EVALUATION OF INTERNAL CONTAMINATION LEVELS AFTER A RADIOLOGICAL DISPERSAL DEVICE USING PORTAL MONITORS

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EVALUATION OF INTERNAL CONTAMINATION LEVELS AFTER A RADIOLOGICAL DISPERSAL DEVICE USING PORTAL MONITORS

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Activity Median Aerodynamic Diameter	(AMAD)
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Becquerel	(Bq)
Cesium 137	(Cs-137)
Cobalt 60	(Co-60)
Counts per Second	(CPS)
Dose and Risk Calculation Software	(DCAL)
International Commission on Radiological Protection	(ICRP)
Iodine 131	(I-131)
Iridium 192	(Ir-192)
Medical Internal Radiation Dose	(MIRD)
miliSievert	(mSv)
Monte Carlo N-Particle Transport Code	(MCNP)
National Council on Radiation Protection and Measurements	(NCRP)
Oak Ridge National Laboratory	(ORNL)
Polymethyl Methacrylate	(PMMA)
Radiological Dispersal Device	(RDD)
Radiological Toolbox	(Rad Toolbox)
Sodium 22	(Na-22)

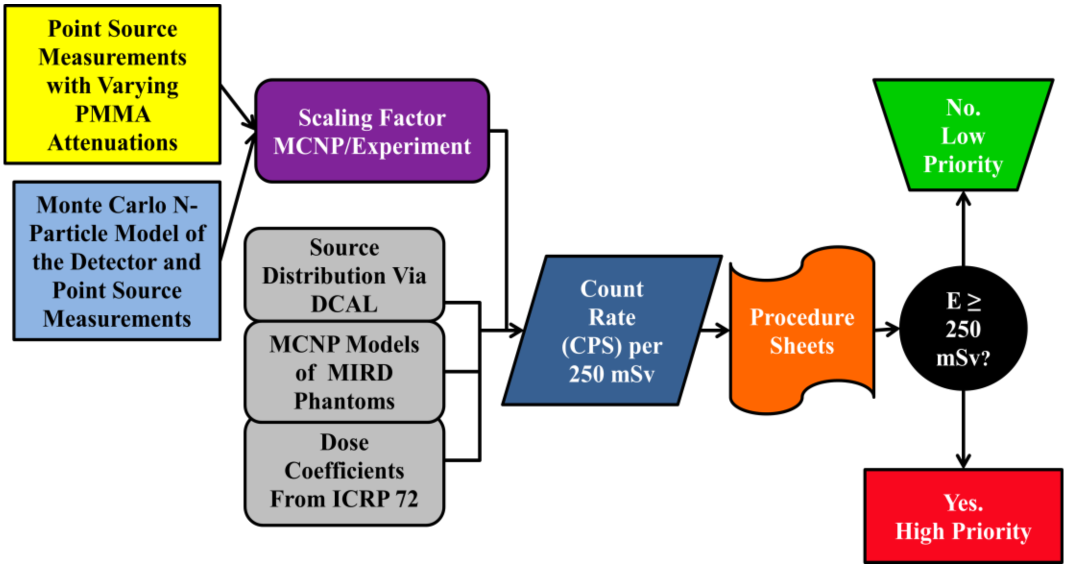
SUMMARY

In the event of a radioactive dispersal device (RDD), the assessment of the internal contamination level of a large number of potential victims is necessary to determine if immediate medical follow-up is necessary. Since the current capacity to screen a large population by traditional whole body counting or laboratory analysis of urine specimen is limited, any means to quickly screen the population and prioritize victims for further analysis would be a valuable tool for emergency responders. Previously, hand-held gamma radiation detectors have been investigated for rapid screening. In this study, Thermo Scientific's TPM-903B Portal Monitor was investigated to determine if it is a suitable first cut screening tool for internal contamination assessment of victims. The TPM-903B was chosen for this study because it is readily accessible, transportable, easy to assemble, and provides whole body count rates. The portal monitor was modeled in Monte Carlo N-Particles Transport Code Version 5 (MCNP) [26]. This computational model was validated against the portal monitor's response to a series of benchmark measurements made with four point sources and performed in a polymethyl methacrylate (PMMA) slab box.

Using the validated MCNP detector model, in conjunction with MCNP models of six MIRD male and female anthropomorphic phantoms, the response of the portal monitor was simulated for the inhalation and ingestion of airborne radionuclides from an RDD. The detectable radionuclides investigated were Co-60, Cs-137, I-131 and Ir-192. The following six phantoms were considered in conjunction with the aforementioned

radionuclides: Reference Male, Reference Female, Adipose Male, Adipose Female, Post-Menopausal Adipose Female, and 10-Year-Old Child.

Biokinetics via Dose and Risk Calculation Software (DCAL) were used to determine the distribution of the radionuclides in the phantoms over a period of 30 days [7]. DCAL was implemented for both the inhalation and ingestion pathways. The MCNP simulation output was multiplied by the DCAL to determine the count rate per Bq for each radionuclide, phantom type and internal contamination pathway for a period of 30 days after exposure. ICRP 72 dose coefficients were employed to determine the count rate of the detector associated with the committed effective dose of 250 mSv [8, 17]. These count rates, referred to as trigger levels, were listed in internal contamination procedure sheets, which can be used by emergency response personnel to triage victims. The process used to develop the procedure sheets is summarized in the following flow chart. Victims with count rates approximately equal to or greater than the trigger levels will have a higher priority for further testing and possible treatment. There are four procedure sheets in total, two for adults and two for children. For each victim type there is an inhalation procedure sheet and an ingestion procedure sheet in which trigger levels for Co-60, Cs-137, I-131 and Ir-192 are listed for up to 30 days after exposure.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Dose Coefficients From ICRP 72
Count Rate (CPS) per 250 mSv
Procedure Sheets
E ≥ 250 mSv?
No. Low Priority
Yes. High Priority

CHAPTER 1: INTRODUCTION

With the risk of terrorist attacks facing the United States, preparation to respond to terrorist attacks which utilize radiological and nuclear devices is imperative. One such device is the radiological dispersal device, or RDD. An RDD is any method of dispersing radioactive material; this can be done through active or passive means. An active method would be through an explosive device, referred to as a dirty bomb; while examples of passive methods include an aerial release of a radionuclide or contamination of a water supply [19]. In addition to causing harm and destruction, an RDD is used to create panic [1].

For individuals in the immediate vicinity of an RDD, external and internal contamination could potentially occur. Since it is not possible to see, smell, feel or taste radiation, individuals in the vicinity of the RDD will need to be evaluated for radioactive contamination. The majority of external contamination can be removed by removing clothing and washing with soap and water [19]. Once the external contamination is removed, evaluation of internal contamination should take place. When an RDD occurs there are two possible pathways of internal contamination; the first and most probable pathway is inhalation and the second pathway is ingestion.

In the event of an RDD, the triaging of a large population may be necessary. In the triage decision making process it is necessary to distinguish individuals who are internally contaminated from those who are clean or whose contamination level is below the screening threshold. The goal is to utilize first cut screening tools to identify individuals in the public who have received a committed effective dose of at least 250 mSv for the purpose of further testing and possibly treatment. NCRP 161 recommends

250 mSv as the threshold value for further testing and possible treatment; for this reason 250 mSv was chosen as the committed effective dose value of interests in this study [17].

Conventional methods to determine internal contamination include *in-vitro* monitoring through bioassay and *in-vivo* monitoring through non-portable whole body counters. Bioassays of urine, feces, nose blow, or blood can be performed to "determine quantity, location and retention of radionuclides in the body" [13]. However, all bioassay samples, other than the nasal swab for the nose blow bioassay, must be taken by organizations that specialize in handling blood and excreta samples [13]. In addition, with both *in-vitro* and *in-vivo* conventional screening methods, only a limited number of victims can be screened. Since a large population could potentially be affected by an RDD, quick preliminary methods are needed to prioritize individuals for further testing via conventional methods.

Three types of radiation can be emitted by radionuclides: alpha, beta, and gamma. Quick preliminary methods for evaluating contamination of individuals are needed for each type of radiation. Using criteria such as radiological toxicity, quantity, half-life, and dispersibility, the DOE and NRC have identified particular radioisotopes as isotopes of greatest concern for use in an RDD [22]. For gamma emitting radionuclides of greatest concern, several detectors have previously been evaluated as first cut screening tools, including Canberra's 802-2x2-inch Sodium-Iodide Detector and two Geiger-Mueller pancake probe detectors [6,16]. Building upon the previous detector evaluations, this work focused on determining the validity of using portal monitors as a first cut screening tool for possible internal contamination of gamma emitting radionuclides; specifically cobalt-60, cesium-137, iodine-131, and iridium-192. This work was performed with an end goal of developing procedure sheets that can be used by emergency response personnel to prioritize people for further screening, laboratory analysis, and possible treatment.

Portal monitors have several features that make them useful when a large population is potentially affected by an RDD. These features included their transportability, ease of assembly and operation, and their wide availability. Because of the long linear extent of the detector in the vertical direction, portal monitors act as whole body counters, this means that only one measurement needs to be taken. The ability to collect a whole body count with a single measurement helps to increase the already relatively large throughput, which is very important for first cut screening tools. This work was performed for the Centers for Disease Control and Prevention (CDC), headquartered in Atlanta, Georgia. The state of Georgia has a acquired TPM-903B Portal Monitors by Thermo Scientific; two portal monitors for each of the 18 health districts and the same model portal monitor was purchased for a number of selected hospitals throughout the state. For this reason Thermo Scientific's TPM-903B Portal Monitor was investigated in this research to determine if it is suitable to assay the level of internal contamination of victims. This study does not imply an endorsement of this or any particular instrument model and a similar approach can be used to investigate other manufacturers' portal monitors.

CHAPTER 2: METHODOLOGY AND MATERIALS

In order to determine the feasibility of portal monitors as first cut screening tools, a series of point source measurements (benchmark measurements) were taken with the TPM-903B Portal Monitor. These measurements were performed for several different point sources surrounded by various thicknesses of polymethyl methacrylate (PMMA). The TPM-903B Portal Monitor, point sources and PMMA geometries were modeled in Los Alamos's Monte Carlo N-Particle Transport Code, Version 5 [26]. The MCNP detector model was validated by comparison against the portal monitor's actual measurements. A scaling factor between the model and measured values was calculated by dividing the MCNP counts by the measured counts. Once the detector model was validated, MCNP models of MIRD phantoms and the portal monitor were combined with organ concentrations from Dose Calculation Software (DCAL) and ICRP 72 Dose Coefficients to determine the count rate corresponding to a committed effective dose of 250 mSv. These count rates were then used to produce internal contamination procedure sheets for the use of portal monitors as first cut screening tools.

2.1 TPM-903B Portal Monitor

Thermo Scientific's TPM-903B Transportable Radiation Portal Monitor was investigated. This portal monitor consists of two BC408 plastic scintillators, with a total volume of 10.4 liters, surrounded on the three exterior sides by 1.6 mm of lead shielding and encased in PVC piping. According to Thermo Scientific's website the TPM 903B Portal Monitor detects gamma rays in the energy range of 60 keV to 2 MeV, weighs approximately 90 pounds, and operates in temperatures ranging from -4 to 122 degrees

Fahrenheit [23]. The TPM-903B Portal Monitor's output is counts per second. A picture of the TPM-903B Portal Monitor is shown in Figure 2.1.1 below [23].

Figure 2.1.1. Thermo Scientific TPM-903 B Transportable Radiation Portal Monitor

2.2 PMMA Benchmark Measurements

Benchmark measurements were performed using a source box composed of 6 mm thick PMMA sheets. A source holder consisting of a 6mm PMMA slab with a center cut out for the placement of a cylindrical source was inserted in the center of the PMMA box. Once the source was placed, varying thicknesses of PMMA were positioned on each side of the source holder between the source and the detector as shown below in Figure 2.2.1. Measurements were taken at 13 different PMMA thicknesses ranging from 6 mm to 115 mm on each side of the source holder (including the source box thickness). For each measurement the count rate per second was averaged over a time interval of one minute for greater accuracy.

