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Selected Geometric Exposure Scenario Considerations for External Dose Reconstruction at Uranium Facilities	Page 1 of 16
Approval:___Signature on file_____ **Date:** _11/23/2010_ **J.W. Neton, Associate Director for Science**	**Supersedes:** **Revision 0**

RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
10/26/2005	10/26/2005	0	Document initiated to provide guidance on the application of geometry-based dose correction factors to external dosimetry badge data for Mallinckrodt workers in particular job classifications.
10/14/2010	11/23/2010	1	Incorporated SC&A comments; reorganized procedure format; included dose reconstruction instructions for the application of geometric correction factors to the upper and lower torso; added information to clarify the bounding parameters associated with the Attila computation; NIOSH internal comments including procedure title change and applicability to other uranium facilities.

1.0   Purpose

The purpose of this technical information bulletin (TIB) is to provide guidance on the application of geometry-based dose correction factors to external dosimetry badge data for uranium process facility workers. A specific example for Mallinckrodt worker job classifications has been used to show how to apply a correction but the process is completely general. Mallinckrodt data has also been used for comparison to ATTILA software computational results. The correction factor is completely determined by geometry. Photon fluence was determined at the surface of the dosimeter on the upper torso and at the surface of the person on the lower torso and head in each scenario.   No dose computation

was performed, only the relative relation between fluence. Before the geometry correction factor can be used the dose reconstructor must determine energy, rotational corrections, and absorption/ penetration through badge filters. After those corrections are made, the geometry correction factor is applied. Bremsstrahlung is not taken into account in this TIB. The dose reconstructor handles that before the correction is applied. A photon from the source, regardless of energy, will reach the surface of the upper torso and lower torso in the same proportion. The factors are to be used for the periods of time where the individual's work history places him/her in a job for which a correction may be necessary. Specific job classifications for which these factors apply are discussed in section 4.0. If abdomen dosimetry data is available, it should be used in place of this TIB. Likewise if wrist/ring dosimetry is available then it should be used instead of extrapolating from this TIB.

2.0   Geometric Exposure Considerations

Consideration must be given to the role that geometry plays in dose reconstruction for uranium facility workers. Jobs at a facility range from those that required continuous hand or near-hand contact during a work day to those jobs where contact was only at a distance and of short duration. The distance and time factors could result in an underestimation of the reconstructed dosimeter and missed dose to organs located in the lower torso region of the body (e.g., stomach, liver, bladder, prostate, ovaries, testes, etc…) for high contact jobs. The degree of underestimation, or in some cases overestimation, is also dependent upon the shielding between the worker and source of radiation.

2.1   Exposure Geometries
Exposure geometry is a special consideration in dose reconstruction of energy employees who worked with uranium metal, powders and residues. 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 distances among the external radiation source, the organ of interest, and the dosimeter. Organs in the lower torso are affected most. The dose to the lung is considered to be reasonably approximated by the lapel dosimeter, at least to within the dosimeter uncertainty, while the dose to the face and head could be lower than the dose measured by the dosimeter worn on the lapel.

2.2   ATTILA Radiation Transport Software
The Attila Radiation Transport Software[1] was used to evaluate several near hand exposure scenarios. Attila is a multi-group deterministic radiation transport program that is capable of modeling complex geometries efficiently and accurately to solve large 3-D problems.

Attila can solve for neutron and photon transport equations and accounts for the same transport effects as Monte Carlo but is faster as no variance reduction is required. Attila directly solves the differential form of the Boltzmann transport equation. For charged particles, the Boltzmann-Fokker-Planck transport equation is solved. It discretizes in space, angle and energy to solve for flux as a function of angle, energy and particle type, at every location in the computational domain.

3.0   Methodology

3.1   ATTILA Model Development, Mallinckrodt Example

A review of table 18, <u>Job titles and classifications with geometry factor</u>, from the *"Basis for Development of an Exposure Matrix for the Mallinckrodt Chemical Company St. Louis Downtown Site and the St Louis Airport Site, St. Louis, Missouri, Period of Operation: 1942– 1958"*[2] was made to determine the type of scenario/s for which ATTILA could be used to develop general correction factors for the lower torso of an energy worker. The lower torso is defined as those organs below the lungs in figure 1. These organs include but are not limited to the stomach, liver, kidney, gall bladder, ureter, pancreas, small intestine, large intestine, rectum, ovaries, uterus, urinary bladder, and prostate.

