B

<u>ATTILA Model Data</u>

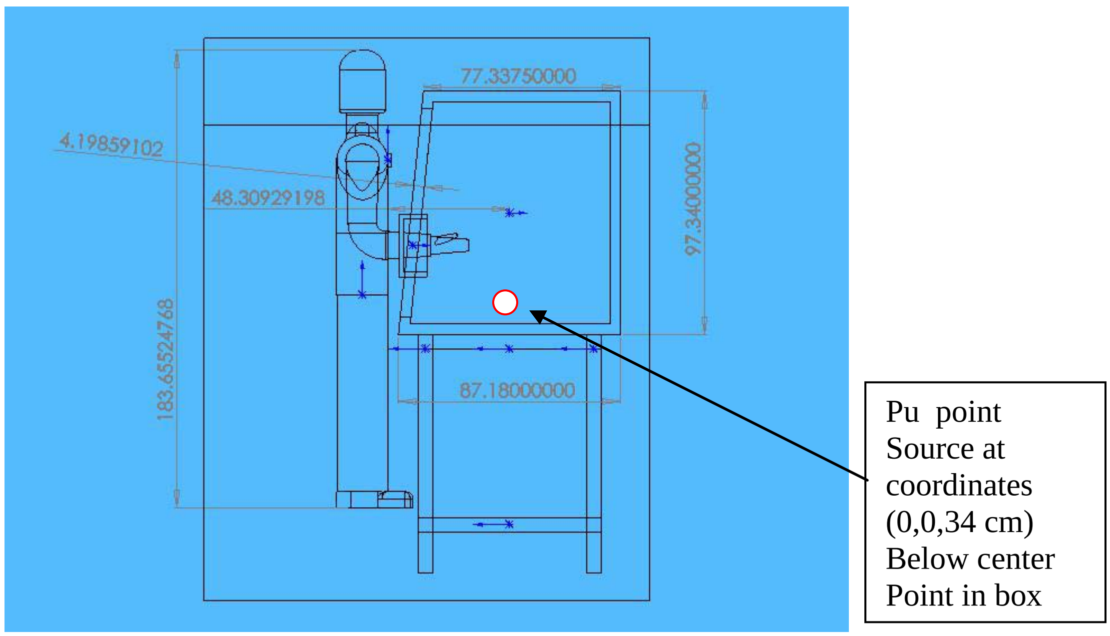

Figure B1 Dimensions (All lengths are in centimeters)

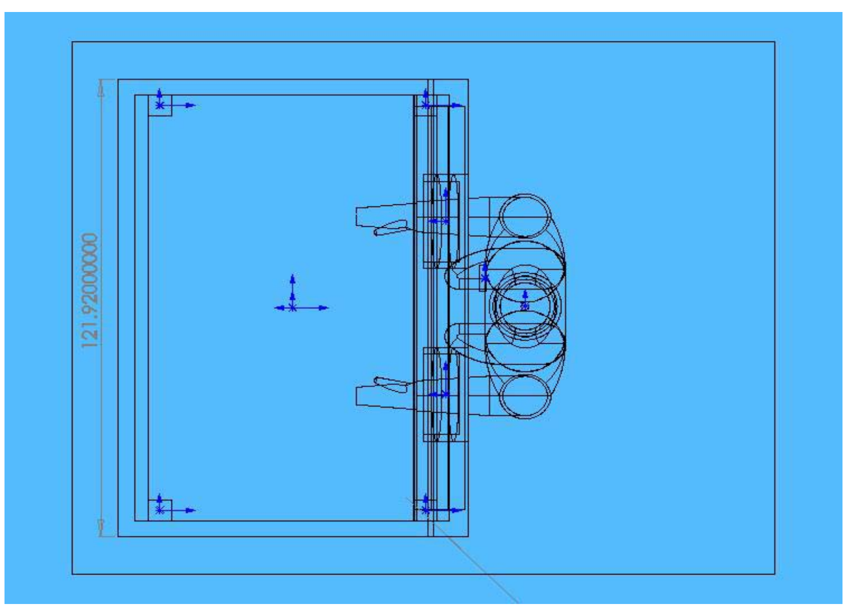

Figure B2 Dimensions (All lengths are in centimeters)

Thirty flux points, at surface of body, randomly chosen from box A and B in Figure B3 below.

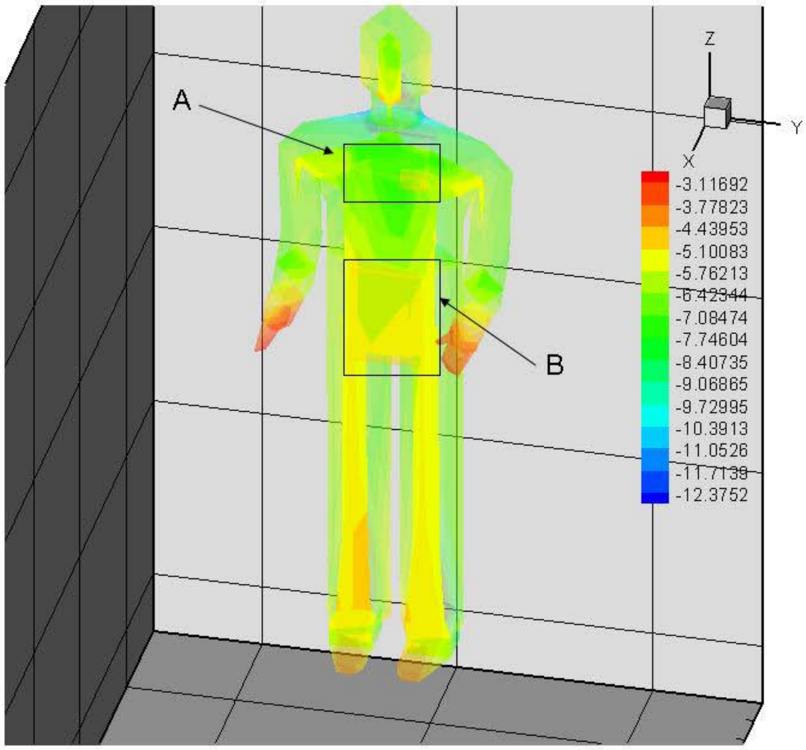

Figure B3 Analysis Points

Table B1 Photon source 1g Pu and 1ppb ^{236}Pu, decayed

Group	Upper Energy (MeV)	No ^{236}Pu (gamma/s)	^{234}Pu (gamma/s)	Total (gamma/s)
1	5.00E-03	1.76E+06	3.82E+01	1.762E+06
2	1.00E-02	2.77E+06	1.12E+02	2.770E+06
3	1.50E-02	2.40E+08	4.34E+02	2.396E+08
4	2.00E-02	9.26E+03	3.78E+01	9.301E+03
5	2.50E-02	5.49E+02	2.49E+01	5.742E+02
6	3.00E-02	5.94E+06	2.18E+01	5.943E+06
7	3.50E-02	3.63E+05	1.77E+01	3.625E+05
8	4.00E-02	1.30E+05	1.45E+01	1.299E+05
9	4.50E-02	3.10E+05	1.23E+01	3.098E+05
10	5.00E-02	2.27E+05	1.43E+01	2.272E+05
11	5.90E-02	5.00E+05	7.07E+00	5.003E+05
12	6.00E-02	9.28E+07	7.07E+00	9.282E+07
13	7.00E-02	5.48E+04	1.23E+01	5.477E+04
14	8.00E-02	4.34E+04	2.23E+02	4.361E+04
15	9.00E-02	4.62E+02	7.84E+01	5.404E+02
16	1.00E-01	1.25E+05	8.78E+00	1.254E+05