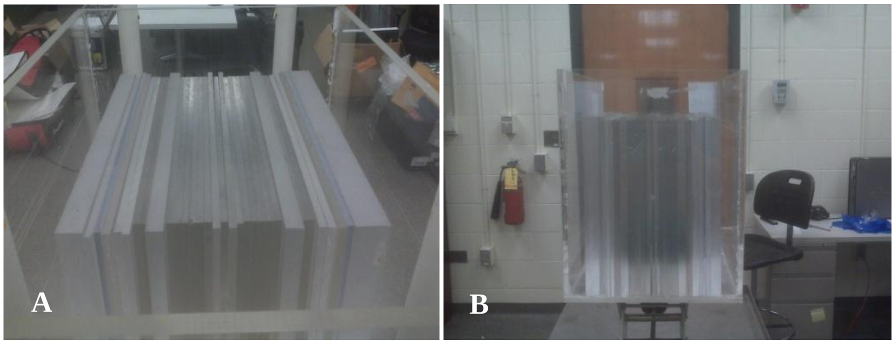

Figure 2.2.1. PMMA Box with Source Holder and PMMA Sheets A) View 1; B) View 2

In the benchmark measurements, PMMA was used because its attenuation of photons is similar to that of tissue and the multiple thicknesses of PMMA served to represent the attenuation effect of varying tissue thicknesses between the source and the detector. The 13 different PMMA thickness measurements were repeated for each of the following radioisotopes: barium 133, cobalt 60, cesium 137, and sodium 22. These four isotopes were chosen because they represent a wide range of photon energies, 30 keV to 1.33 MeV, with sufficient photon emission intensities that lie within the TPM-903B's detectable energy range of 60 keV to 2 MeV. The properties of the isotopes used for point source measurements are shown below in Table 2.2.1. Photon energies and intensities were taken from Rad Toolbox [8].

Table 2.2.1. Isotopes Used in the Point Source Measurements and MCNP Models

Isotope	Photon Energy (MeV)	Photon Emission Intensity
Ba-133	0.384, 0.356, 0.303, 0.276, 0.081, 0.035, 0.031, 0.030	0.089, 0.622, 0.184, 0.071, 0.338, 0.122, 0.631, 0.341
Co-60	1.332, 1.1730	0.999, 0.999
Cs-137	0.662, 0.0322, 0.0318	0.898, 0.0392, 0.0213
Na-22	1.275, 0.511	0.999, 1.798

The benchmark measurements were taken with the source box located in five different positions. For three of the positions, the source box was centered in the portal monitor, as illustrated in Figure 2.2.2. In the first location, position 1, the source was at a height of 140 cm from the floor, while the height of position 2 was 133 cm and position 3 was 116 cm. For the other two benchmark measurement positions the source box was at a height of 133 cm and was positioned 50 cm outside the center of the portal monitor on either side.

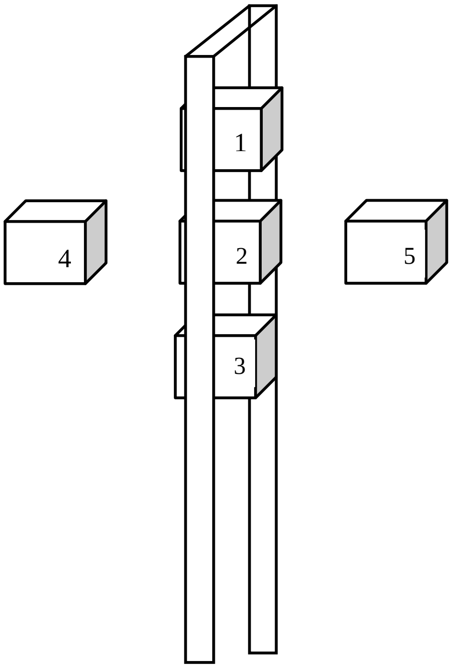

Figure 2.2.2. Source Box Positions with Respect to the Portal Monitors

Cesium-137 was used in additional measurements to better identify the dependence of the count rate on source position. These 27 additional measurements were taken with nine different positions at three different heights and minimum attenuation. The positions of the 27 measurements are illustrated below in Figures 2.2.3 and 2.2.4.

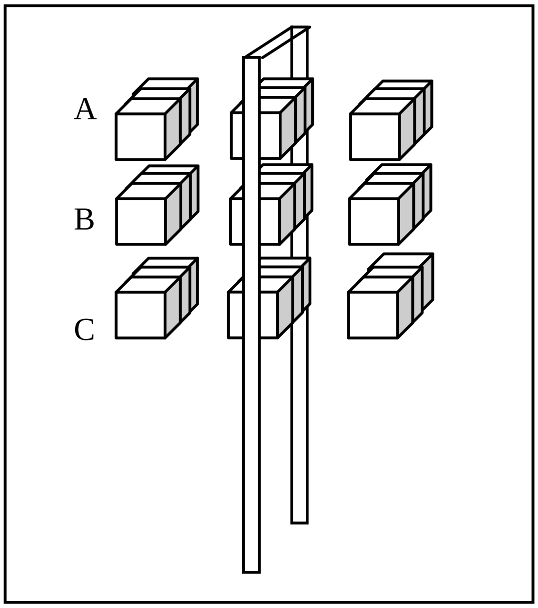

Figure 2.2.3. PMMA Box Orientation for Source Positional Data

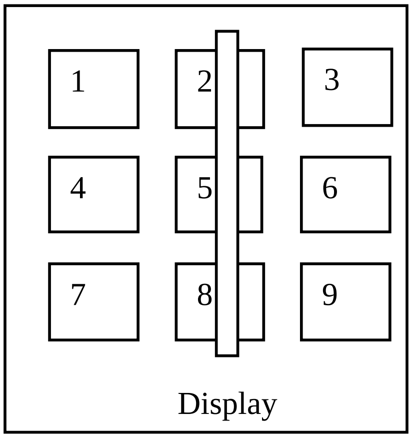

Figure 2.2.4. PMMA Box Orientation for Source Positional Data, Bird's Eye View

2.3 TPM-903B MCNP Model Validation

The TPM-903B Portal Monitor and the benchmark measurements were modeled in MCNP. The benchmark measurements were modeled for the four isotopes for all thicknesses and source positions, resulting in 260 MCNP input files. A pulse height tally was executed over the BC408 material. This pulse height tally gave the pulse height spectra for each isotope, PMMA thickness, and position as the normalized intensity in each energy bin per source particle. The count rates from the MCNP simulations were then calculated by summing the MCNP pulse height tally and multiplying it by the activity of the source and the photons per decay. The resulting simulated count rates were then compared to the actual count rate readings obtained during the benchmark measurements. The ratio of MCNP count rates to the measured count rate were computed and analyzed for all four isotopes and all 13 PMMA thicknesses. The analysis of the ratios of the MCNP count rate to measured count rate included determining an energy cutoff to be used in modeling the TPM-903B. The energy cutoff was determined by summing the MCNP pulse height tally above various lower energy cutoffs and finding the ratio that was most consistent over the varying thicknesses for all isotopes and positions. The energy cutoff was then applied to all simulation results by summing the MCNP pulse height tally for energies above the cutoff energy.

The computational to measurement ratios were evaluated for the three different source heights inside the detector zone. The resulting ratios were then averaged for each isotope to obtain the scaling factor. Here the scaling factor refers to the mean value of the ratio for a given isotope over all thicknesses and averaged for different height locations.

This scaling factor can be used to adjust the simulated response for other more complicated geometries.

2.4 MIRD Phantoms

Using the validated MCNP5 model, in conjunction with MCNP models of the Medical Internal Radiation Dose (MIRD) male and female anthropomorphic phantoms, the response of the portal monitors were simulated for the inhalation and ingestion of airborne radionuclides considered radioisotopes of concern in the event of an RDD [22]. The four radioisotopes considered in this research were cobalt-60, cesium-137, iodine -131, and iridium-192. Along with these four isotopes, six MIRD based phantoms were considered: Reference Male, Reference Female, Adipose Male, Adipose Female, Post-Menopausal Adipose Female, and 10-Year-Old Child. Six anthropomorphic phantoms were used to provide the distribution of count rates corresponding to a committed effective dose of 250 mSv over a wide range of body shapes.

The Reference Male and Reference Female phantoms were developed at Oak Ridge National Laboratory [5]. The three adipose phantoms were developed at Georgia Institute of Technology, by adding adipose tissue to the Reference Male and Reference Female and the model of the 10 year old androgynous child was constructed using Body Builder [21, 24]. The characteristics of the six anthropomorphic phantoms are summarized below in Table 2.4.1.

Table 2.4.1. Characteristics of the Six Anthropomorphic Phantoms

Phantom	Height (cm)	Mass (kg)	Body Mass Index
Reference Male	179	73.1	23
Reference Female	168	56.5	20
Adipose Male	179	93.7	30
Adipose Female	168	73.9	26
Post-Menopausal Adipose Female	168	85.9	30
10 year old Child	140	32.7	n/a

2.5 Biokinetics and Trigger Levels

Biokinetics via Dose and Risk Calculation Software (DCAL) were implemented to determine the distribution of the radionuclides for both inhalation and ingestion pathways. Developed at Oak Ridge National Laboratory, DCAL lists the amount of radioactivity distributed in each organ of interest in the body as a function of time [7].

Dose coefficients obtained from Rad Toolbox were employed to determine the count rate of the detector associated with specific dose limits [8]. A committed effective dose of 250 mSv was chosen as the specific dose limit for this study because NCRP 161 recommends that this effective dose value be used “as a screening level indicating the need for a more detailed investigation of tissue-specific absorbed doses” [17]. Therefore, the count rates corresponding to a committed effective dose of 250 mSv were determined for the various isotopes and phantoms. These count rates, referred to as trigger levels, were then compiled into pocket-sized sheets to be used by first responders during the triaging of victims following an RDD.

2.6 Assumptions

In order to characterize the detectors for use in the event of an RDD, assumptions had to be made. The first assumption made was that all external contamination will be removed by showering and changing clothing before the victim enters the portal monitors. In addition, the results of this research will only be used for first stage triage of internal contamination. The procedure sheet count rates correspond to a committed effective dose of 250 mSv and further evaluation is needed for people with count rates equal to or higher than the procedure sheet count rates. It is also assumed that only one isotope is used in the RDD, and that the isotope has been identified prior to triage. Finally, it was assumed that the first cut screening of the victim will occur between six hours and 10 days after the time of contamination of the victim and that the initial time of inhalation or ingestion by the victim is known.

CHAPTER 3: COMPUTATIONAL MODELS

3.1 TPM-903B Portal Monitor Model

A detailed MCNP model of the TPM-903B was constructed for use in photon transport simulations. Included in the model were the two BC408 plastic scintillators with dimensions of 183.0 x 7.5 x 3.8 cm, the lead shielding around the three sides, the PVC piping, and the aluminum feet. The dimensions of the TPM-903B were measured on the physical device. A VisEd representation of the TPM-903B MCNP model is shown in Figure 3.1.1.

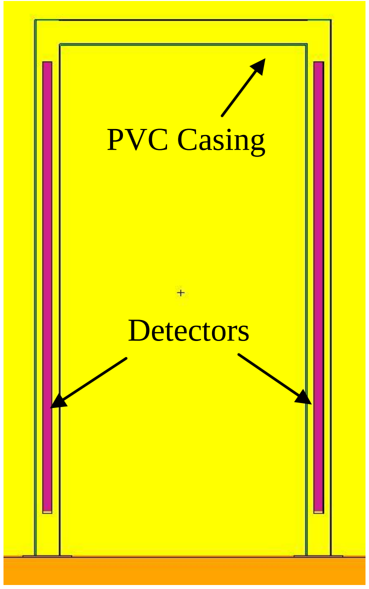

Figure 3.1.1. VisED Representation of TPM-903B MCNP Model [20]

The density and composition of the materials used in the MCNP model of the TPM-903B are listed below in Table 3.1.1 [14,18].

Table 3.1.1. Materials Used in Portal Monitor Computations

Material	Density	Composition
BC408	1.032 g/cm^3	91.5% carbon & 8.5% hydrogen
PVC Piping	1.32 g/cm^3	56.7% chlorine, 38.5% carbon & 4.8% hydrogen
Lead Shielding	11.3 g/cm^3	100% lead
Aluminum Feet	2.7 g/cm^3	100% aluminum
Air	1.2(10^{-3}) g/cm^3	75.5% nitrogen, 23.2% oxygen, 1.28% argon & 0.012% carbon

3.2 PMMA Benchmark Model

Once the detailed MCNP model of the portal monitor was complete, the source, PMMA box, and PMMA attenuation slabs were added to the MCNP model to simulate the benchmark measurements. Models were created for all sources, source positions, and attenuation thicknesses. To simulate the detector response for each MCNP input file, a pulse height tally was performed over the BC408 material, giving the pulse height spectra for each isotope, PMMA thickness, and position as the normalized intensity in each energy bin per source particle.

VisED representations of the MCNP models of the benchmark measurements are shown below in Figure 3.2.1, and a sample MCNP input file for the TPM-903B and benchmark measurement can be seen in Appendix A [20].