Using Attila, three near hand job exposure scenarios were evaluated that exemplified the range of body/source orientations for which badge correction factors could be determined. These were pitchblende/cleanup activities, ingot/machining activities and de-nitration pot activities. For development of the geometry correction factor, only the photon contribution was analyzed, since only the relative values between body locations and the photon components were of interest. For the model development, the human figure was divided into head, upper torso, badge, lower torso and hands. Dose correction factors were developed based on fluence at the badge relative to the other body locations.

It should be reiterated that the purpose of this ATTILA model was to demonstrate that, due to geometry, a relative flux factor exists between the badge and different points of the body for each of 3 source term scenarios. Because of this it was necessary to create a realistic model of a human body or provide photon fluence at those points.
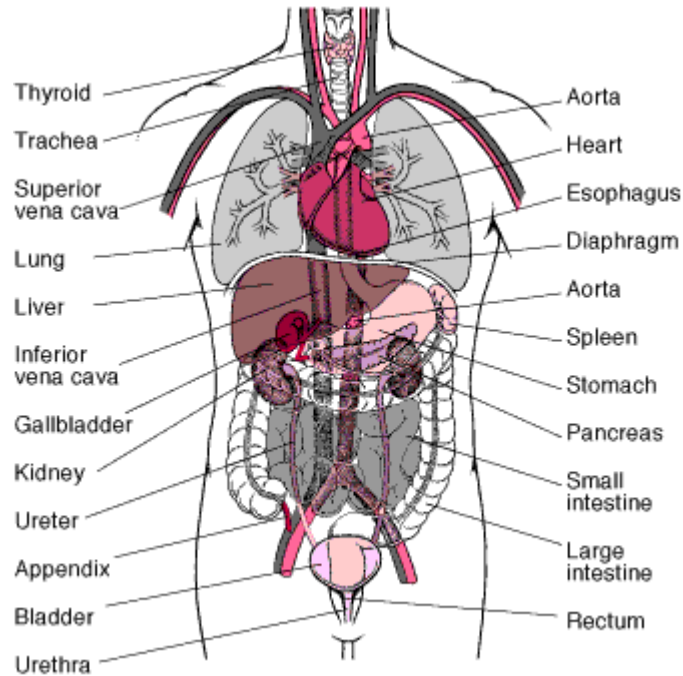
Figure 1: Diagram of Human Torso [3]

The results for pitchblende/cleanup activities, ingot/machining activities and de-nitration pot activities are provided for in figures 2, 3 and 4 respectively.   Each geometric correction factor is relative to the dosimeter/badge worn on the upper mid-chest. The human figure is six feet tall. The factors, as calculated, are provided in Table 1. Based on the ingot and pitchblende exposure scenario results, a factor of 2.1 should be applied to the lower torso. The detail of each scenario follows in the next three sections. Relational distances are provided after each figure.

Table 1 Geometry Correction Factors for Specific Jobs

Body Location	Attila Exposure Scenario		
	Ingot / Machining	Pitchblende Clean-up	De-nitration Pot
Head	0.4	0.41	0.57
Badge (Upper Chest)	1.00	1.00	1.00
Lower Torso	2.13	2.11	0.03
Hands	3.65	1.20	1.67