Group	Upper Energy (MeV)	No ^{236}Pu (gamma/s)	^{234}Pu (gamma/s)	Total (gamma/s)
17	1.25E-01	1.99E+05	1.81E+01	1.989E+05
18	1.50E-01	1.42E+05	8.36E+00	1.422E+05
19	1.75E-01	1.49E+04	5.89E+00	1.487E+04
20	2.00E-01	5.83E+03	8.10E+00	5.841E+03
21	2.50E-01	5.33E+04	3.57E+02	5.361E+04
22	3.00E-01	5.24E+03	4.06E+01	5.284E+03
23	3.50E-01	3.76E+04	1.60E+01	3.763E+04
24	4.00E-01	7.01E+04	2.87E+00	7.007E+04
25	4.50E-01	3.77E+04	2.24E+00	3.767E+04
26	5.00E-01	2.21E+03	3.69E+00	2.218E+03
27	6.00E-01	3.00E+02	2.74E+02	5.741E+02
28	7.00E-01	2.82E+03	1.26E+00	2.820E+03
29	8.00E-01	1.34E+03	9.77E+01	1.438E+03
30	9.00E-01	4.37E+01	3.50E+01	7.864E+01
31	1.00E+00	1.37E+01	3.18E+00	1.691E+01
32	1.25E+00	3.98E+01	7.71E+00	4.748E+01
33	1.50E+00	2.94E+01	2.15E-01	2.964E+01
34	1.75E+00	1.68E+01	2.32E+01	3.997E+01
35	2.00E+00	1.45E+01	1.39E+00	1.592E+01
36	2.60E+00	1.74E+01	2.25E-04	1.743E+01
37	2.70E+00	7.07E-07	2.41E+02	2.410E+01
38	3.00E+00	9.85E+00	1.23E-06	9.852E+00
39	3.50E+00	5.86E+00	6.52E-07	5.860E+00
40	4.00E+00	3.37E+00	3.34E-07	3.367E+00
41	5.00E+00	3.01E+00	2.55E-07	3.007E+00
42	6.00E+00	1.00E+00	6.80E-08	1.001E+00
43	8.00E+00	4.30E-01	2.25E-08	4.301E-01
44	1.10E+01	4.89E-02	1.76E-09	4.891E-02
	Total	3.45E+08	2.21E+03	3.452E+08

Use total gammas per second column and the associated energies for 1 gram Pu metal.

Glove box materials

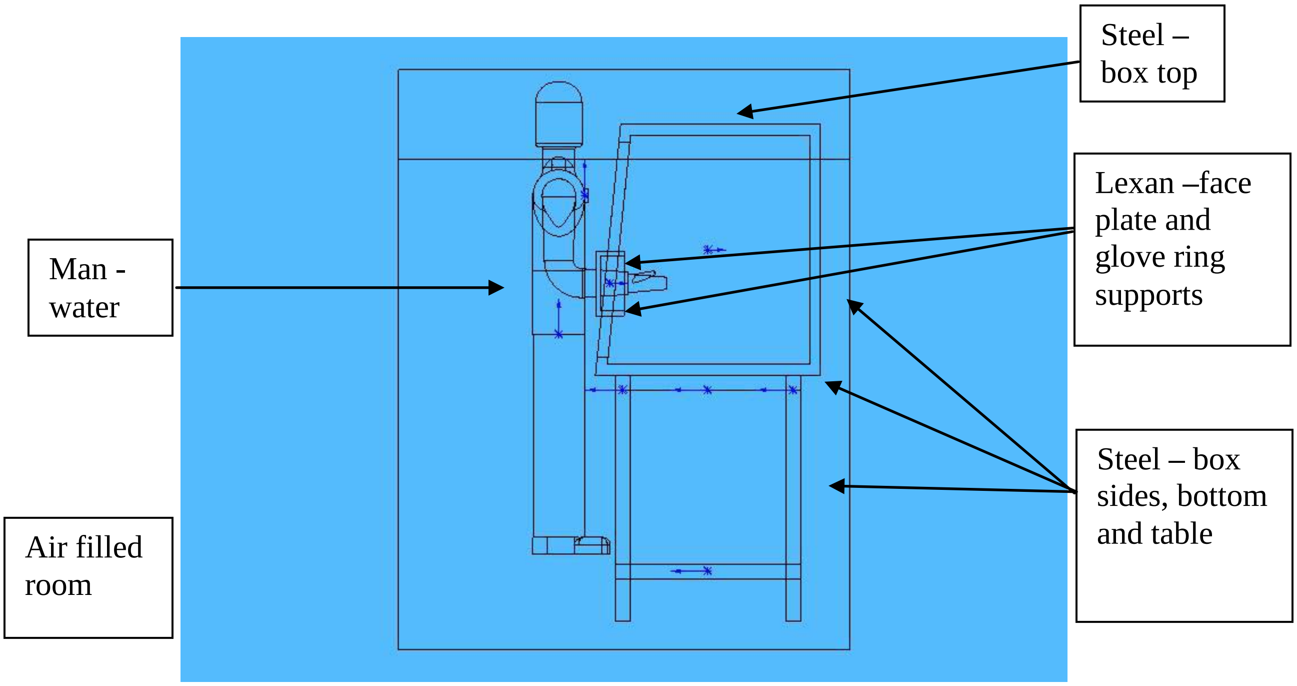

Figure B4 Glove box materials

Appendix C

Verification by Monte Carlo Simulation of Glove Box[0]

Introduction

In this evaluation, the dose rate from non-uniform exposure geometries has been evaluated. For this evaluation worker exposures scenarios involving two types of gloveboxes were modeled using MCNPX. The first scenario assumed a stainless steel glovebox ¼ inch thick with a full Lucite front. In the second scenario, the lower portion of the glovebox front was assumed to be stainless steel. The results of this modeling indicate that the dose rate measured by a dosimeter worn on the lapel was found to underestimate the dose rate to the abdomen by approximately 20% when the source was approximately 14 inches from the abdomen from the Lucite front glovebox. Conversely, when stainless steel comprised the lower portion of the glovebox, the dose rate measured at the lapel would overestimate the dose rate to the abdomen by about a factor of 8. These simple scenarios clearly indicate the importance of glovebox configuration. Based on these results, a simple correction for exposure geometry may not be sufficient to accurately measure the dose to the abdomen. The remainder of this report discusses the methodology and assumptions used to estimate the dose rate at the various anatomical locations.

Methodology

In the evaluation MCNPX was used to model the photon transport from a source contained in a glovebox. This section is broken down by the major input components required by the MCNPX code, which are geometry, source and material information, and tally methodology.

MCNPX Geometry and Materials
There were four basic geometric objects (glovebox, worker, source, and the room) modeled in this evaluation. During this evaluation, several different glovebox designs used to handle plutonium were investigated. Although the designs varied significantly, the main difference appeared to be the material and shape comprising the front of the glove box. Some glove boxes have vertical fronts that were entirely transparent, others had a configuration in which half of the front was vertical and the top half was at an angle to allow easier viewing. The basic design of a slightly slanted glovebox face was chosen for this evaluation, however to account for the differences in exposure, the bottom half was modeled as both Lucite and stainless steel.