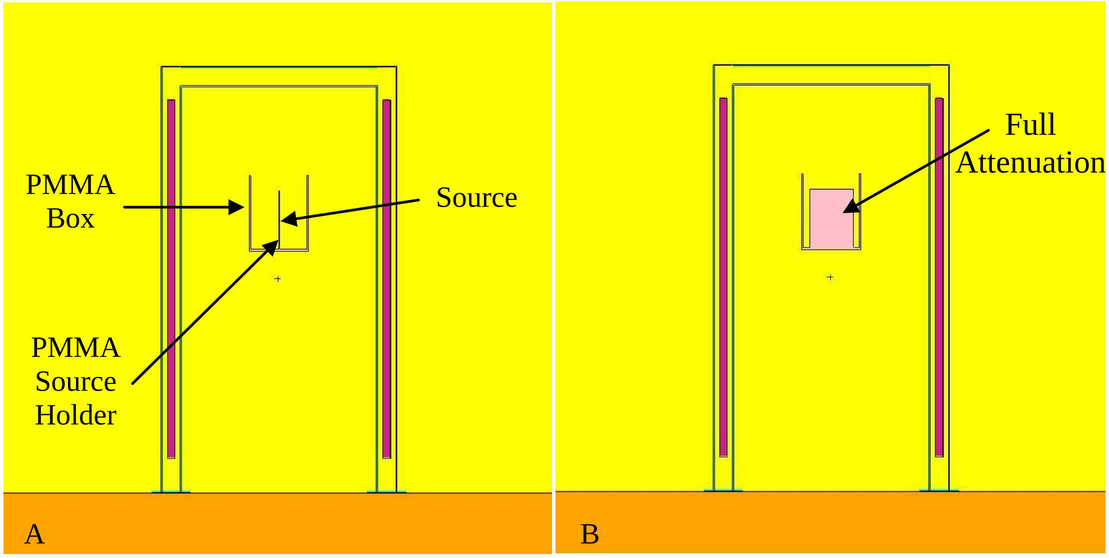

Figure 3.2.1. MCNP Model of the Benchmark Measurements for Position 2 as Displayed in VisEd A) Minimum Attenuation B) Maximum Attenuation

The density and composition of the materials used in modeling the PMMA box and attenuating PMMA are listed below in Table 3.2.1, and the assay data of the four sources used during the benchmark measurements is summarized below in Table 3.2.2 [18].

Table 3.2.1. Materials Used in Modeling PMMA Box

Material	**Density**	**Composition**
PMMA	1.19 g/cm^3	60.0% carbon, 32.0% oxygen & 8.0% hydrogen
Air	1.2(10^{-3}) g/cm^3	75.5% nitrogen, 23.2% oxygen, 1.28% argon & 0.012% carbon

Table 3.2.2. Assay Data of Isotopes Used in the Slab Measurements

Isotope	Assay Date	Initial Activity (μCi)	Half Life (y)	Experiment Date	Experiment Activity (μCi)
Ba-133	12/13/05	5.2	10.7	7/29/10	3.9
Co-60	12/09/05	5.1	5.27	7/29/10	2.8
Cs-137/Ba-137m	12/09/05	4.9	30.0	7/29/10	4.4
Na-22	12/09/05	5.0	2.60	7/29/10	1.5

3.3 MIRD Phantom Model

In order to simulate the response of the portal monitors to internal radiation in humans, six anthropomorphic human phantom MCNP models were used in conjunction with the MCNP TPM-903B Portal Monitor model. In the MCNP simulation, the phantom was placed such that the anterior and posterior sides of the phantom faced the elements of the detector. This orientation was chosen to achieve the highest count rate and is the suggested orientation of potentially contaminated individuals in the procedure sheets listed in Appendix D. An example MCNP input file of the Reference Male phantom inside the TPM-903B with an I-131 source is presented in Appendix B. The VisED representations of the MCNP Reference Male, Adipose Male and Child phantoms are shown below in Figure 3.3.1 [20].

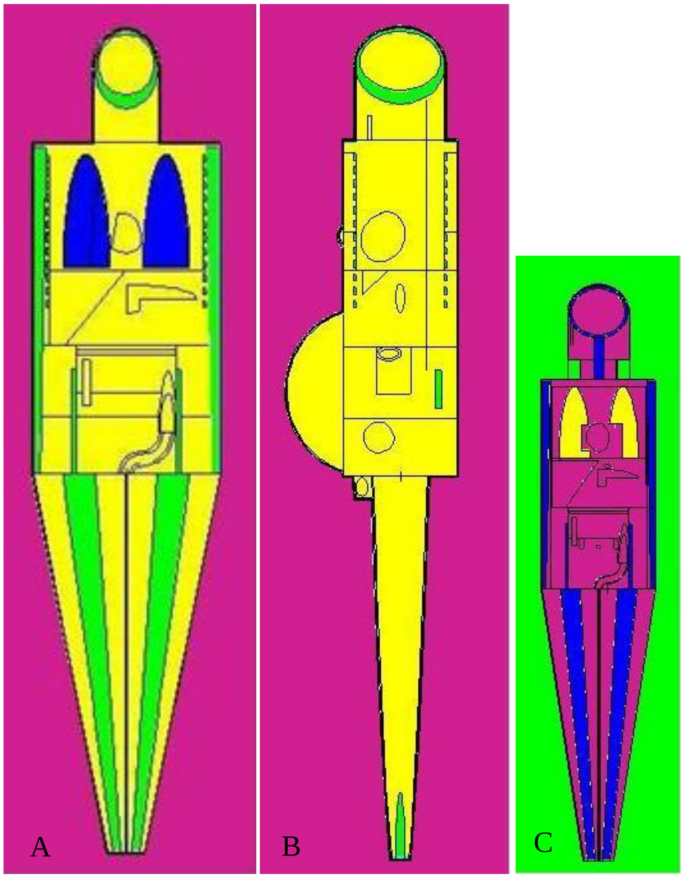

Figure 3.3.1. MCNP Models the Reference Male, Adipose Male and Child as Displayed VisEd A) Frontal View of Reference Male Phantom B) Side View of Adipose Male Phantom C) Frontal View of Child Phantom

The distributions within the human body of the four radionuclides investigated in this work as potential RDD isotopes vary with radioisotope, contamination pathway, and time. The organs of interest in the MIRD phantoms for each radioisotope (Co-60, Cs-137, I-131 and Ir-192) were ascertained using biokinetic modeling. DCAL was implemented for the biokinetic modeling to determine the concentration of each radionuclide over a 30 day period after internal contamination for both inhalation and ingestion pathways. For each radionuclide-phantom-pathway combination, a unit source was placed in each organ of interest and a pulse height tally was performed to obtain the counts per unit source for each organ. To identify the organ in which each source particle originated, an SCX special treatment for the pulse height tally was implemented [26]. The MCNP output was then multiplied by the number of particles per decay to give the count rate per Bq for each organ of interest. These steps were repeated for all radionuclide-phantom-pathway combinations.

3.4 Biokinetic Modeling and Trigger Levels

The MCNP pulse height tally output was used in conjunction with Oak Ridge National Laboratory's Dose and Risk Calculation Software (DCAL) and Radiological Toolbox to evaluate trigger levels corresponding to a committed effective dose of 250 mSv for each radionuclide of interest and each phantom. The MCNP pulse height tally for each MIRD organ, or region of interest for a particular isotope, was summed for all energies above the energy cutoff. The sum was then multiplied by the number of photons per decay converting the MCNP output of intensity (or fraction of count) to counts per second (CPS) per Bq, as shown in the equation below. For each radionuclide, the number of photons per decay was determined using Rad Toolbox [8].

$$\frac{Fraction\ of\ Counts\ in\ Sum\ of\ Energy\ Bin}{1\ Particle} \times \frac{Number\ of\ Partilces}{1\ Decay} = \frac{CPS}{Bq}$$

The resulting CPS per Bq for each organ of interest in each phantom was multiplied by the corresponding biokinetics, determined by DCAL, for each radionuclide and region of interest. The DCAL software was run twice for each of the four radioisotopes of concern; the mode of uptake was set to inhalation on the first run and ingestion on the second. The method of uptake for both scenarios was set to environmental and the particle size activity median aerodynamic diameter (AMAD) was set to 1µm for both scenarios in DCAL. The CPS per Bq results were used along with the DCAL from the two different modes of uptake to calculate two sets of values, one for inhalation and one for ingestion. The DCAL outputs for Cs-137 and I-131 are displayed in Figures 3.4.1-3.4.4. The DCAL outputs for these two radionuclides illustrate the variations in source distribution in the body based on the radionuclide; Cs-137 distributes relatively evenly throughout the body and I-131concentrates in a specific organ, the thyroid.

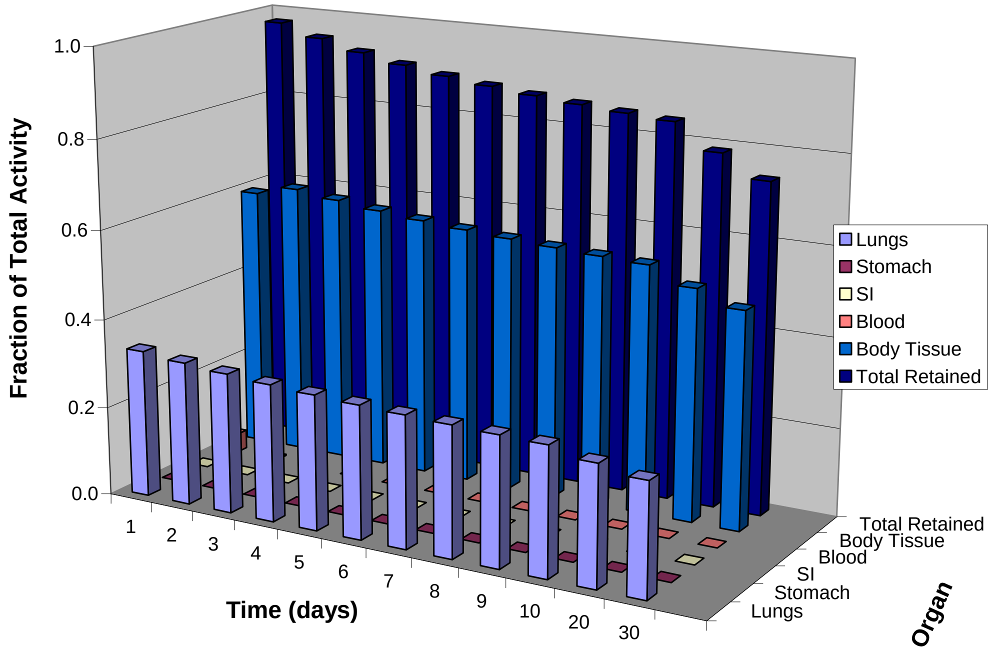

Figure 3.4.1. Cs-137 DCAL Source Distribution in Organs of Interest Over 30 Days after Inhalation

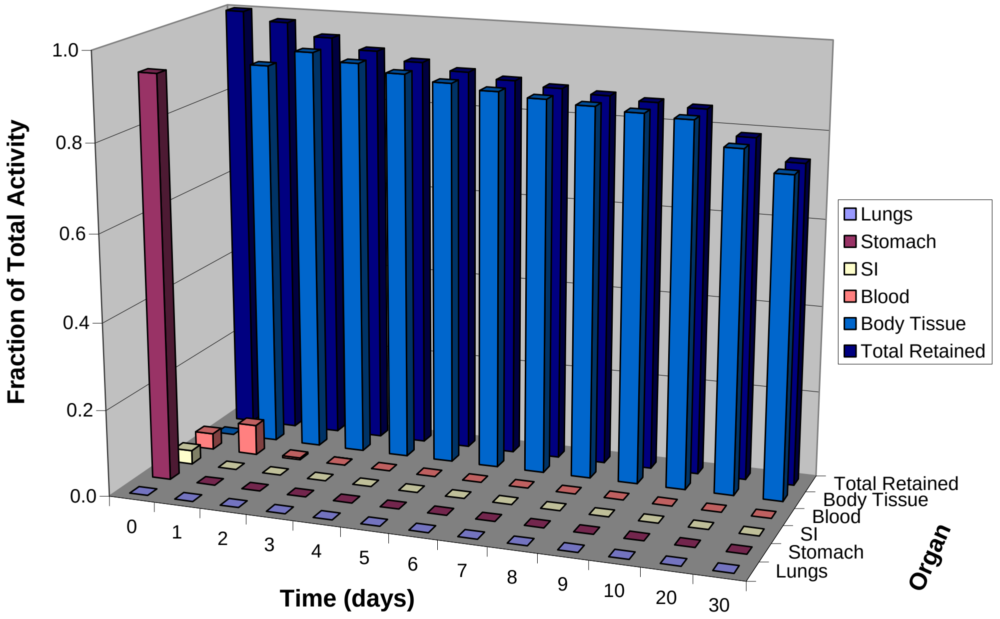

Figure 3.4.2. Cs-137 DCAL Source Distribution in Organs of Interest Over 30 Days after Ingestion