3.1.1 Pitchblende/Cleanup scenario

Cleanup activities at Mallinckrodt occurred on a frequent basis in several areas. The purpose of this scenario was to simulate the positional relationship between the worker and a pitchblende/cleanup spill. The material was spread in a circular pattern on the floor. This was seldom a hands-on activity.
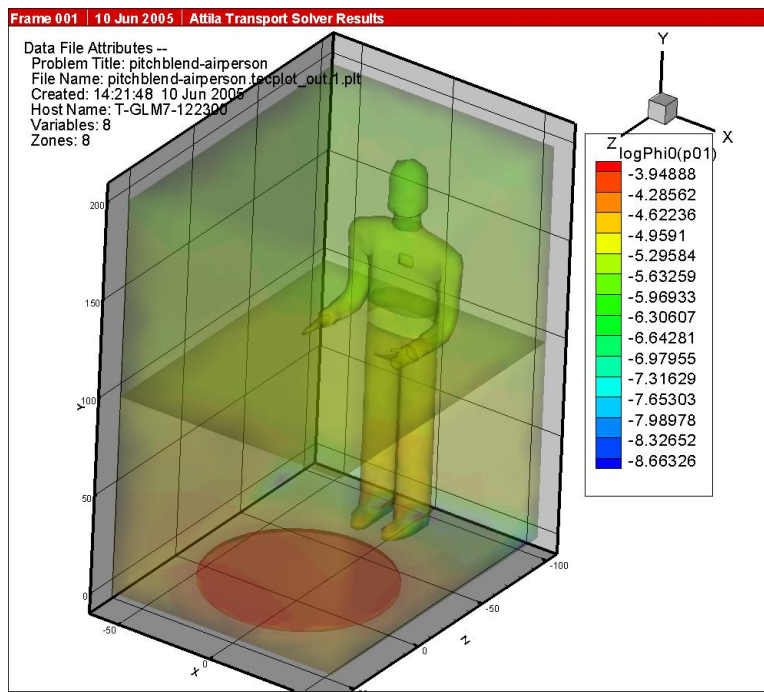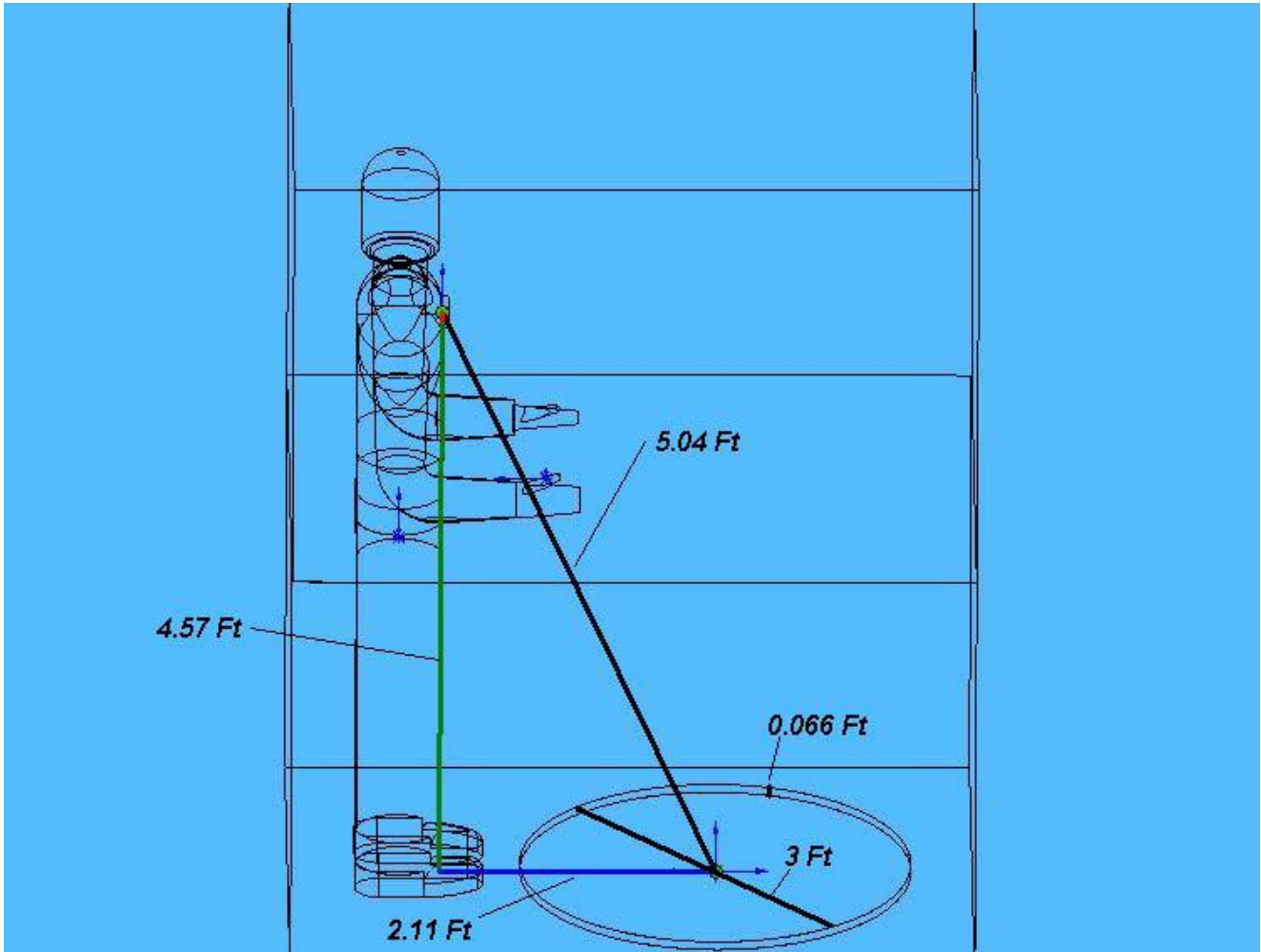