A standard glovebox with dimension 48”x24”x30” was used. The top, bottom and sides of the glovebox were ¼” thick stainless steel. The legs of the glovebox were assumed to be 1.5” square by 36” tall and were assumed to be solid stainless steel. As noted above, a slanted face glove box was the basic model for this evaluation (i.e. a worker standing in front of a glovebox with a slight angle for the face shield with his forearms in the glovebox. A cutaway section of the glovebox was modeled in MCNPX .

For the worker the basic dimensions of the Lawrence Livermore National Laboratory (LLNL) Bottle Manikin Absorption phantom[(2)] were used. This phantom was slightly modified to account for some subtle differences in exposure geometry. The BOMAB phantom is a relatively short phantom in that the total height is only 5’6” tall.
The most disconcerting dimension with this phantom was the excessively long neck of nearly 4 inches. This dimension was reduced by a factor of two with the additional height being given to the workers chest, thus making the lapel farther from the abdomen. The only other modification was to the arms of the phantom. The straight cylindrical arms were split into the upper arms and the forearms such that they could be bent and placed into the glovebox. The basic dimensions for the BOMAB phantom used in this model are provided in Table C1. For simplicity, the phantom was assumed to consist of pure water.

Table C1 Representative Dimensions of Modeled Reference Man BOMAB

Container	Quantity	Cross section Shape	Cross section Dimensions (cm)	Height (cm)
1. Head	1	ellipsoid	19x14	20
2. Neck	1	circular	13 dia	10
3. Chest	1	ellipsoid	30x20	40
4. Pelvis	1	ellipsoid	36x20	20
5. Forearms	2	circular	9.7 dia	30
6. Upper arms	2	circular	12.5 dia	30
7. Thighs	2	circular	15 dia	40
8. Calves	2	circular	12 dia	40
Total	**12**			**170**

The source geometry was a right circular cylinder that was 2 inches in diameter and 1 centimeter in height. This configuration was chosen since it most closely approximated an actual plutonium button or puck used in gloveboxes throughout the Department of Energy (DOE) complex.

The room was modeled as a 20’x10’x10’ room with the back of the glovebox positioned one foot from the back wall. The floor was modeled as 6” of ordinary concrete and the back wall as 4” of ordinary concrete. A cutaway view of the room along the yz axis is a 10’x10’ dimension.

A total of 6 different materials were used in the evaluation. Table C2 provides the MCNPX ZAID, the relative weight fractions, density and references used for the various materials in this evaluation.

Table C2 Material information used in the modeling

Material	Density (g/cm^3)	Element / Isotope	MCNPX ID ZAID	Weight Fraction	Reference
Air Dry	1.205e-3	C	6000	0.000124	PNWD-3544 (4)
		N-14	7014	0.755267	
		O-16	8016	0.231781	
		Ar	18000	0.012827	
Plutonium (Weapons Grade)	15.92	Pu-238	94238	0.000399	PNWD-3544 (4)

Material	Density (g/cm^3)	Element / Isotope	MCNPX ID ZAID	Weight Fraction	Reference
		Pu-239	94239	0.934952	
		Pu-240	94240	0.059969	
		Pu-241	94241	0.001896	
		Pu-242	94242	0.000499	
		Am-241	95241	0.001996	
		Be-9	4009	0.000003	
		B-10	5010	0.000010	
		B-11	5011	0.000040	
		C-13	6013	0.000002	
		Mg	12000	0.000105	
		Al-27	13027	0.000130	
Concrete, Ordinary, Type 4	2.35	H	1001	0.005532	ANS/ANSI 6.4-1997 (5)
		O-16	8016	0.498298	
		Na-23	11023	0.017021	
		Mg	12000	0.002553	
		Al-27	13027	0.045532	
		Si	14000	0.315748	
		S-32	16032	0.001277	
		K	19000	0.019149	
		Ca	20000	0.082553	
Water	1.0	H	1000	2[a]	
		O	8000	1[a]	
Lucite	1.19	H	1001	0.0805	Radiological Health Handbook (6)
		C	6000	0.5999	
		O	8000	0.3196	
304 Stainless Steel	8.0	Fe	26000	0.710	MCNP 5 Class Handouts
		Cr	24000	0.180	
		Ni	28000	0.080	
		Mn	25000	0.020	
		C	6000	0.008	
		P	15000	0.001	
		S	16000	0.001	

[a] Atom Fraction

MCNPX Source Term

The photon source term for this evaluation was taken from Traub et al.,[4] and assumes 15 year aged weapons grade plutonium. According to Traub et al,[4] the actual yield of a 1 gram Pu sample is 3.452e8 photons/sec. For this evaluation a 400 gram plutonium sample was assumed, thus the total emission rate was 1.3824e11 photons/sec. The normalized photon spectra distribution is provided in Table C3.

.

Table C3 Normalized photon energy intervals

Photon Energy (MeV)	Probability	Photon Energy (MeV)	Probability
0.001	0	0.500	6.41E-06
0.005	5.09E-03	0.600	1.66E-06
0.010	8.02E-03	0.700	8.16E-06
0.015	6.94E-01	0.800	4.16E-06
0.020	2.69E-05	0.900	2.28E-07
0.025	1.66E-06	1.000	4.88E-08
0.030	1.72E-02	1.250	1.37E-07
0.035	1.05E-03	1.500	8.57E-08
0.040	3.76E-04	1.750	1.16E-07
0.045	8.97E-04	2.000	4.60E-08
0.050	6.57E-04	2.600	5.03E-08
0.059	1.45E-03	2.700	6.97E-07
0.060	2.69E-01	3.000	2.85E-08
0.070	1.59E-04	3.500	1.70E-08
0.080	1.26E-04	4.000	9.75E-09
0.090	1.56E-06	5.000	8.71E-09
0.100	3.62E-04	6.000	2.89E-09
0.125	5.76E-04	8.000	1.24E-09
0.150	4.11E-04	11.000	1.41E-10
0.175	4.31E-05		
0.200	1.69E-05		
0.250	1.55E-04		
0.300	1.53E-05		
0.350	1.09E-04		
0.400	2.03E-04		
0.450	1.09E-04		

Results

In this evaluation two glovebox scenarios were modeled and the dose rate calculated at three anatomical locations, the upper chest or lapel, the lower abdomen, and the wrist for each scenario. The upper chest or lapel was selected as this is the typical location a worker would wear a radiation dosimeter. At some facilities, workers also wore wrist dosimeters, thus the ratio between the lapel and the wrist was also of interest. The primary focus of this evaluation was to investigate the variation in dose to the lower abdomen for different glovebox configurations. By developing the ratio between the lapel and the abdomen, an estimate of the degree of overestimation and underestimation can be examined. For these results, the source was positioned in the center of the glovebox (12 inches from the edge) and approximately 14 inches from the lower abdomen.

In this evaluation, two tally types were conducted. The first tally F4 simply examined the exposure rate at the three locations. The second method using a F5 point detector in conjunction with ICRP 74 dose conversion factors enabled an estimate of dose.
In the first scenario, the entire front of the glovebox was modeled as Lucite. As observed in Table C4 the dose to the lower abdomen was greater than the dose measured at the lapel.