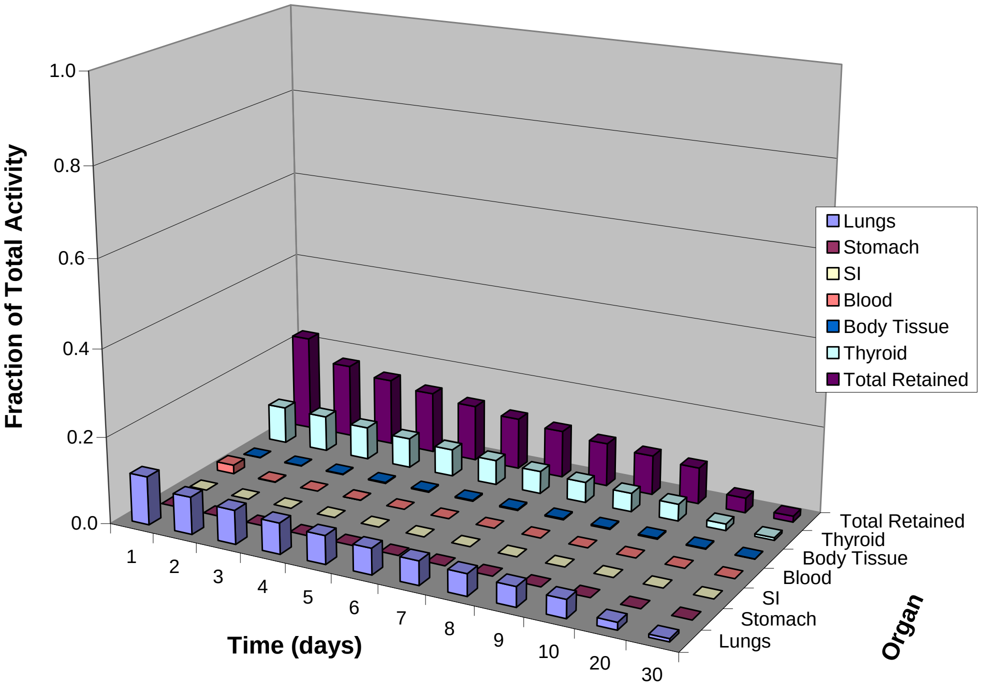

Figure 3.4.3. I-131 DCAL Source Distribution in Organs of Interest Over 30 Days after Inhalation

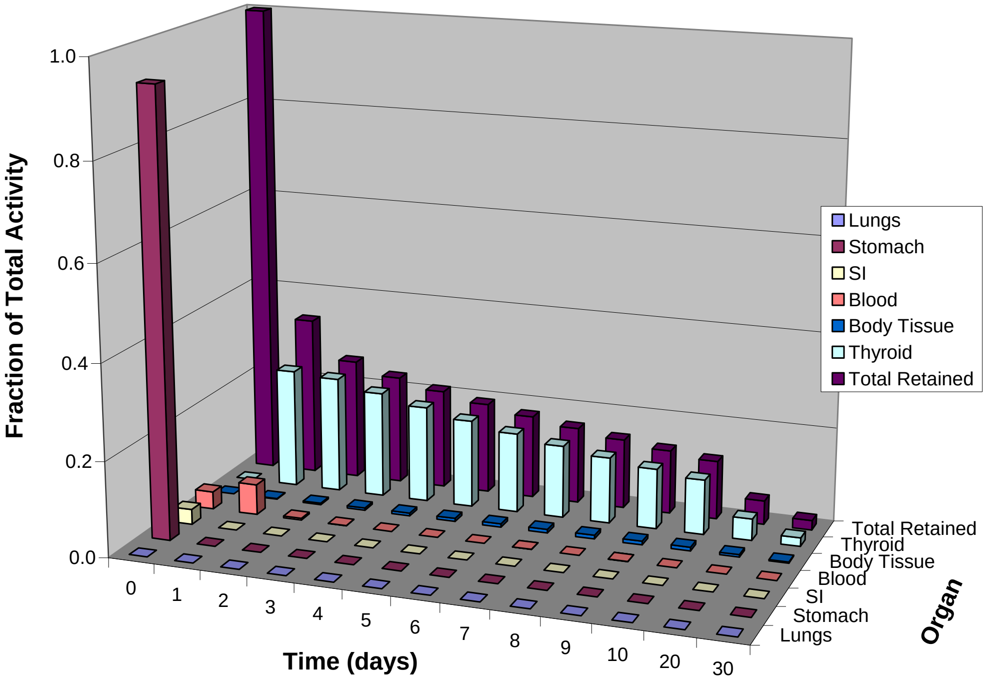

Figure 3.4.4. I-131 DCAL Source Distribution in Organs of Interest Over 30 Days after Ingestion

For both modes of uptake the blood DCAL was distributed to each organ based on the blood distributions listed in ICRP 89, and the body tissue received the remaining fraction of blood that was not distributed to the organs [11]. For the child MCNP simulation results the adult DCAL for each radioisotope was used, because it resulted in a lower count rate, thus providing more conservative selection criteria for the child.

The count rate per Bq values were then divided by the scaling factor to adjust the simulated response to the response of the detector. These values were then multiplied by the dose coefficients from Rad Toolbox for public ingestion and inhalation [8]. The dose coefficients listed in Rad Toolbox are based on the ICRP 72 values for Co-60, Cs-137, I-131, and Ir-192 and are given in units of rem per Bq. ICRP recommended inhalation classes were utilized for the inhalation dose coefficients. Slow (S), moderate (M) and fast (F) inhalation classes describe how quickly a radionuclide is absorbed in the lungs. The inhalation was set to fast for Cs-137 and I-131 and moderate for Co-60 according to the specifications of ICRP 72 [10]. In most of the inhalation absorption experiments conducted using different chemical forms of Cs-137 and I-131, the lung absorption was found to be fast [9]. Thus, in the event that “specific information” about the chemical form is not given, a fast inhalation class is recommended for both Cs-137 and I-131 [9]. All three inhalation classes have been observed in studies of various chemical forms of Co-60, for this reason ICRP recommends that the inhalation class of Co-60 be set to moderate when “specific information” about the chemical form is not known [9]. Since a recommended inhalation class for Ir-192 was not specified in ICRP 72, its inhalation class was assumed to be moderate. By assuming an inhalation class of moderate, the likelihood of grossly overestimating or underestimating the dose coefficient is reduced [9]. The dose coefficients obtained from Rad Toolbox are listed below in Table 3.4.1.

Table 3.4.1. Rad Toolbox Dose Coefficients for Adult and Child (rem per Bq)

Phantom	**Co-60**	**Cs-137**	**I-131**	**Ir-192**
Adult Inhalation	1.00E-06	4.60E-07	7.40E-07	5.20E-07
Child Inhalation	1.50E-06	3.70E-07	1.90E-06	7.60E-07
Adult Ingestion	3.40E-07	1.30E-06	2.20E-06	1.40E-07
Child Ingestion	1.10E-06	1.00E-06	5.20E-06	2.80E-07

Multiplying the count rate per Bq by the dose coefficients resulted in the count rate per rem. The count rate per 25 rem was then calculated, giving a final result of counts per second per 250 mSv.

CHAPTER 4: RESULTS

The first step in determining the feasibility of portal monitors as a first cut screening tool, was the acquisition of benchmark measurements used to validate an MCNP model of the TPM-903B. The validation of the MCNP model led to scaling factors that relate the model to the measured values. Once the detector model was validated the MNCP model of the TPM-903B was combined with MIRD Phantoms to determine the count rate corresponding to a committed effective dose of 250 mSv. These count rates were then listed in internal contamination procedure sheets for the use of portal monitors as first cut screening tools.

4.1 Lower Limit of Detection and Minimum Detectable Activity

The lower limit of detection and the minimum detectable activity were calculated using the background recorded during the experimental measurements. They were also calculated for double the background observed during the experimental measurements. These values we calculated following the procedure outlined by Knoll [14].

The lower limit of detection was calculated using the Currie Equation shown below [14].

$$N_D = 4.653\sigma_{N_B} + 2.706$$

In this equation "N_D as defined above can now be interpreted as the minimum number of counts needed from the source to ensure a false-negative rate no larger than 5% when the system is operated with a critical level of L_C that, in turn, ensures a false-positive rate of no greater than 5%" and σ_{N_B} is the standard deviation of the background [14]. Once the lower limit of detection was calculated the minimum detectable activity was calculated using the following equation:

$$\alpha = \frac{N_D}{f\varepsilon T}$$

where f is the radiation yield per disintegration, T is counting time and ε is the absolute detection efficiency [14].

The equation shown below was used to calculate the absolute detection efficiency [14].

$$\varepsilon = \frac{number\ of\ pulses\ recorded}{number\ of\ radiation\ quanta\ emitted\ by\ source}$$

The absolute detection efficiency was determined using the recorded count for the thickest slab measurement for Co-60. This thickness was chosen since it is similar to the thickness of a human body. During benchmark measurements counts were taken for three different source heights in the center of the detector, these positions were referred to as 1, 2 and 3. Because all three of these positions are located within the region which a human body would cover, the counts were average for the three positions and the average was used as the “number of pulses recorded”. The minimum detectable activity was then calculated using a radiation yield per disintegration of two for Co-60 and a counting time of one second. The values calculated as the lower limit of detection and minimum detectable activity of Co-60 for the TPM-903B Portal Monitor are shown below in Table 4.1.1.

Table 4.1.1. TPM-903B Lower Limit of Detection and Minimum Detectable Activity of Co-60

Background Level at Which Data Was Taken		
Background	4477	CPS
Standard Deviation	67	CPS
Lower Limit of Detection (above background)	314	CPS
Lower Limit of Detection	4791	CPS
Absolute Detection Efficiency	8.59E-03	
Minimum Detectable Activity of Co-60	1.83E+04	Bq
Double Background Level		
Background	8954	CPS
Standard Deviation	95	CPS
Lower Limit of Detection (above background)	443	CPS
Lower Limit of Detection	9397	CPS
Absolute Detection Efficiency	8.59E-03	
Minimum Detectable Activity of Co-60	2.58E+04	Bq

4.2 PMMA Benchmark Measurement Results

Benchmark measurements were taken with the TPM-903B portal monitor in order to validate the MCNP detector model. The data taken during the benchmark measurements are shown in Figures 4.2.1-4.2.4. For each of the radioisotopes the variation in count rate with change in attenuation thickness and source position can be seen. When the sources were placed in the center between the two legs of the detector, the count rates were approximately two times larger than when the sources were placed slightly outside the detector. The lower limit of detection is included in Figures 4.2.1-4.2.4, to show that the counts per second recorded for the sources for all PMMA thicknesses are distinguishable from the background.