Figure 2: Pitchblende/Cleanup

Figure 2a: Dimensions for Pitchblende/Cleanup

3.1.2 Uranium Ingot Scenario

In some situations workers would come in close contact with uranium metal during machining or sawing. This scenario demonstrated the positional relationship of an ingot at waist level in close association to the worker's body.
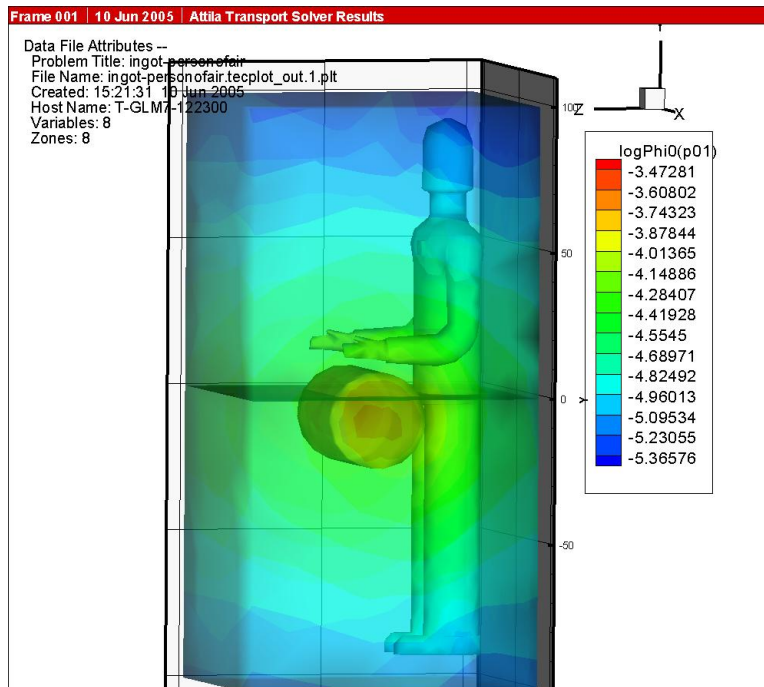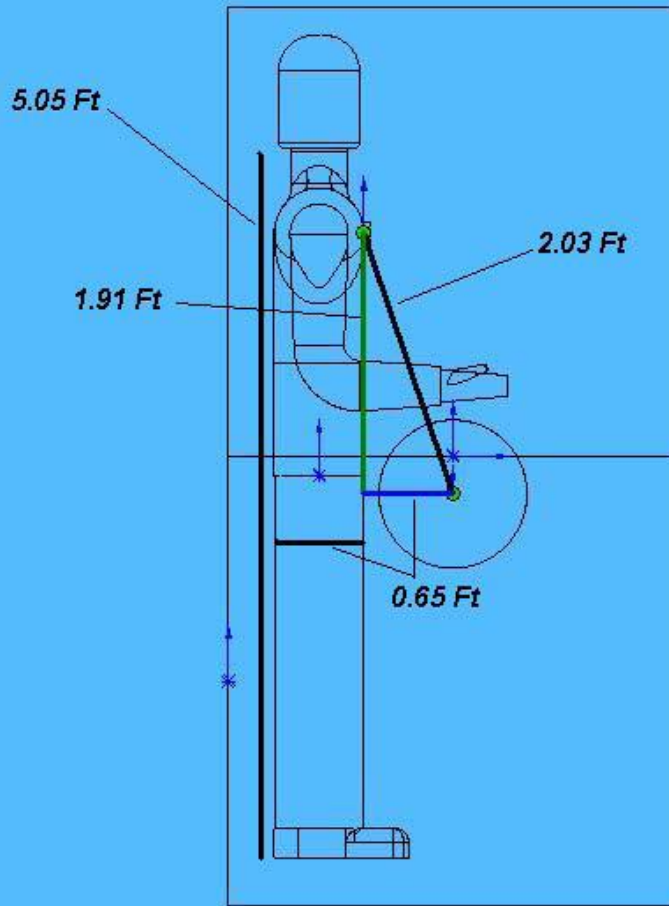