Table C4 Tally results for the full Lucite glovebox

Position on Body	F4 Cell Tally (mR/hr)	F4 Cell Tally Ratio X : Lapel	F5 Point Detector Tally (mrad/hr)	F5 Point Detector Tally Ratio X : Lapel	Inverse Squares (mrad/hr)	Inverse Squares Ratio X : Lapel
Lapel	1.95	1:01	1.75	1:01	2.00[a]	1:01
Abdomen	2.3	1.18 :1	1.98	1.13 :1	5.57	2.79 :1
Wrist	15.9	8.15 :1	15.93	9.10 :1	26.78	13.39 :1

a- assumed dose for ratio methodology

Interestingly in this model, the abdomen dose while greater than the lapel was not as high as would be predicted from the simple inverse squares law. This indicates that attenuation plays a significant role. This is somewhat expected due to the low energy emission spectra from the plutonium source, but wasn't expected to be as marked a difference. A mesh tally in which the photon fluence was accumulated in 1 cm x 1 cm cells across the centerline of the problem geometry makes it clear to see that the dose to organs in the lower abdomen would be underestimated if a worker solely worked with gloveboxes with full Lucite fronts and the dosimeter worn on the lapel were used to estimate the dose.

In the second scenario, the lower front of the glovebox was modeled as stainless steel. It should be noted that although the lower vertical portion of the glovebox was modeled as stainless steel, the gloveports (entrance area) were not. The entrance area where a worker inserts his/her arms into the glovebox were simply modeled as the workers arms (water). As a result, there was still some scatter through the ports to the lower abdomen. In this scenario, the effect of shielding is clearly observed as the dose to the abdomen was only about 1/8 the dose to the lapel (Table C5). In this scenario, using the dose measured on the lapel would significantly overestimate the dose to the lower abdomen.

Table C5 Tally results for the half stainless steel and half Lucite glovebox

Position On Body	F4 Cell Tally		F5 Point Detector Tally		Inverse Squares	
	(mR/hr)	Ratio X : Lapel	(mrad/hr)	Ratio X : Lapel	(mrad/hr)	Ratio X : Lapel
Lapel	1.73	1:01	1.89	1:01	2.00[a]	1:01
Abdomen	0.24	0.14 : 1	0.22	0.12 : 1	5.57	2.79 : 1
Wrist	16.84	9.73 : 1	20.4	10.79 : 1	26.78	13.39 : 1

[a] assumed dose for ratio methodology

It should be noted that the F4 Cell Tally uncertainty in this model was nearly double that of the Lucite model as transporting photons through the stainless steel diminished the number of interactions in the tally cell significantly. Figure C1 below depicts the photon fluence mesh tally for the half stainless steel and half Lucite front of the glovebox. Note the sharp coloration difference at the Lucite stainless steel interface clearly demonstrating the streaming effect. The dark green to cyan coloration at the lower abdomen clearly indicates the reduced photon fluence and the effect of shielding. In addition, the blending of colors around the body in the figure are more pronounced thus better illustrating the scatter through the body.

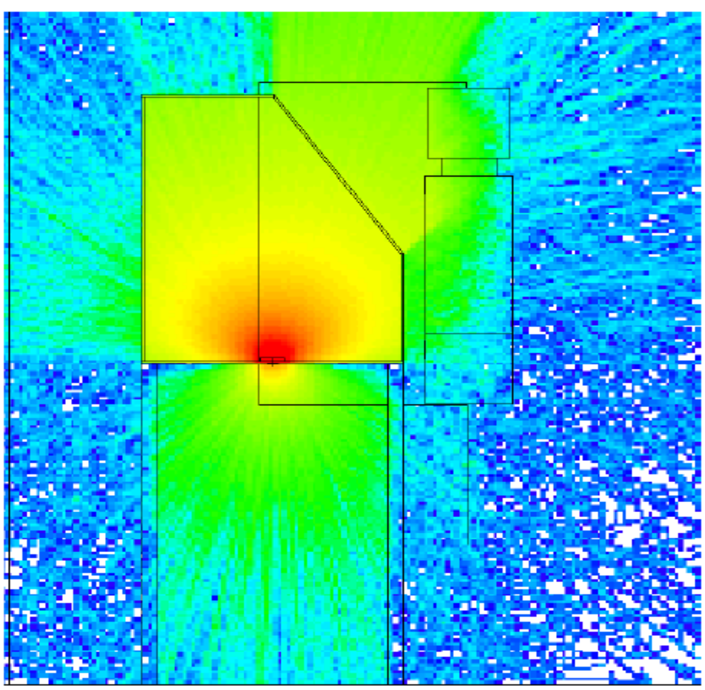

Figure C1 Photon fluence from a half stainless steel and half Lucite front glovebox.

When moving the source and varying the glovebox thickness, it is important to consider the rather lengthy computer runtimes that are required. Although in this problem photons near the tally area were given a higher importance, the runtime to develop the figure took approximately 150 hours (6 days) of continuous computer time on a 3.0 GHz hyper-threaded Pentium 4. This is why ATTILA is more time-efficient.

Summary
In this evaluation the dose rate from non-uniform exposure geometries was evaluated. This evaluation clearly demonstrates the importance of glovebox materials on the dose rate. In the case of a full Lucite front, the dose measured at the lapel by a dosimeter would underestimate the dose to the lower abdomen. However, when the lower portion of the glovebox was replaced with stainless steel, the dose was approximately 1/8 the dose that would be measured at the lapel. Both of these results indicate that the inverse squares law greatly overestimates the actual dose to plutonium glovebox workers. In the case of the stainless steel lower front… attenuation trumps distance.

Notes to Appendix C:

0. Taulbee, T. Part of course assignment in Monte Carlo simulation at the University of Cincinnati

1. Coffinberry, A. S. and Miner W. N. The Metal Plutonium. Chicago, Illinois: The University of Chicago Press; 1961; ISBN: 61-17072.

2. Hickman, David. The LLNL Seamless BOMAB [Web Page]. Accessed 2005 Nov.

3. Office of Environmental Management (U.S. Department of Energy). Closing the Circle on the Splitting of the Atom. Washington D.C.: U.S. Department of Energy; 1996 Jan; DOE/EM-0266.

4. Traub, Richard J.; Scherpelz, Robert I., and Taulbee, Timothy D. Personal Dose Equivalent Rates from Three Plutonium Objects. Pacifc Northwest Division: Battelle; 2005 Mar; PNWD-3544.

5. ANSI/ANS-6.4-1997. Nuclear Analysis and Design of Concrete Radiation Shielding for Nuclear Power Plants. La Grange Park, Il 60525: American Nuclear Society; 1997.

6. Shleien, Bernard; Slabeck, Lester A., and Birky, Brian Kent. Handbook of Health Physics and Radiological Health 3rd Edition. Baltimore, Maryland: Williams & Wilkins; 1998; ISBN: 0-683-18334-6.