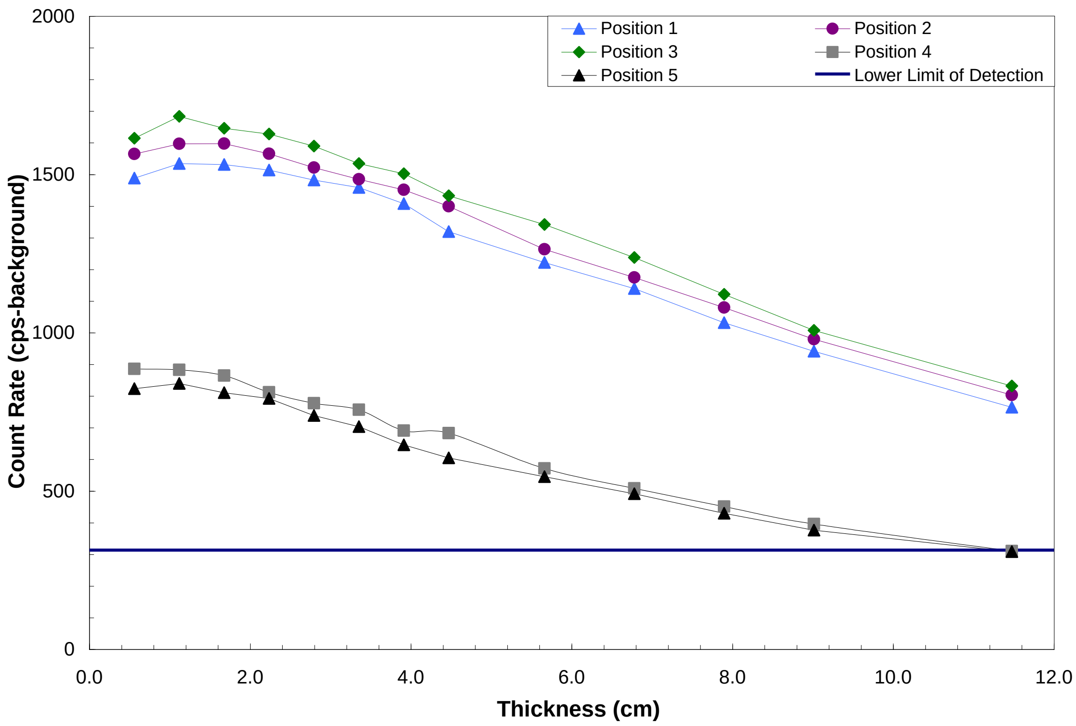

Figure 4.2.1. TPM-903B Benchmark Measurements for Ba-33

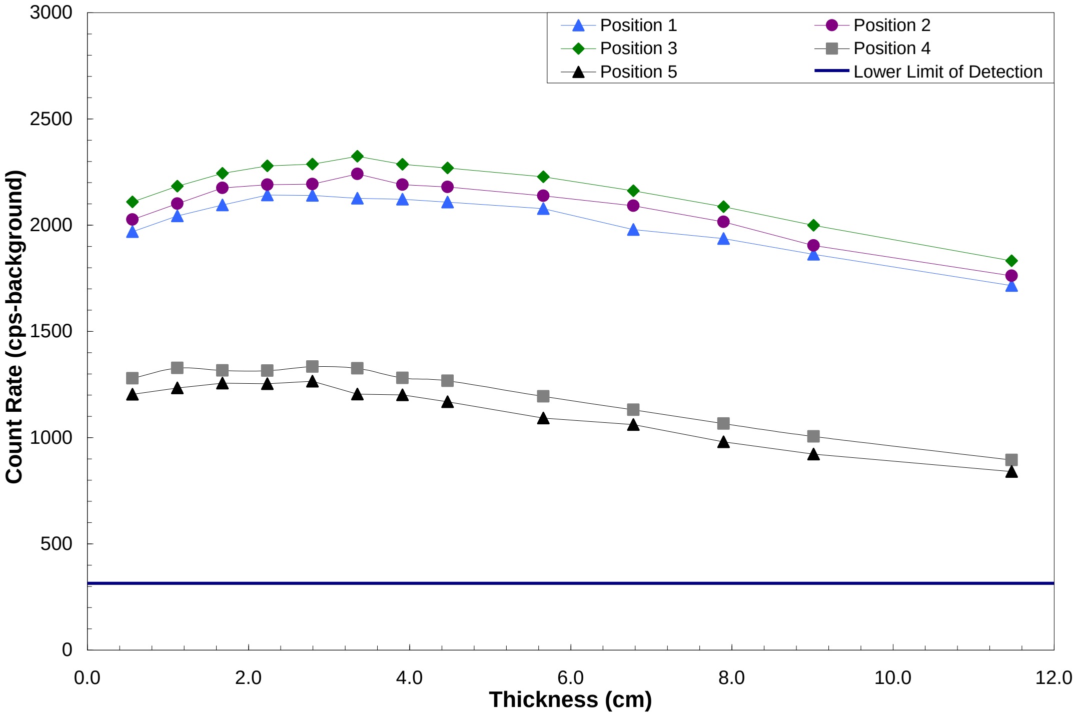

Figure 4.2.2. TPM-903B Benchmark Measurements for Co-60

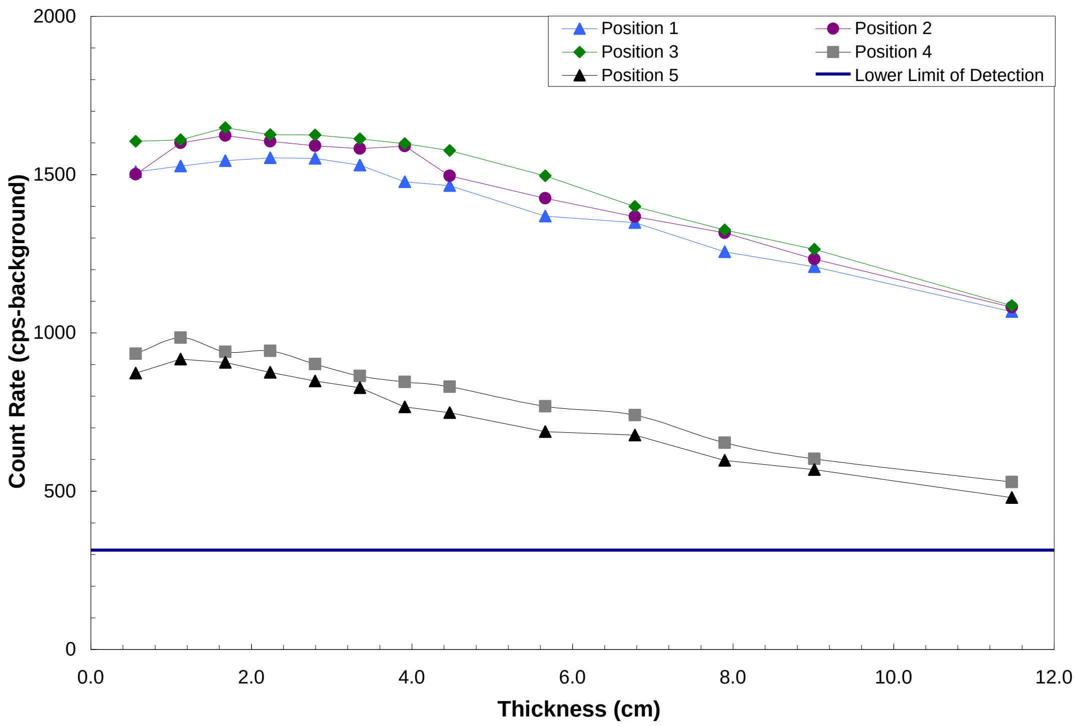

Figure 4.2.3. TPM-903B Benchmark Measurements for Cs-137

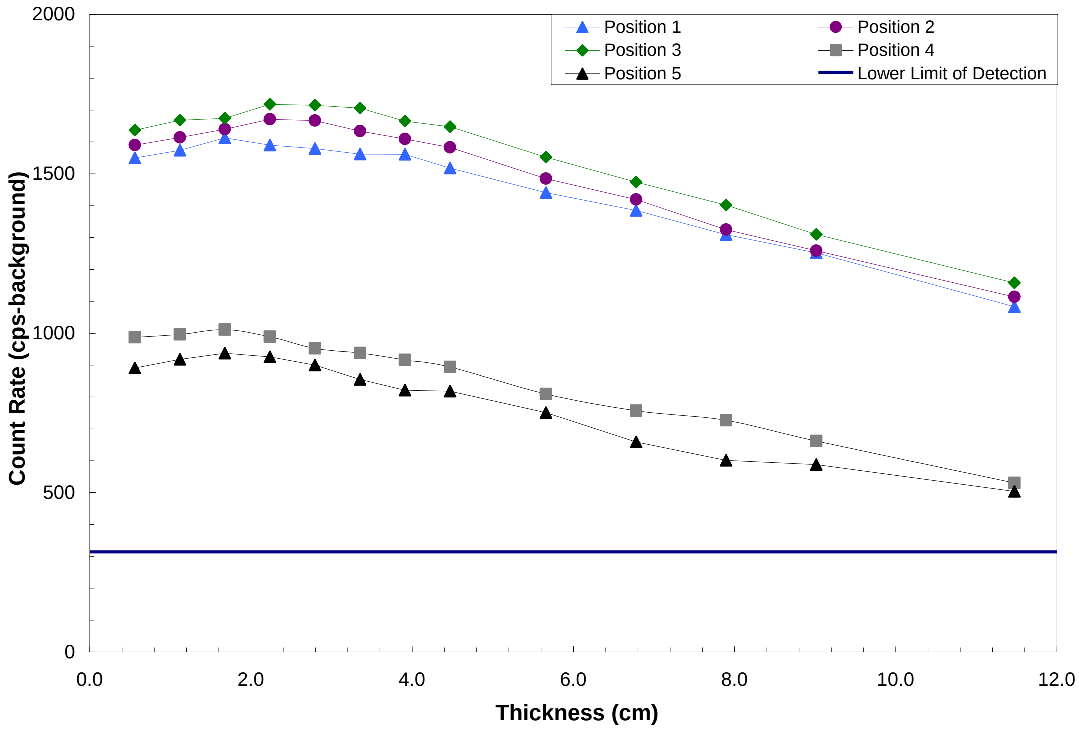

Figure 4.2.4. TPM-903B Benchmark Measurements for Na-22

The count rates corresponding to the additional 27 measurements taken using Cs-137 are shown in Figure 4.2.5. The positions in which the source was next to a leg of the detector, positions 2 and 8, gave the highest counts with the next highest counts resulting from the central position, position 5 (see Figures 2.2.3 and 2.2.4). In addition, all the positions located outside of the detector gave similar counts. These trends were seen for all three source heights. For simplicity and ease of use the central position, position 5, was used for phantom location in simulation and is recommended as victim location in the procedure sheets.

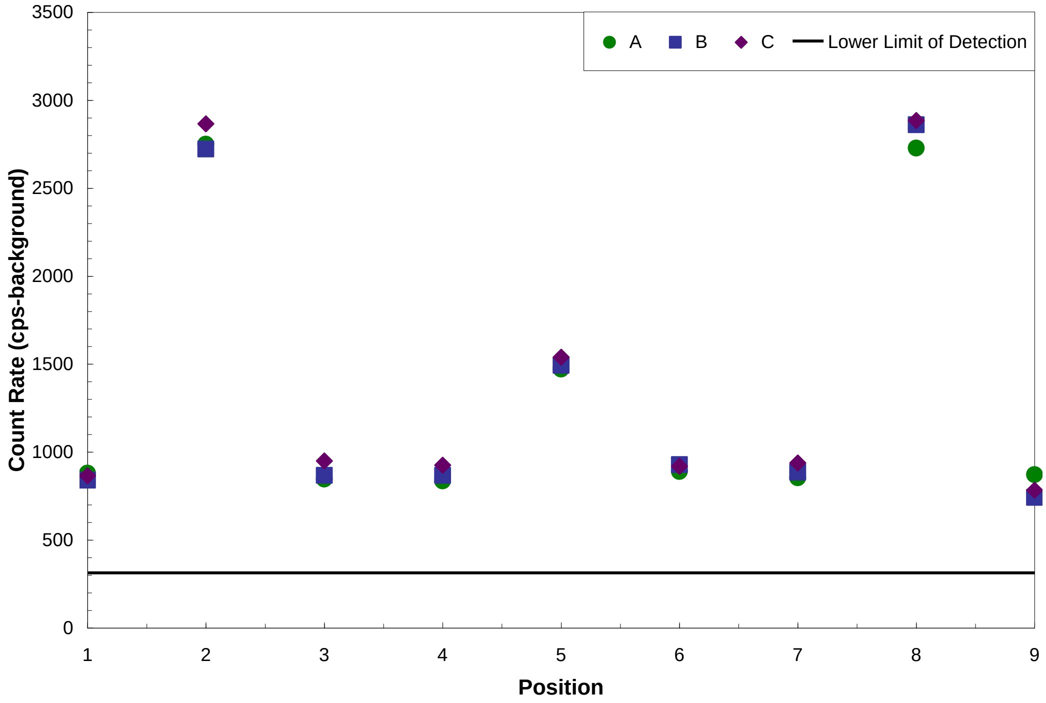

Figure 4.2.5. TPM-903B Measured Count Rates for Source Positional Data

4.3 Model Validation

For Ba-133, Co-60, Cs-137, and Na-22, the count rates from the MCNP simulations were compared to the benchmark measurement in order to validate the detector model. The ratios of the simulated count rates to the measured readings were computed and analyzed for all PMMA thicknesses. In an ideal simulation the MCNP output would be exactly the same as the measured count rates resulting in a ratio of one regardless of the thicknesses of attenuation. However, secondary effects not included in the modeling can lead to ratios that are not unity. These secondary effects include the transport of scintillation light, as well as variations in material compositions and density and unknown variations in detection efficiency as a function of photon energy. When the ratios are not unity, the scaling factor, which is the mean value of the ratio for a given isotope over all thicknesses, can be used to adjust the simulated response to the response that would be observed by the detector.

In order to best simulate the response of the TPM-903B a low energy cutoff value was evaluated using the MCNP count rate to measured count rate ratio. Gamma rays with energy below the low energy cutoff cannot be detected by the TPM-903B Portal Monitor. This low energy cut off value was determined by summing the MCNP pulse-height spectra above different energy thresholds until the simulated count rates formed the best match to the measured count rates at all PMMA thicknesses for all the radiation sources. According to Thermo Scientific the energy threshold of the detector is 60 keV [23]. This value was confirmed from the comparison of the MCNP simulated count rates to the measured count rates. The MCNP output for Cs-137 at position 3 with 0.559 cm of PMMA attenuation can be seen in Figure 4.3.1. An example comparison of the experimental count rate values to the simulated count rate values for various energy cutoffs for Cs-137at position 1 is shown in Figure 4.3.2.