Figure 3: Ingot/Machining

Figure 3a: Dimensions for Ingot/Machining

3.1.3 De-Nitration Pot Scenario

Some activities would place a worker near a uranium de-nitration pot or drum. The individual would have the lower torso shielded by metal or some other material with the majority of photon flux being delivered to the hands, upper torso and head.
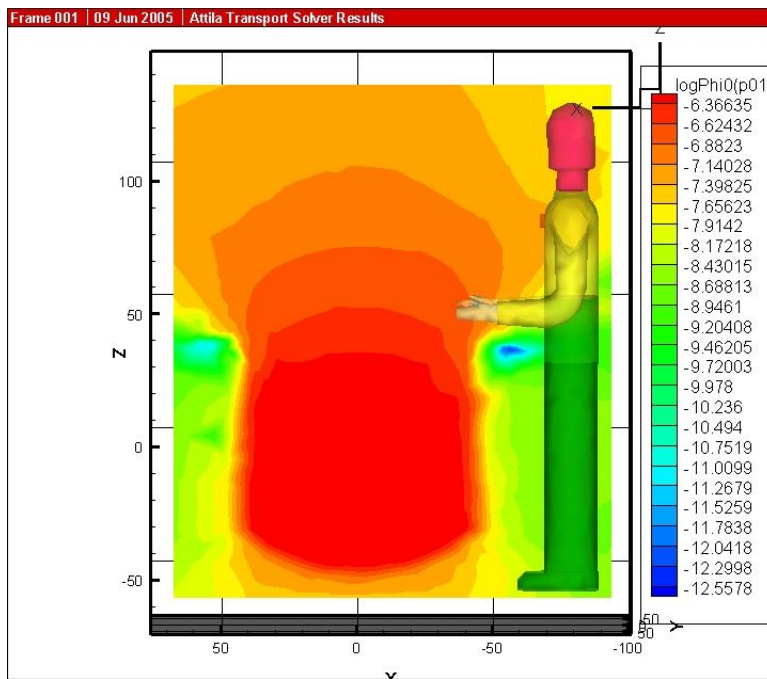