MCNPX Input Decks

Input Deck 1 - Full Lucite front to the glove box

```
Glovebox Simulation - Monte Carlo Final Project
C 3456789112345678921234567893123456789412345678951234567896123456789 7
C This MCNP simulation calulates the dose rate
C difference between the wrist, lapel, and abdomen
C for a typical glovebox worker. The glovebox used
C in this simulation is a standard stainless steel
C glovebox with a lucite face. The front plate containing
C the glove entrances is Lucite. The standard man
C is the Bottle Man Phantom (BOMAB), with minor modifications.
C
C Created by Tim Taulbee
C
C ***************** Cell Cards **********************
C
C ** Glovebox Cells
C
1 2 -8.0 -1 imp:p=1 $ Bottom Plate
2 2 -8.0 -2 imp:p=1 $ Back Plate
3 2 -8.0 -3 imp:p=1 $ Top Plate
4 6 -1.19 -4 30 31 imp:p=10 $ Front Plate
5 2 -8.0 -5 imp:p=1 $ Lower L Side
6 2 -8.0 -6 imp:p=1 $ Lower R Side
7 2 -8.0 -7 imp:p=1 $ Upper L Side
8 2 -8.0 -8 imp:p=1 $ Upper R Side
9 2 -8.0 -9 imp:p=1 $ L Triangular Piece
10 2 -8.0 -10 imp:p=1 $ R Triangular Piece
11 6 -1.19 -11 3 4 imp:p=10 $ Face plate
12 2 -8.0 -12 imp:p=1 $ Back Left Leg
13 2 -8.0 -13 imp:p=1 $ Back Right Leg
14 2 -8.0 -14 imp:p=1 $ Front Left Leg
15 2 -8.0 -15 imp:p=1 $ Front Right Leg
16 2 -8.0 -16 imp:p=1 $ Back Middle Leg
17 2 -8.0 -17 imp:p=1 $ Front Middle Leg
C
c
C ** BOMAB Phantom Cells
C
20 3 -1.0 -20 imp:p=1 $ Right Calf
21 3 -1.0 -21 imp:p=1 $ Left Claf
22 3 -1.0 -22 imp:p=1 $ Right Thigh
23 3 -1.0 -23 imp:p=1 $ Left Thigh
24 3 -1.0 -24 imp:p=1 $ Pelvis
25 3 -1.0 -25 imp:p=1 $ Chest
26 3 -1.0 -26 imp:p=1 $ Neck
27 3 -1.0 -27 imp:p=1 $ Head
28 3 -1.0 -28 30 imp:p=1 $ Upper Right Arm
29 3 -1.0 -29 31 imp:p=1 $ Upper Left Arm
30 3 -1.0 -30 imp:p=1 $ Lower Right Arm
31 3 -1.0 -31 imp:p=1 $ Lower Left Arm
```

```
C
C
C ** Source Cell
35 4 -15.92 -35 imp:p=1 $ Source Cell
C
C
C ** Dosimeters
40 3 -1.0 -40 imp:p=10 $ Lapel Dosimeter
41 3 -1.0 -41 imp:p=10 $ Abdomen Dosimeter
42 3 -1.0 -42 imp:p=10 $ Wrist Dosimeter
C
C ** Room and Air Cells
C
50 1 -1.205e-3 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
20 21 22 23 24 25 26 27 28 29 30 31 35 40 41 42 53 -50 imp:p=1 $Room Air
51 5 -2.35 -51 imp:p=1 $ Concrete Floor
52 5 -2.35 -52 imp:p=1 $ Back Concrete Wall
53 1 -1.205e-3 1 3 4 5 6 7 8 9 10 11 14 15 17

22 23 24 25 26 27 28 29 30 31 35 40 41 42 -53 imp:p=10
60 0 50 51 52 imp:p=0 $ Outside Universe
C **************** Surface Cards ********************
C
C ** Glovebox Surfaces
C
1 rpp -60.96 60.96 -30.48 30.48 -0.3175 0.3175 $ Bottom Plate -4'x 2'
2 rpp -60.96 60.96 -30.48 -29.845 0.3175 75.8825 $ Back Plate
3 rpp -60.96 60.96 -30.48 0.34 75.8825 76.5175 $ Top Plate
4 rpp -60.96 60.96 29.845 30.48 0.3175 31.15 $ Front Plate
5 rpp -60.96 -60.325 -29.845 29.845 0.3175 30.7975 $ Lower L Side
6 rpp 60.325 60.96 -29.845 29.845 0.3175 30.7975 $ Lower R Side
7 rpp -60.96 -60.325 -29.845 0 30.7975 75.8825 $ Upper L Side
8 rpp 60.325 60.96 -29.845 0 30.7975 75.8825 $ Upper R Side
9 wed -60.96 0 30.7975 0 29.845 0 0 0 45.085 0.635 0 0 $ L Triangluar
10 wed 60.96 0 30.7975 0 29.845 0 0 0 45.085 -0.635 0 0 $ R Triangluar
11 1 rpp 0 121.92 0 0.635 0 54.4 $ Face Plate
12 rpp -60.96 -57.15 -30.48 -26.67 -91.7575 -0.3175 $ Back Left Leg
13 rpp 57.15 60.96 -30.48 -26.67 -91.7575 -0.3175 $ Back Right Leg
14 rpp -60.96 -57.15 26.67 30.48 -91.7575 -0.3175 $ Front Left Leg
15 rpp 57.15 60.96 26.67 30.48 -91.7575 -0.3175 $ Front Right Leg
16 rpp -1.905 1.905 -30.48 -26.67 -91.7575 -0.3175 $ Back Middle Leg
17 rpp -1.905 1.905 26.67 30.48 -91.7575 -0.3175 $ Front Middle Leg
C
C
C **** BOMAB Phantom
C
C Note the Surfaces are defined from the bottom up
20 rcc -7.5 45.56 -91.7575 0 0 40 6 $ Right Calf
21 rcc 7.5 45.56 -91.7575 0 0 40 6 $ Left Calf
22 rcc -7.5 45.56 -51.7575 0 0 40 7.5 $ Right Thigh
23 rcc 7.5 45.56 -51.7575 0 0 40 7.5 $ Left Thigh
24 rec 0 45.56 -11.7575 0 0 20 18 0 0 0 10 0 $ Pelvis
25 rec 0 45.56 8.2425 0 0 45 15 0 0 0 10 0 $ Chest
```

```
26 rcc 0 45.56 53.2425 0 0 5 6.5 $ Neck
27 rec 0 45.56 58.2425 0 0 20 7 0 0 0 9.5 0 $ Head
28 2 rcc 0 0 0 0 0 -35 6.25 $ Upper Right Arm
29 3 rcc 0 0 0 0 0 -35 6.25 $ Upper Left Arm
30 4 rcc 0 0 0 0 0 -35 4.85 $ Lower Right Arm
31 5 rcc 0 0 0 0 0 -35 4.85 $ Lower Right Arm
C
C ** Cylindrical Source
35 rcc 0 0 0.3175 0 0 1 2.83 $ Source
C
C
C ** Dosimeter Surfaces - Tally Cell Surfaces
40 rpp -2.54 2.54 35.30 35.50 48.1625 53.2425 $ Lapel Dosimeter
41 rpp -2.54 2.54 35.30 35.50 1.0 6.08 $ Abdomen Dosimeter
42 rpp 16.1 16.3 10.0 15.08 7.46 12.54 $ Wrist Dosimeter
C
C
C ** Room and Concrete Slab
C
50 rpp -304.8 304.8 -60.96 304.8 -91.7575 213.0425 $ Room Air
51 rpp -304.8 304.8 -68.58 304.8 -106.9975 -91.7575 $ Concrete Floor
52 rpp -304.8 304.8 -68.58 -60.96 -91.7575 213.0425 $ Concrete Back Wall
53 rpp -61 61 -3 45 -12 80 $ Important Air Volume