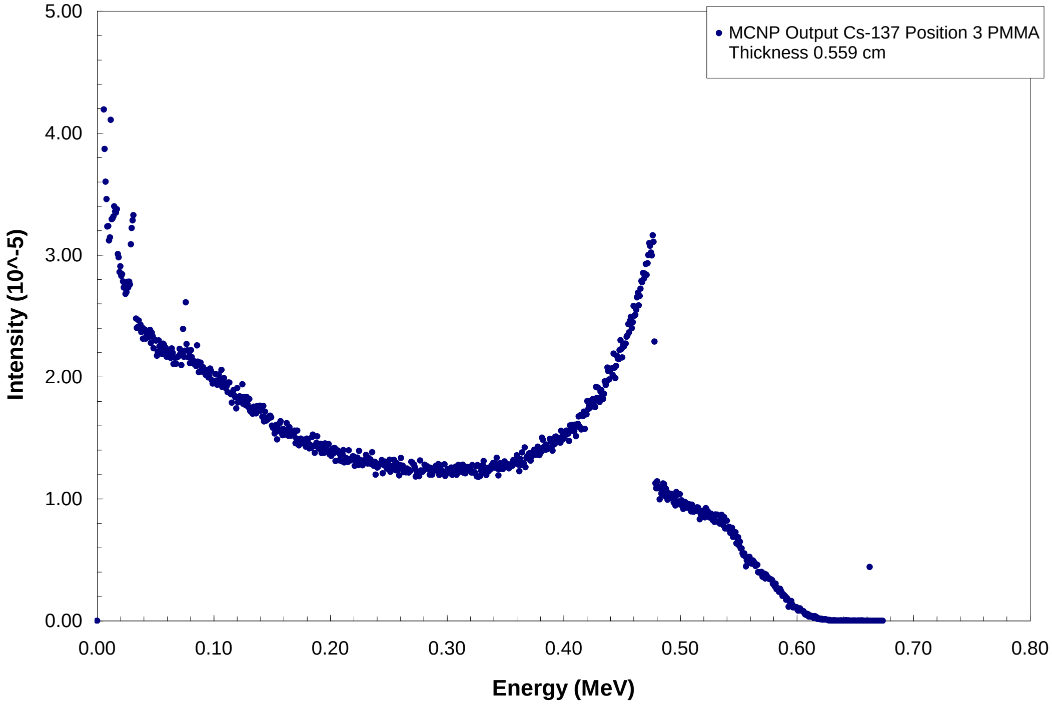

Figure 4.3.1. MCNP Output for Cs-137, Position 3 with 0.559 cm of PMMA Attenuation

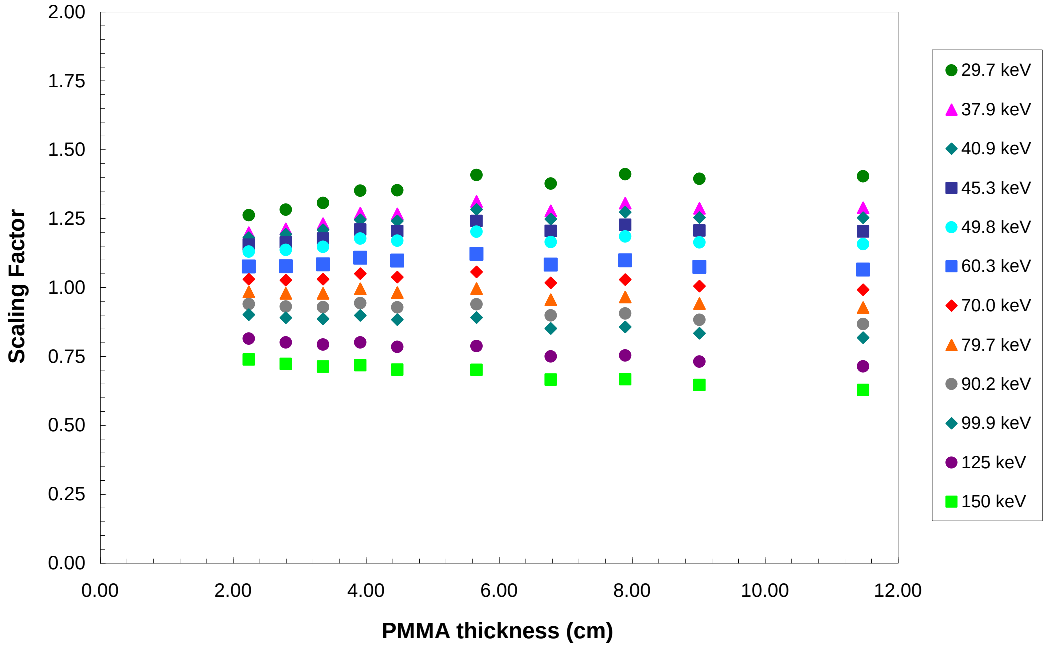

Figure 4.3.2. Comparison of the Experimental Count Rate Values and the Simulated Count Rate Values for Various Energy Cutoffs and All PMMA Attenuation Thicknesses

After proper selection of the pulse-height threshold, the scaling factors for the three positions inside the detector were calculated. The scaling factors for positions 1, 2, and 3 (see Figure 2.2.2) are shown below in Figures 4.3.3-4.3.6. Constant ratios of calculated to measured counts for all attenuator thicknesses were observed for positions 1 and 3. However, position 2 had a higher scaling factor value, which corresponded to the lower count rate observed for all isotopes at position 2 in the slab benchmark measurements. These trends were observed for all four radioisotopes used in the benchmark measurements. Since all three locations are of importance, as they represent individuals of differing heights, the scaling factors at the three heights were averaged to obtain the value applied in the anthropomorphic phantom modeling discussed in the next section.

Benchmark measurements were not taken with I-131 and Ir-192; therefore their scaling factors were calculated by interpolating the scaling factors from the isotopes used in the benchmark measurements. This interpolation was performed using the mean photon energies for the isotopes. The scaling factors were then used to convert the MCNP simulation of the TPM-903B and phantoms count rates to the detector count rates. The scaling factors for all of the isotopes are listed below in Table 4.3.1.

Table 4.3.1. Scaling Factors

Isotope	Scaling Factor
Ba-133	0.96
Co-60	0.98
Cs-137	1.08
I-131	1.00
Ir-192	0.99
Na-22	1.02