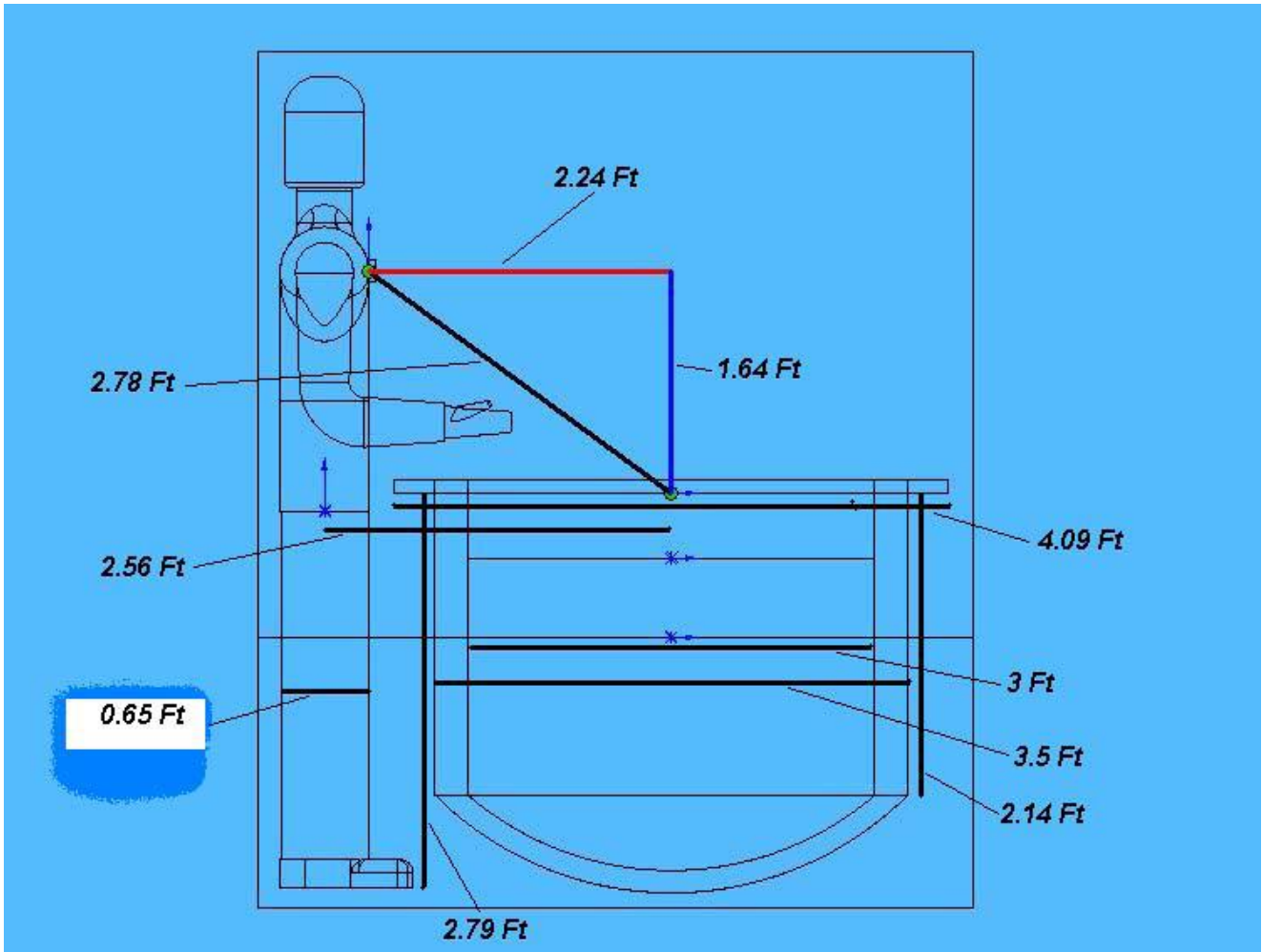Figure 4: Cut away exposure view of De-nitration Pot

Figure 4a: Dimensions for cut away exposure view of De-nitration Pot

3.2 Comparison of Attila Model Estimate to Mallinckrodt Dosimetry Data

Limited ring badge dosimetry data was used to validate the Attila modeled geometry ratio. In 1949, for a 5 week period, selected Mallinckrodt workers were issued ring dosimeters in addition to their whole body dosimeter.[4] At the current time, a full comparison of site dosimeter data is not possible since the detailed dosimetry for most of the study participants has not yet been obtained from DOE. However, for three individuals with a non-zero dose, a comparison of the ring dosimeter to whole dosimeter was possible. Table 2 provides the data comparison and the calculated geometric correction ratio. Figure 5 provides this limited data on a probability plot to indicate the range of values with the three Attila point estimates.

Table 2 Comparison of Ring Dosimeter to Whole Body Dosimeter

Study Subject	Radiation Type	Ring Dose	Whole Body Dose	Geometric Correction Ratio
1	Beta	195	85	2.29
2	Beta	95	30	3.17
1	Gamma	440	150	2.93
3	Gamma	560	275[a]	2.04
4	Gamma	460	275[a]	1.67
Maximum Attila Estimated Hand Ratio				3.65