C
C ****************** Data Cards ********************
mode p
C
C **** Translocation Cards
C
c X Y Z B1 B2 B3 B4 B5 B6 B7 B8 B9
*tr1 -60.96 29.845 30.7975 0 90 90 90 33.5 56.5 90 123.5 33.5 $ Face Plate
*tr2 -21.25 45.56 53.2425 0 90 90 90 10 100 90 80 10 $ Upper Right Arm
*tr3 21.25 45.56 53.2425 0 90 90 90 10 100 90 80 10 $ Upper Left Arm
*tr4 -21.25 42.75 20 0 90 90 90 70 160 90 20 70 $ Lower Right Arm
*tr5 21.25 42.75 20 0 90 90 90 70 160 90 20 70 $ Lower Left Arm
C
C
C **** Material Cards
C
C Dry Air: Density = 1.205e-3 g/cc (ICRU 37, 1984)
m1 6000 -0.000124 7014 -0.755267 8016 -0.231781 18000 -0.012827
C
C 304 Stainless Steel: Density = 8.0 g/cc
m2 26000 -0.710 24000 -0.18 28000 -0.08 25000 -0.02
6000 -0.008 15000 -0.001 16000 -0.001
C
C Water: Density = 1.0 g/cc
m3 1000 0.66667 8000 0.33333
C
C Plutonium: Density = 15.92 g/cc (DOE-STD-3013-2000)
m4 94238 -0.000399 94239 -0.934952 94240 -0.059969 94241 -0.001896
94242 -0.000499 95241 -0.001996 4009 -0.000003 5010 -0.000010
5011 -0.000040 6013 -0.000002 12000 -0.000105 13027 -0.000130
```

```
C
C Ordinary Concrete: Density = 2.35 g/cc (ANSI/ANS-6.4-1997)
m5 1001 -0.005532 8016 -0.498298 11023 -0.017021 12000 -0.002553
13027 -0.045532 14000 -0.315748 16032 -0.001277 19000 -0.019149
20000 -0.082553
C
C Lucite: Density = 1.19 g/cc (Radiological Health Handbook, 1998)
m6 1001 -0.0805 6000 -0.5999 8000 -0.3196
c
C
C **** Source Definition Card
C
C 15 year aged Pu-239
C
SDEF par=2 pos=0 0 0.3175 axs 0 0 1 rad=d1 ext=d2 erg=d3
C
C Cylindrical Distribution approximately 2 inch diameter 1 cm height
si1 0 2.83
sp1 -21 1
si2 0 1
sp2 -21 0
C Energy Distribution from PNWD-3544 (March 2005)
si3 h 0.001 0.005 0.010 0.015 0.020 0.025 0.030 0.035
0.040 0.045 0.050 0.059 0.060 0.070 0.080 0.090
0.100 0.125 0.150 0.175 0.200 0.250 0.300 0.350
0.400 0.450 0.500 0.600 0.700 0.800 0.900 1.000
1.250 1.500 1.750 2.000 2.600 2.700 3.000 3.500
4.000 5.000 6.000 8.000 11.000
sp3 d 0 5.09E-03 8.02E-03 6.94E-01 2.69E-05 1.66E-06 1.72E-02 1.05E-03
3.76E-04 8.97E-04 6.57E-04 1.45E-03 2.69E-01 1.59E-04 1.26E-04 1.56E-06
3.62E-04 5.76E-04 4.11E-04 4.31E-05 1.69E-05 1.55E-04 1.53E-05 1.09E-04
2.03E-04 1.09E-04 6.41E-06 1.66E-06 8.16E-06 4.16E-06 2.28E-07 4.88E-08
1.37E-07 8.57E-08 1.16E-07 4.60E-08 5.03E-08 6.97E-07 2.85E-08 1.70E-08
9.75E-09 8.71E-09 2.89E-09 1.24E-09 1.41E-10
C
C
C **** Tally Cells
C
C F4 Tallys
C
fc4 Exposure Rate at Lapel
f4:p 40 $ Tally on Cell 40
fm4 3.75778e5 1 -5 -6
C F4 Tally Multiplier
C 1.3808e11 photons/sec * 3600 sec/hr *
C 6.6222e-10 (rads/photon) / 0.876 (rads/Roentgen) = 3.75778 e5 R/hr
C
fc14 Exposure Rate at Abdomen
f14:p 41 $ Tally on Cell 41
fm14 3.75778e5 1 -5 -6
C
C
fc24 Exposure Rate at Wrist
```

```
f24:p 42 $ Tally on Cell 42
fm24 3.75778e5 1 -5 -6
C
C
C F5 Tallys using ICRP 74 Dose Conversion Factors
C
fc5 Exposure Rate at Lapel
f5:p 0 35.36 50.725 0
fm5 49708.8
C Tally Multiplier
C fm15=(1.3808e11 photons/sec)*(3600 sec/hr)*(1e-10 rad/pGy)= 49708.8 rad/hr
C
C Photon fluence to dose conversion factors obtained from ICRP 74
C Table A.1 pg 159. Ka/Phi (Units: pGy cm^2)
C
de5 0.010 0.015 0.020 0.030 0.040 0.050 0.060 0.080 0.100 0.150 0.200 0.300
0.400 0.500 0.600 0.800 1.000 1.500 2.000 3.000 4.000 5.000 6.000 8.000
df5 7.430 3.120 1.680 0.721 0.429 0.323 0.289 0.307 0.371 0.599 0.856 1.380
1.890 2.380 2.840 3.690 4.470 6.140 7.550 9.960 12.10 14.10 16.10 20.10
C
fc15 Exposure Rate at Abdomen
f15:p 0 35.36 3.54 0
fm15 49708.8
C Tally Multiplier
C fm15=(1.3808e11 photons/sec)*(3600 sec/hr)*(1e-10 rad/pGy)= 49708.8 rad/hr
C
C Photon fluence to dose conversion factors obtained from ICRP 74
C Table A.1 pg 159. Ka/Phi (Units: pGy cm^2)
C
de15 0.010 0.015 0.020 0.030 0.040 0.050 0.060 0.080 0.100 0.150 0.200 0.300
0.400 0.500 0.600 0.800 1.000 1.500 2.000 3.000 4.000 5.000 6.000 8.000
df15 7.430 3.120 1.680 0.721 0.429 0.323 0.289 0.307 0.371 0.599 0.856 1.380
1.890 2.380 2.840 3.690 4.470 6.140 7.550 9.960 12.10 14.10 16.10 20.10
C
C
fc25 Exposure Rate at Wrist
f25:p 16.1 12.54 10 0
fm25 49708.8
C Tally Multiplier
C fm15=(1.3808e11 photons/sec)*(3600 sec/hr)*(1e-10 rad/pGy)= 49708.8 rad/hr
C
C Photon fluence to dose conversion factors obtained from ICRP 74
C Table A.1 pg 159. Ka/Phi (Units: pGy cm^2)
C
de25 0.010 0.015 0.020 0.030 0.040 0.050 0.060 0.080 0.100 0.150 0.200 0.300
0.400 0.500 0.600 0.800 1.000 1.500 2.000 3.000 4.000 5.000 6.000 8.000
df25 7.430 3.120 1.680 0.721 0.429 0.323 0.289 0.307 0.371 0.599 0.856 1.380
1.890 2.380 2.840 3.690 4.470 6.140 7.550 9.960 12.10 14.10 16.10 20.10
C
C
C **** Mesh Tally
tmesh
rmesh1:p flux
```

```
cora1 -2.54 2.54
corb1 -63.0 199i 137
corc1 -92 199i 108
endmd
C
C nps 2000000 $ Number of Particles
ctme 540 $ Runtime
Input Deck -2 Half Stainless Steel Front Input Deck
Glovebox Simulation - Monte Carlo Final Project