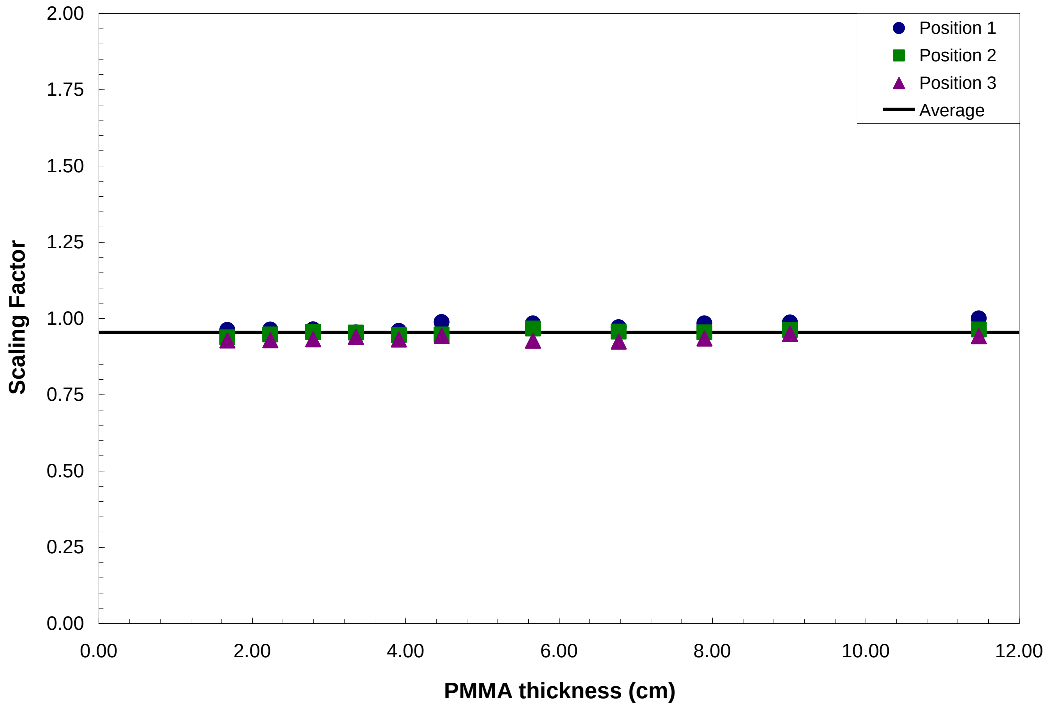

Figure 4.3.3. Ba-133 Scaling Factor

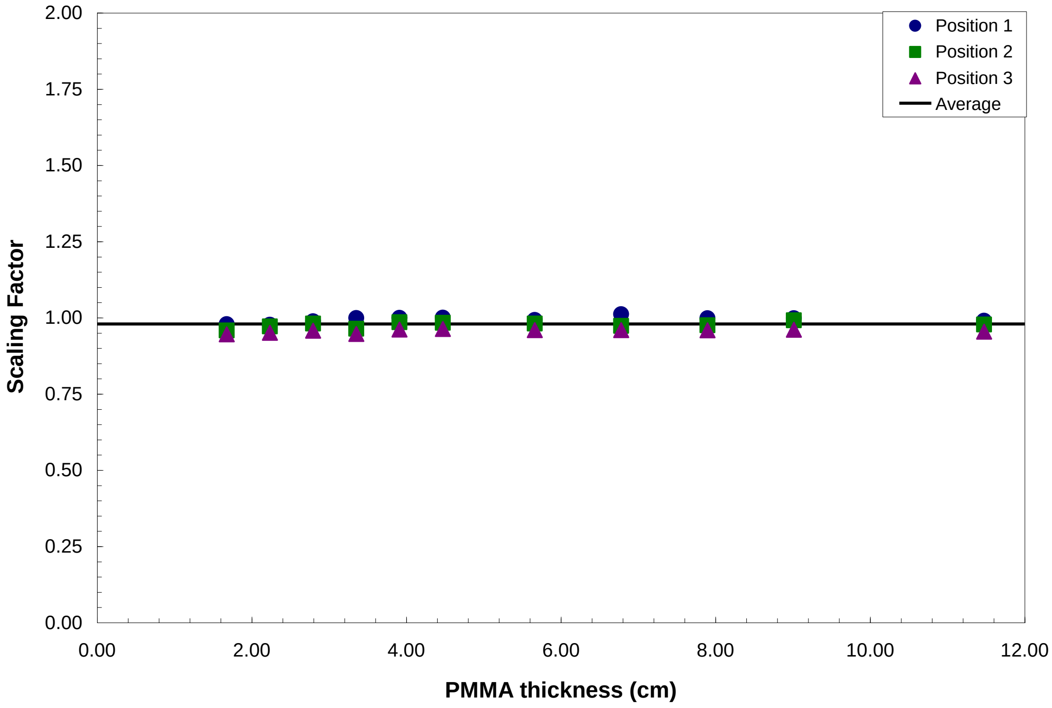

Figure 4.3.4. Co-60 Scaling Factor

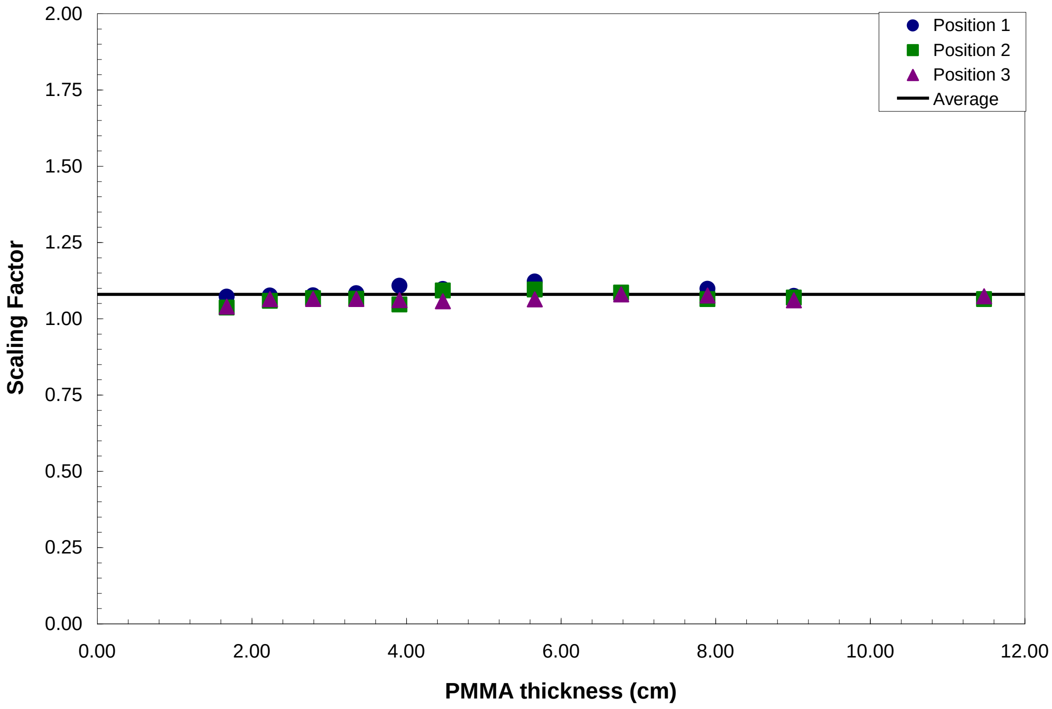

Figure 4.3.5. Cs-137 Scaling Factor

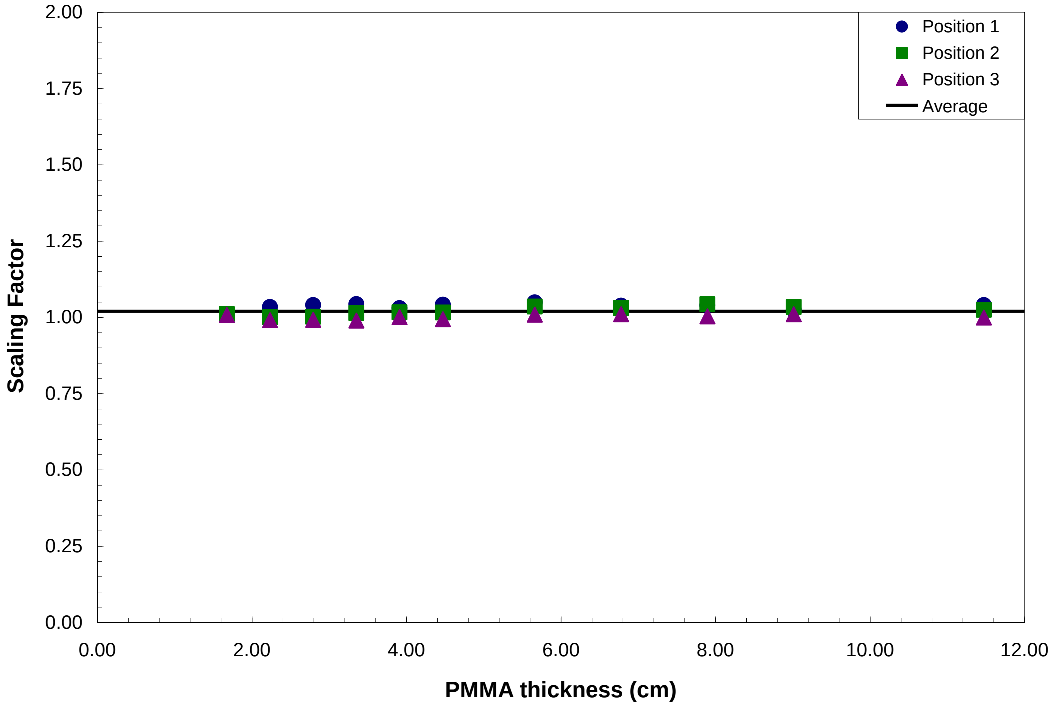

Figure 4.3.6. Na-22 Scaling Factor

4.4 MIRD Phantom Results

With the validation of the MCNP model complete, the TPM's count rates corresponding to a committed effective dose of 250 mSv were determined. Count rates were determined for both the inhalation and ingestion of Co-60, Cs-137, I-131 and Ir-192. The isotopes were used in conjunction with six anthropomorphic stylized phantoms: Reference Male, Reference Female, Adipose Male, Adipose Female, Post-Menopausal Adipose Female, and 10-Year Old Child. The comparison of the phantom counts per second corresponding to a committed effective dose of 250 mSv can be seen in Figures 4.4.1-4.4.8. This comparison is shown for each radionuclide and both internal contamination pathways for a time period of thirty days after contamination.

As seen in the graphs, the Adipose Male consistently gives the lowest or equal to the lowest count rate per 250 mSv for both inhalation and ingestion and all isotopes. Thus, the Adipose Male provides the most conservative selection criteria for adult screening and for this reason the Adipose Male count rates were selected as the adult trigger levels.

From Figures 4.4.3 and 4.4.6 one can see that 20 days after the ingestion of I-131 the count rate is approximately the same as the lower limit of detection for the background level that was observed in the experimental measurements. This means that other screening tools must be used for the screening of ingested I-131 for 20 days or more after ingestion.

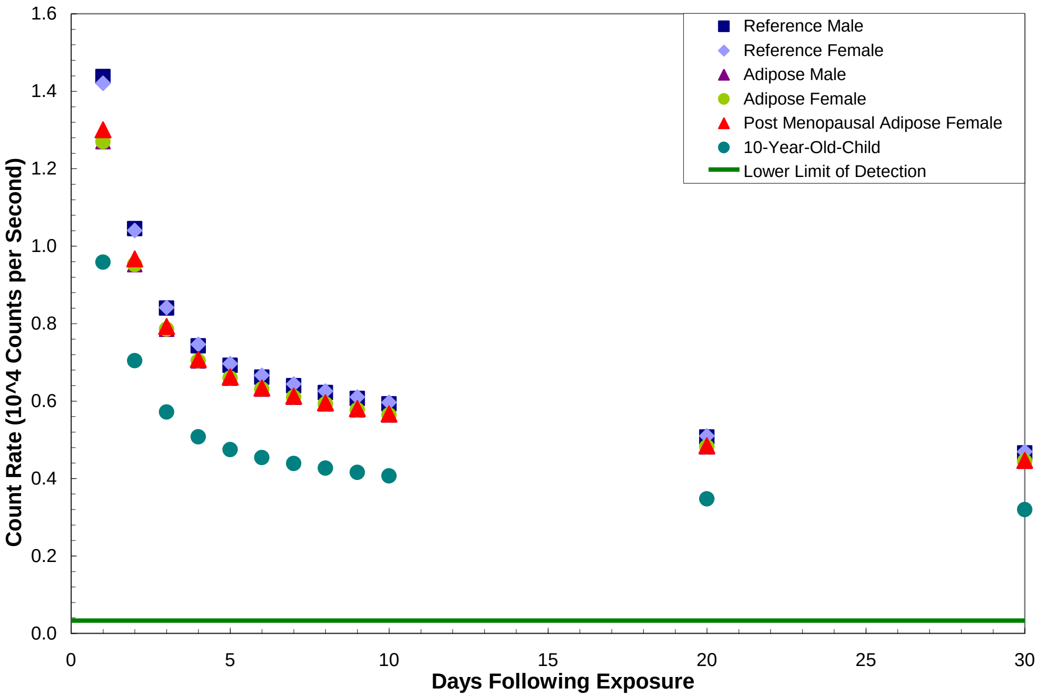

Figure 4.4.1. TPM-903B CPS per 250 mSv for Anthropomorphic Phantoms for Inhaled Co-60

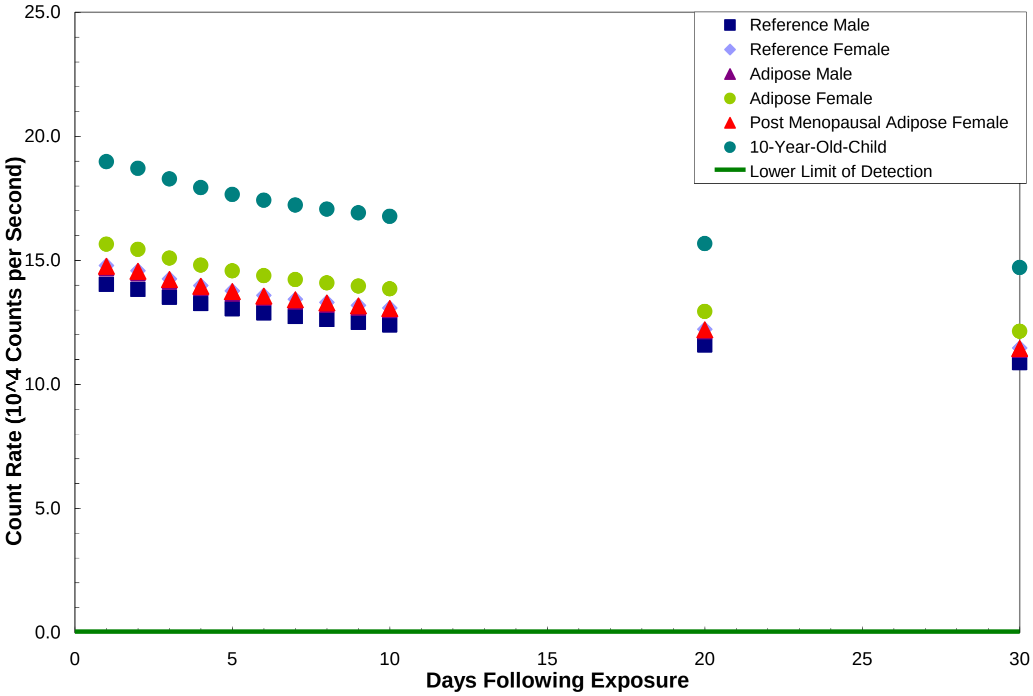

Figure 4.4.2. TPM-903B CPS per 250 mSv for Anthropomorphic Phantoms for Inhaled Cs-137

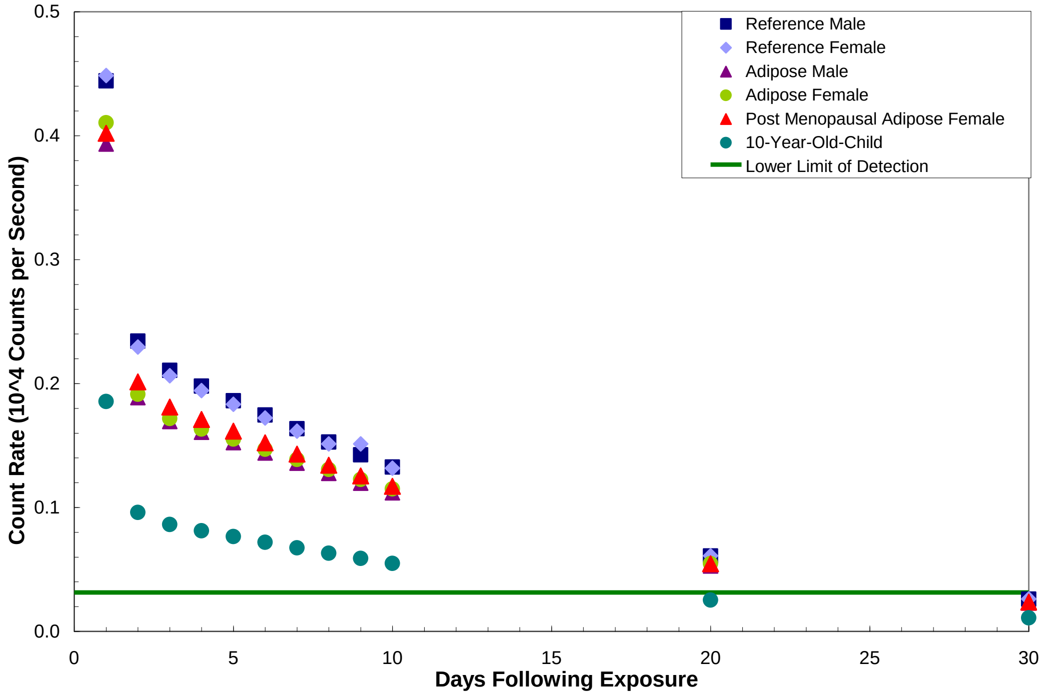

Figure 4.4.3. TPM-903B CPS per 250 mSv for Anthropomorphic Phantoms for Inhaled I-131