(a) Estimated Midpoint – the data indicate whole body dosimeter was between 251 mR and 300 mR.
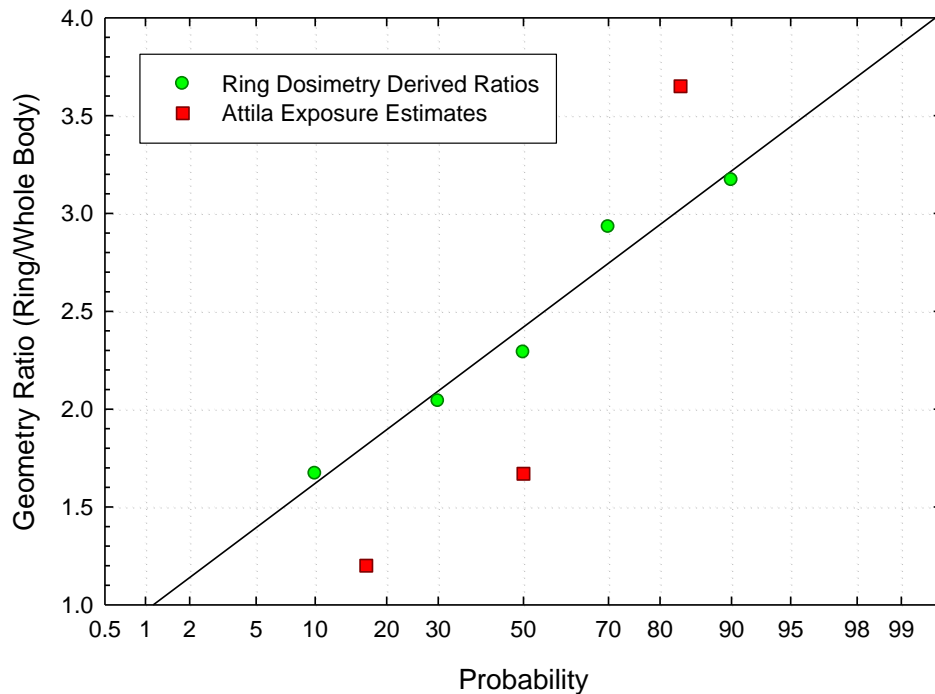
Geometric Correction Ratio for the Hands

Figure 5: Probability Plot of Attila modeled point estimates and limited
ring dosimetry comparison data.

The limited dosimetry data clearly indicate that the model reasonably predicts the geometric correction factor.   As a result, the dose reconstruction to organs in the lower torso should multiply the measured and the missed dose by the factor 2.1 as indicated by the Attila model.

Also for comparison, the geometry factors generated from ATTILA and used in the Glove Box Worker Technical Information Bulletin 00010 provide a reasonable idea of the spread of ratio values between upper and lower torso.   The geometric mean and standard deviation of the glove box are as follows: 2.19 and 1.34 respectively. This spread is based on a Crystal Ball Monte Carlo analysis of 30 different upper and lower torso points. Since this is only geometry dependent, it would hold for this TIB as well.

3.2.1 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 model design. Human figure is 6 ft tall, above the average. The correction factor over-estimates dose for shorter persons.
- Assignment of badge results where actual reduction due to geometry occurs
- Assignment of correction factor for all tasks within the job classification

Obtaining data to precisely evaluate each of these parameters requires extensive time and research on an individual basis and in some instances it is not known if the information can be obtained (i.e., facility has undergone D&D or other significant modification over time).

4.0   Application of Geometry Correction Factor

It should be noted however that there is a significant reduction in dose to the head for all scenarios. In addition, due to shielding provided by the De-nitration Pot, there was also a significant reduction in dose to the lower torso. Assigning the badge dose to these body locations is claimant favorable. However, as illustrated in Table 1, there are some organs in certain exposure scenarios for which dose could be underestimated.

In a review of selected work histories and dust study estimates of internal exposure, it is clear that most operators conducted various different tasks over their career. As a result the application of a single factor over their entire work history is also considered claimant favorable as some tasks would involve near-hand exposures while others would not.

As noted there are numerous different work stations (tasks) for which a geometry correction factor should be applied to accurately estimate the dose to organs in the lower torso from a film badge worn on the lapel. For example, a review of the claimant work history information in conjunction with the job descriptions (Tasks) in Table 18 of the Mallinckrodt technical basis document indicates that many Production and Chemical Operators worked at various stations, some of which require a geometry correction and some do not. Time estimates used in the dust studies could be used to estimate the fraction of time a worker would be in one geometry versus another; however, the external dose cannot be reasonably partitioned based on time since the external dose rate changes from location to location. In addition, trades and crafts workers conducted work in and around radioactive materials throughout the facility. As with chemical and production operators, time motion dust study data could be used to estimate the general time they were in a specific area; however, the external dose

rates changed such that it is not practical to partition the dose measured on the lapel dosimeter accordingly.

As a result, the additional claimant favorable assumption is made that the geometry correction factor should be applied to all measured and missed dose for the general occupations listed in Table 3.

Table 3 Job Types for which the geometric correction factor should be applied.