C 3456789112345678921234567893123456789412345678951234567896123456789 7
C This MCNP simulation calulates the dose rate
C difference between the wrist, lapel, and abdomen
C for a typical glovebox worker. The glovebox used
C in this simulation is a standard stainless steel
C glovebox with a steel face. The front plate containing
C the glove entrances is Lucite. The standard man
C is the Bottle Man Phantom (BOMAB), with minor modifications.
C
C Created by Tim Taulbee
C
C ***************** Cell Cards **********************
C
C ** Glovebox Cells
C
1 2 -8.0 -1 imp:p=1 $ Bottom Plate
2 2 -8.0 -2 imp:p=1 $ Back Plate
3 2 -8.0 -3 imp:p=1 $ Top Plate
4 2 -8.0 -4 30 31 imp:p=10 $ Front Plate
5 2 -8.0 -5 imp:p=1 $ Lower L Side
6 2 -8.0 -6 imp:p=1 $ Lower R Side
7 2 -8.0 -7 imp:p=1 $ Upper L Side
8 2 -8.0 -8 imp:p=1 $ Upper R Side
9 2 -8.0 -9 imp:p=1 $ L Triangular Piece
10 2 -8.0 -10 imp:p=1 $ R Triangular Piece
11 6 -1.19 -11 3 4 imp:p=10 $ Face plate
12 2 -8.0 -12 imp:p=1 $ Back Left Leg
13 2 -8.0 -13 imp:p=1 $ Back Right Leg
14 2 -8.0 -14 imp:p=1 $ Front Left Leg
15 2 -8.0 -15 imp:p=1 $ Front Right Leg
16 2 -8.0 -16 imp:p=1 $ Back Middle Leg
17 2 -8.0 -17 imp:p=1 $ Front Middle Leg
C
c
C ** BOMAB Phantom Cells
C
20 3 -1.0 -20 imp:p=1 $ Right Calf
21 3 -1.0 -21 imp:p=1 $ Left Claf
22 3 -1.0 -22 imp:p=1 $ Right Thigh
23 3 -1.0 -23 imp:p=1 $ Left Thigh
24 3 -1.0 -24 imp:p=1 $ Pelvis
25 3 -1.0 -25 imp:p=1 $ Chest
26 3 -1.0 -26 imp:p=1 $ Neck
27 3 -1.0 -27 imp:p=1 $ Head
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28 3 -1.0 -28 30 imp:p=1 $ Upper Right Arm
29 3 -1.0 -29 31 imp:p=1 $ Upper Left Arm
30 3 -1.0 -30 imp:p=1 $ Lower Right Arm
31 3 -1.0 -31 imp:p=1 $ Lower Left Arm
C
C
C ** Source Cell
35 4 -15.92 -35 imp:p=1 $ Source Cell
C
C
C ** Dosimeters
40 3 -1.0 -40 imp:p=10 $ Lapel Dosimeter
41 3 -1.0 -41 imp:p=10 $ Abdomen Dosimeter
42 3 -1.0 -42 imp:p=10 $ Wrist Dosimeter
C
C ** Room and Air Cells
C
50 1 -1.205e-3 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
20 21 22 23 24 25 26 27 28 29 30 31 35 40 41 42 53 -50 imp:p=1 $Room Air
51 5 -2.35 -51 imp:p=1 $ Concrete Floor
52 5 -2.35 -52 imp:p=1 $ Back Concrete Wall
53 1 -1.205e-3 1 3 4 5 6 7 8 9 10 11 14 15 17
22 23 24 25 26 27 28 29 30 31 35 40 41 42 -53 imp:p=10
60 0 50 51 52 imp:p=0 $ Outside Universe
C **************** Surface Cards ********************
C
C ** Glovebox Surfaces
C
1 rpp -60.96 60.96 -30.48 30.48 -0.3175 0.3175 $ Bottom Plate -4'x 2'
2 rpp -60.96 60.96 -30.48 -29.845 0.3175 75.8825 $ Back Plate
3 rpp -60.96 60.96 -30.48 0.34 75.8825 76.5175 $ Top Plate
4 rpp -60.96 60.96 29.845 30.48 0.3175 31.15 $ Front Plate
5 rpp -60.96 -60.325 -29.845 29.845 0.3175 30.7975 $ Lower L Side
6 rpp 60.325 60.96 -29.845 29.845 0.3175 30.7975 $ Lower R Side
7 rpp -60.96 -60.325 -29.845 0 30.7975 75.8825 $ Upper L Side
8 rpp 60.325 60.96 -29.845 0 30.7975 75.8825 $ Upper R Side
9 wed -60.96 0 30.7975 0 29.845 0 0 0 45.085 0.635 0 0 $ L Triangluar
10 wed 60.96 0 30.7975 0 29.845 0 0 0 45.085 -0.635 0 0 $ R Triangluar
11 1 rpp 0 121.92 0 0.635 0 54.4 $ Face Plate
12 rpp -60.96 -57.15 -30.48 -26.67 -91.7575 -0.3175 $ Back Left Leg
13 rpp 57.15 60.96 -30.48 -26.67 -91.7575 -0.3175 $ Back Right Leg
14 rpp -60.96 -57.15 26.67 30.48 -91.7575 -0.3175 $ Front Left Leg
15 rpp 57.15 60.96 26.67 30.48 -91.7575 -0.3175 $ Front Right Leg
16 rpp -1.905 1.905 -30.48 -26.67 -91.7575 -0.3175 $ Back Middle Leg
17 rpp -1.905 1.905 26.67 30.48 -91.7575 -0.3175 $ Front Middle Leg
C
C
C **** BOMAB Phantom
C
C Note the Surfaces are defined from the bottom up
20 rcc -7.5 45.56 -91.7575 0 0 40 6 $ Right Calf
21 rcc 7.5 45.56 -91.7575 0 0 40 6 $ Left Calf
22 rcc -7.5 45.56 -51.7575 0 0 40 7.5 $ Right Thigh
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23 rcc 7.5 45.56 -51.7575 0 0 40 7.5 $ Left Thigh
24 rec 0 45.56 -11.7575 0 0 20 18 0 0 0 10 0 $ Pelvis
25 rec 0 45.56 8.2425 0 0 45 15 0 0 0 10 0 $ Chest
26 rcc 0 45.56 53.2425 0 0 5 6.5 $ Neck
27 rec 0 45.56 58.2425 0 0 20 7 0 0 0 9.5 0 $ Head
28 2 rcc 0 0 0 0 0 -35 6.25 $ Upper Right Arm
29 3 rcc 0 0 0 0 0 -35 6.25 $ Upper Left Arm
30 4 rcc 0 0 0 0 0 -35 4.85 $ Lower Right Arm
31 5 rcc 0 0 0 0 0 -35 4.85 $ Lower Right Arm
C
C ** Cylindrical Source
35 rcc 0 0 0.3175 0 0 1 2.83 $ Source
C
C
C ** Dosimeter Surfaces - Tally Cell Surfaces
40 rpp -2.54 2.54 35.30 35.50 48.1625 53.2425 $ Lapel Dosimeter
41 rpp -2.54 2.54 35.30 35.50 1.0 6.08 $ Abdomen Dosimeter
42 rpp 16.1 16.3 10.0 15.08 7.46 12.54 $ Wrist Dosimeter
C
C
C ** Room and Concrete Slab
C
50 rpp -304.8 304.8 -60.96 304.8 -91.7575 213.0425 $ Room Air
51 rpp -304.8 304.8 -68.58 304.8 -106.9975 -91.7575 $ Concrete Floor
52 rpp -304.8 304.8 -68.58 -60.96 -91.7575 213.0425 $ Concrete Back Wall
53 rpp -61 61 -3 45 -12 80 $ Important Air Volume
C
C ****************** Data Cards ********************
mode p
C
C **** Translocation Cards
C
c X Y Z B1 B2 B3 B4 B5 B6 B7 B8 B9
*tr1 -60.96 29.845 30.7975 0 90 90 90 33.5 56.5 90 123.5 33.5 $ Face Plate
*tr2 -21.25 45.56 53.2425 0 90 90 90 10 100 90 80 10 $ Upper Right Arm
*tr3 21.25 45.56 53.2425 0 90 90 90 10 100 90 80 10 $ Upper Left Arm
*tr4 -21.25 42.75 20 0 90 90 90 70 160 90 20 70 $ Lower Right Arm
*tr5 21.25 42.75 20 0 90 90 90 70 160 90 20 70 $ Lower Left Arm
C
C
C **** Material Cards
C
C Dry Air: Density = 1.205e-3 g/cc (ICRU 37, 1984)
m1 6000 -0.000124 7014 -0.755267 8016 -0.231781 18000 -0.012827
C
C 304 Stainless Steel: Density = 8.0 g/cc
m2 26000 -0.710 24000 -0.18 28000 -0.08 25000 -0.02
6000 -0.008 15000 -0.001 16000 -0.001
C
C Water: Density = 1.0 g/cc
m3 1000 0.66667 8000 0.33333
C
C Plutonium: Density = 15.92 g/cc (DOE-STD-3013-2000)
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m4 94238 -0.000399 94239 -0.934952 94240 -0.059969 94241 -0.001896
94242 -0.000499 95241 -0.001996 4009 -0.000003 5010 -0.000010
5011 -0.000040 6013 -0.000002 12000 -0.000105 13027 -0.000130
C
C Ordinary Concrete: Density = 2.35 g/cc (ANSI/ANS-6.4-1997)
m5 1001 -0.005532 8016 -0.498298 11023 -0.017021 12000 -0.002553
13027 -0.045532 14000 -0.315748 16032 -0.001277 19000 -0.019149
20000 -0.082553
C
C Lucite: Density = 1.19 g/cc (Radiological Health Handbook, 1998)
m6 1001 -0.0805 6000 -0.5999 8000 -0.3196
c
C
C **** Source Definition Card
C
C 15 year aged Pu-239
C
SDEF par=2 pos=0 0 0.3175 axs 0 0 1 rad=d1 ext=d2 erg=d3
C
C Cylindrical Distribution approximately 2 inch diameter 1 cm height
si1 0 2.83
sp1 -21 1
si2 0 1
sp2 -21 0
C Energy Distribution from PNWD-3544 (March 2005)
si3 h 0.001 0.005 0.010 0.015 0.020 0.025 0.030 0.035
0.040 0.045 0.050 0.059 0.060 0.070 0.080 0.090
0.100 0.125 0.150 0.175 0.200 0.250 0.300 0.350
0.400 0.450 0.500 0.600 0.700 0.800 0.900 1.000
1.250 1.500 1.750 2.000 2.600 2.700 3.000 3.500
4.000 5.000 6.000 8.000 11.000
sp3 d 0 5.09E-03 8.02E-03 6.94E-01 2.69E-05 1.66E-06 1.72E-02 1.05E-03
3.76E-04 8.97E-04 6.57E-04 1.45E-03 2.69E-01 1.59E-04 1.26E-04 1.56E-06
3.62E-04 5.76E-04 4.11E-04 4.31E-05 1.69E-05 1.55E-04 1.53E-05 1.09E-04
2.03E-04 1.09E-04 6.41E-06 1.66E-06 8.16E-06 4.16E-06 2.28E-07 4.88E-08
1.37E-07 8.57E-08 1.16E-07 4.60E-08 5.03E-08 6.97E-07 2.85E-08 1.70E-08
9.75E-09 8.71E-09 2.89E-09 1.24E-09 1.41E-10
C
C
C **** Tally Cells
C
C F4 Tallys
C
fc4 Exposure Rate at Lapel
f4:p 40 $ Tally on Cell 40
fm4 3.75778e5 1 -5 -6
C F4 Tally Multiplier
C 1.3808e11 photons/sec * 3600 sec/hr *
C 6.6222e-10 (rads/photon) / 0.876 (rads/Roentgen) = 3.75778 e5 R/hr
C
fc14 Exposure Rate at Abdomen
f14:p 41 $ Tally on Cell 41
fm14 3.75778e5 1 -5 -6
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C
C
fc24 Exposure Rate at Wrist
f24:p 42 $ Tally on Cell 42
fm24 3.75778e5 1 -5 -6
C
C
C F5 Tallys using ICRP 74 Dose Conversion Factors
C
fc5 Exposure Rate at Lapel
f5:p 0 35.36 50.725 0
fm5 49708.8
C Tally Multiplier
C fm15=(1.3808e11 photons/sec)*(3600 sec/hr)*(1e-10 rad/pGy)= 49708.8 rad/hr
C
C Photon fluence to dose conversion factors obtained from ICRP 74
C Table A.1 pg 159. Ka/Phi (Units: pGy cm^2)
C
de5 0.010 0.015 0.020 0.030 0.040 0.050 0.060 0.080 0.100 0.150 0.200 0.300
0.400 0.500 0.600 0.800 1.000 1.500 2.000 3.000 4.000 5.000 6.000 8.000
df5 7.430 3.120 1.680 0.721 0.429 0.323 0.289 0.307 0.371 0.599 0.856 1.380
1.890 2.380 2.840 3.690 4.470 6.140 7.550 9.960 12.10 14.10 16.10 20.10
C
fc15 Exposure Rate at Abdomen
f15:p 0 35.36 3.54 0
fm15 49708.8
C Tally Multiplier
C fm15=(1.3808e11 photons/sec)*(3600 sec/hr)*(1e-10 rad/pGy)= 49708.8 rad/hr
C
C Photon fluence to dose conversion factors obtained from ICRP 74
C Table A.1 pg 159. Ka/Phi (Units: pGy cm^2)
C
de15 0.010 0.015 0.020 0.030 0.040 0.050 0.060 0.080 0.100 0.150 0.200 0.300
0.400 0.500 0.600 0.800 1.000 1.500 2.000 3.000 4.000 5.000 6.000 8.000
df15 7.430 3.120 1.680 0.721 0.429 0.323 0.289 0.307 0.371 0.599 0.856 1.380
1.890 2.380 2.840 3.690 4.470 6.140 7.550 9.960 12.10 14.10 16.10 20.10
C
C
fc25 Exposure Rate at Wrist
f25:p 16.1 12.54 10 0
fm25 49708.8
C Tally Multiplier
C fm15=(1.3808e11 photons/sec)*(3600 sec/hr)*(1e-10 rad/pGy)= 49708.8 rad/hr
C
C Photon fluence to dose conversion factors obtained from ICRP 74
C Table A.1 pg 159. Ka/Phi (Units: pGy cm^2)
C
de25 0.010 0.015 0.020 0.030 0.040 0.050 0.060 0.080 0.100 0.150 0.200 0.300
0.400 0.500 0.600 0.800 1.000 1.500 2.000 3.000 4.000 5.000 6.000 8.000
df25 7.430 3.120 1.680 0.721 0.429 0.323 0.289 0.307 0.371 0.599 0.856 1.380
```

```
1.890 2.380 2.840 3.690 4.470 6.140 7.550 9.960 12.10 14.10 16.10 20.10
C
C
C **** Mesh Tally
tmesh
rmesh1:p flux
cora1 -2.54 2.54
corb1 -63.0 199i 137
corc1 -92 199i 108
endmd
C
C nps 2000000 $ Number of Particles
ctme 2040 $ Runtime
```