General Category	Specific Job Titles
Operators and Material Handlers	Chemical Operator, Production Operator, Material Handler
Trades and Crafts	Pipefitters, Carpenters, Welders, Sheet Metal Workers, Electricians, Foremen, etc…

It should be noted, however, that occupations other than those listed above should be evaluated on a case by case basis to determine if a correction factor should be applied. A review of the current active Mallinckrodt claims indicates that the application of a geometric correction factor would not be appropriate for a significant fraction (≈43%) of the current Mallinckrodt claimant population. Figure 6 provides the general occupation distribution of the current claims received for Mallinckrodt workers.

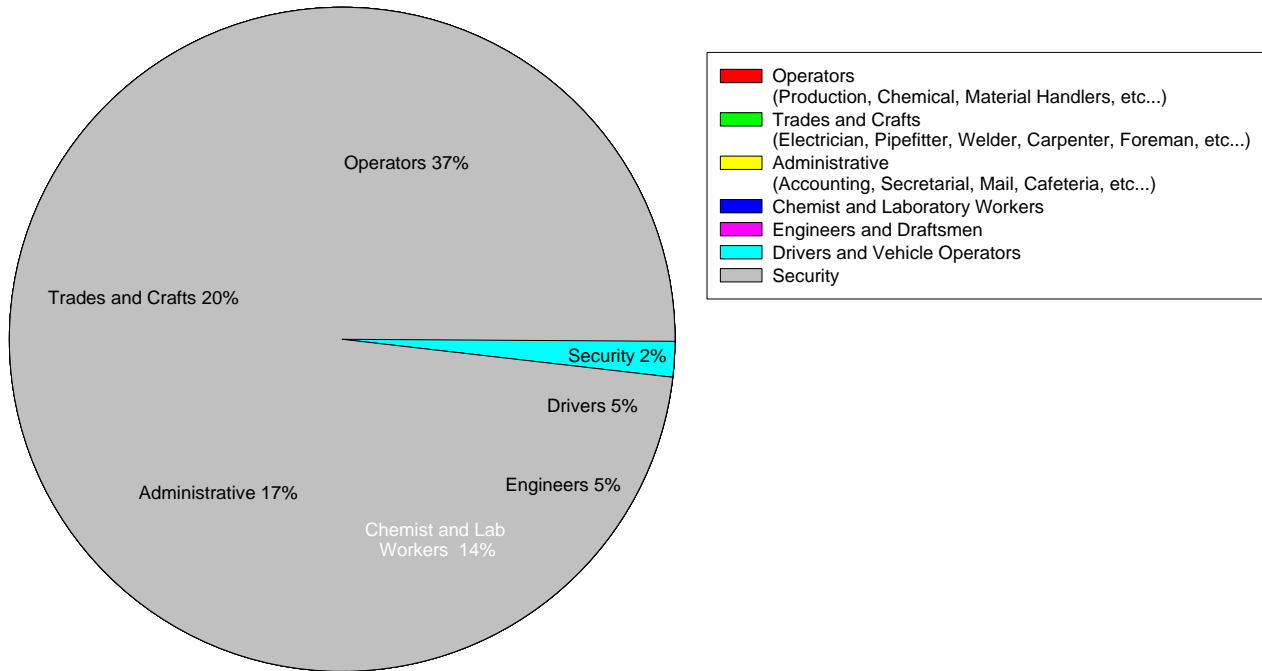Active Mallinckrodt Claims Occupations

Figure 6: Breakdown of Active Mallinckrodt Claims

5.0   Summary

This Technical Information Bulletin provides guidance for dose reconstruction to organs located in the lower torso. For dose reconstruction to organs in the lower torso the measured and missed dose should be multiplied by the factor 2.1 for all members of the general job categories of Table 3.

This TIB can be used for all uranium process facilities using the methods described for Mallinckrodt.

6.0   References

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

2.   ORAUT (2005), *Basis for Development of an Exposure Matrix for the Mallinckrodt Chemical Company St. Louis Downtown Site and the St Louis Airport Site, St. Louis, Missouri, Period of Operation: 1942–1958.* ORAUT-TKBS-0005, Rev 1.

3.   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

4.   MCW Memorandum (1949), Memo from A Piccot to K. Caplan providing results of the analysis of the film rings worn beginning April 25, 1949 through May 30, 1949.

5.   Best Estimate External Dose Reconstruction for Glovebox Workers, DCAS-TIB-0010-Rev-3.