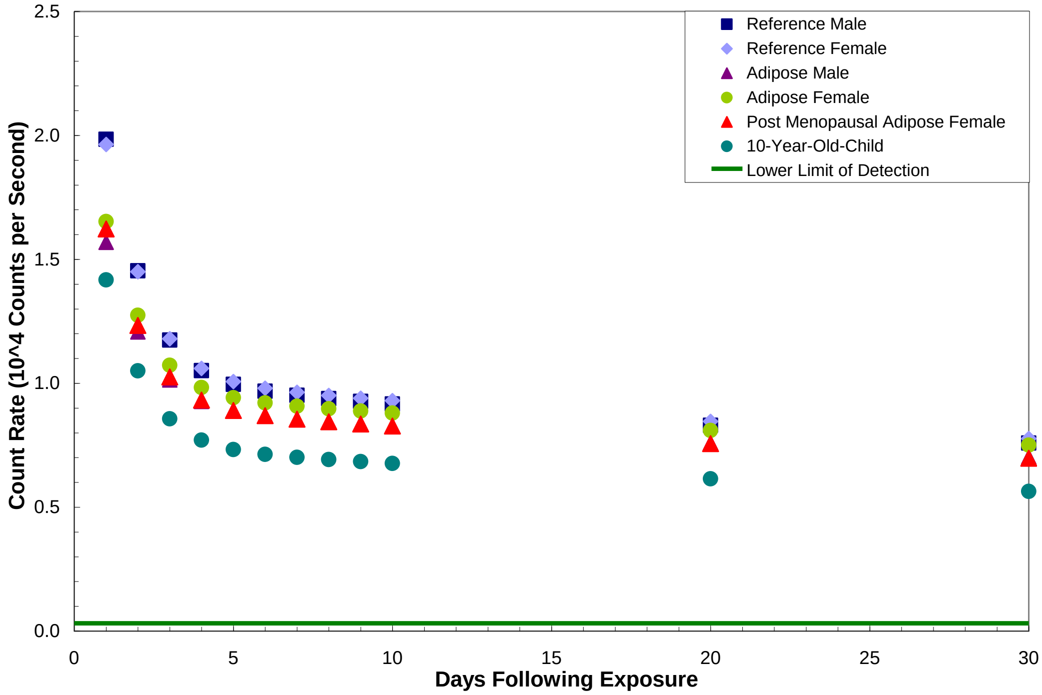

Figure 4.4.4. TPM-903B CPS per 250 mSv for Anthropomorphic Phantoms for Inhaled Ir-192

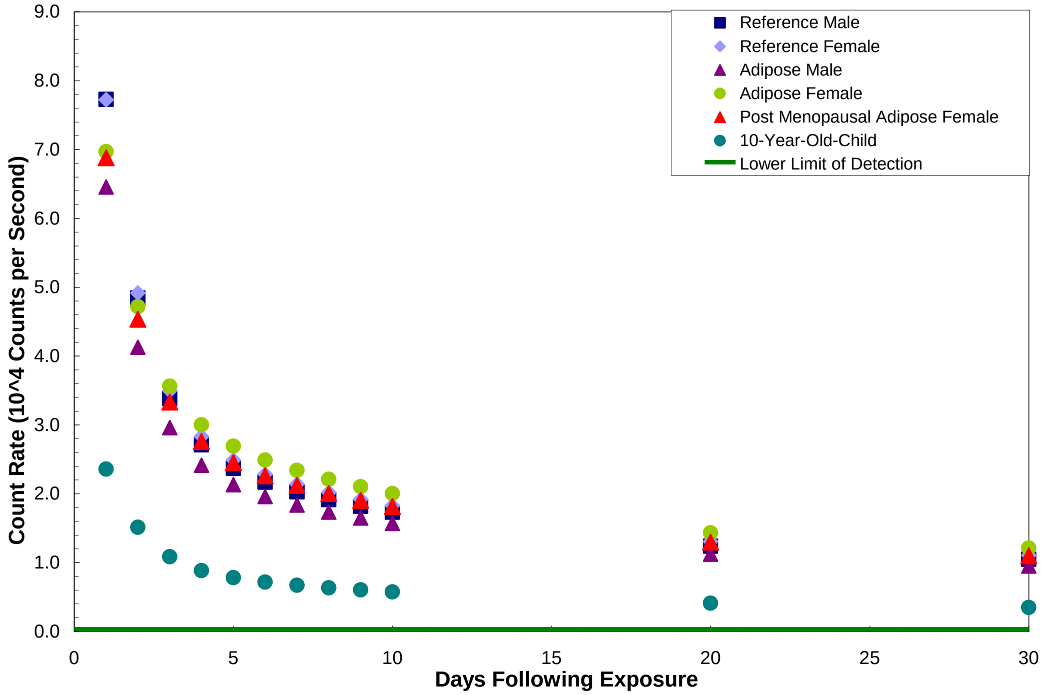

Figure 4.4.5. TPM-903B CPS per 250 mSv for Anthropomorphic Phantoms for Ingested Co-60

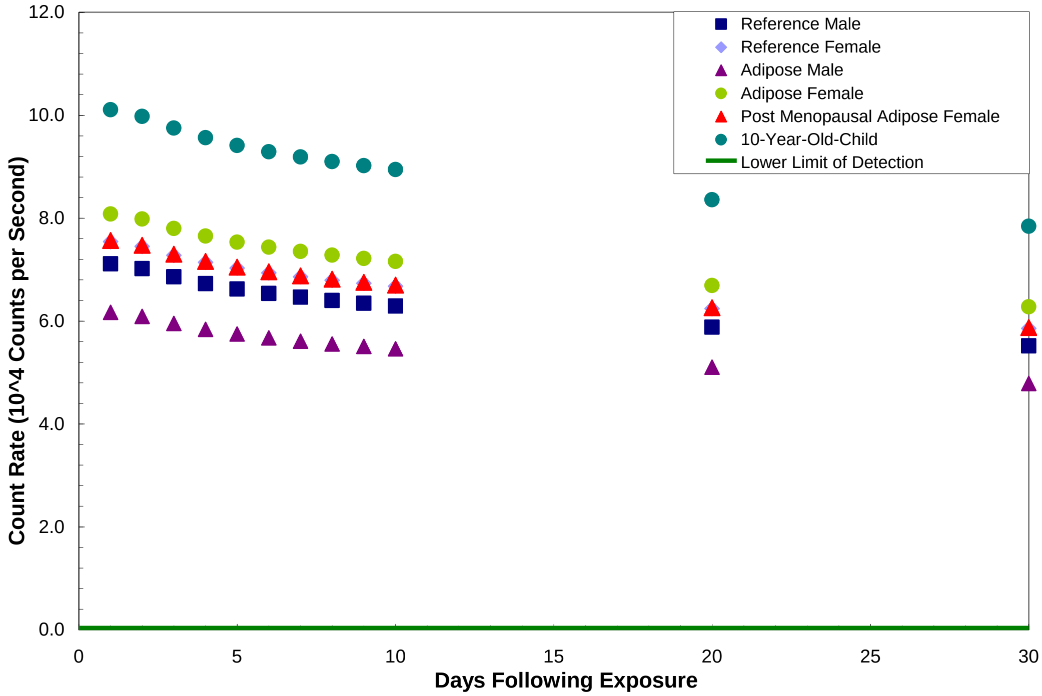

Figure 4.4.6. TPM-903B CPS per 250 mSv for Anthropomorphic Phantoms for Ingested Cs-137

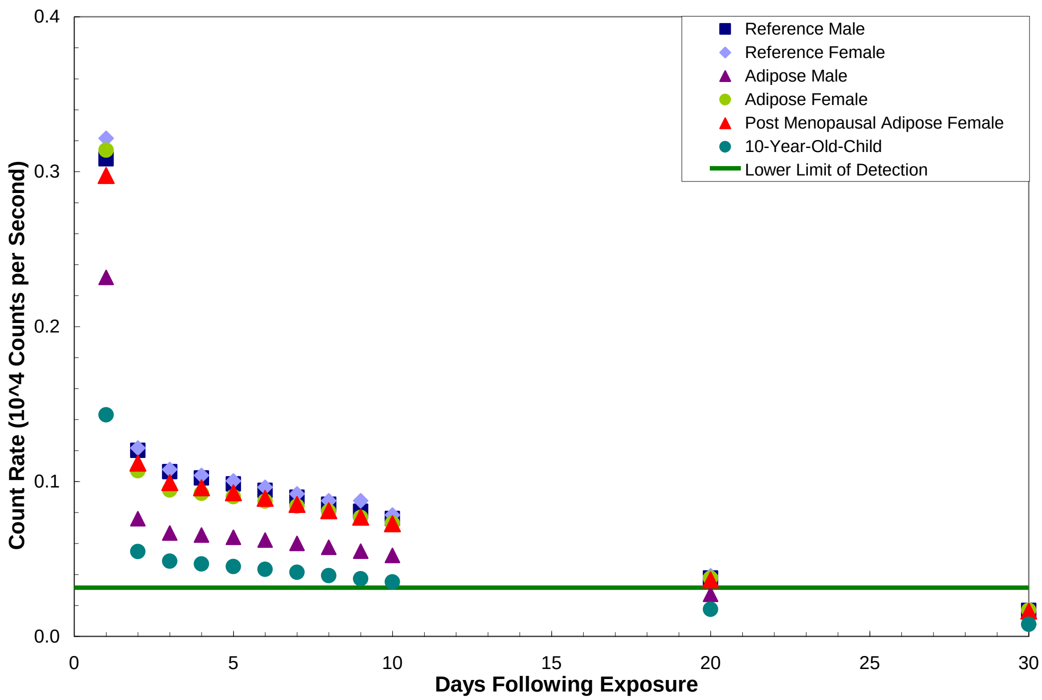

Figure 4.4.7. TPM-903B CPS per 250 mSv for Anthropomorphic Phantoms for Ingested I-131

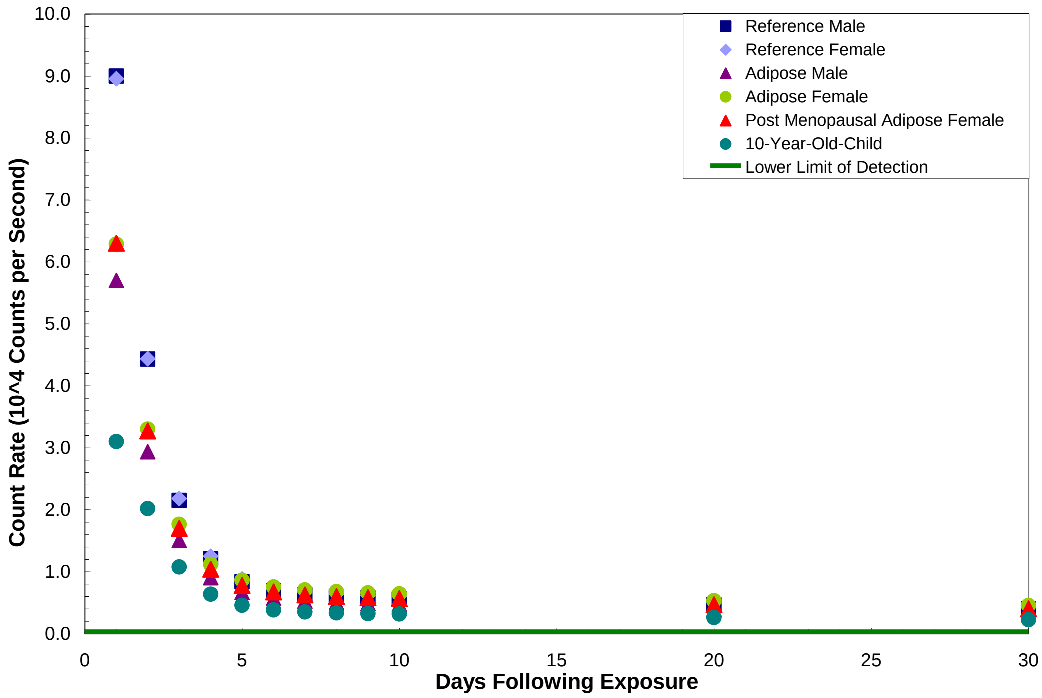

Figure 4.4.8. TPM-903B CPS per 250 mSv for Anthropomorphic Phantoms for Ingested Ir-192

4.5 Trigger Levels

Procedure sheets, for emergency response personnel, were compiled using the count rate per 250 mSv for the anthropomorphic phantoms. The count rates corresponding to the effective dose threshold value of 250 mSv are listed as trigger levels in the procedure sheets. The Adipose Male results were used for the adult trigger levels because they give the lowest count rates which result in more conservative selection criteria. Also the adult DCAL was used in determining the count rate for the child. This was chosen because it resulted in a lower count rate for an effective dose 250 mSv than the use of child DCAL, leading to more conservative selection criteria. The trigger levels used in the procedure sheets are listed in Tables 4.5.1-4.5.4. The procedure sheets can be found in Appendix D. Trigger levels that are approximately the lower limit of detection or below the lower limit of detection are shaded gray.

Table 4.5.1. TPM-903B Conservative Adult Trigger Levels for Inhalation

Time (days)	Co-60 (cps)	Cs-137 (cps)	I-131 (cps)	Ir-192 (cps)
0.25	1.47E+04	1.33E+05	1.91E+04	1.80E+04
0.50	1.45E+04	1.41E+05	1.06E+04	1.76E+04
1.00	1.27E+04	1.47E+05	3.93E+03	1.57E+04
2.00	9.52E+03	1.45E+05	1.89E+03	1.21E+04
3.00	7.85E+03	1.41E+05	1.69E+03	1.01E+04
4.00	7.03E+03	1.39E+05	1.61E+03	9.27E+03
5.00	6.59E+03	1.36E+05	1.52E+03	8.87E+03
6.00	6.31E+03	1.35E+05	1.44E+03	8.67E+03
7.00	6.10E+03	1.33E+05	1.36E+03	8.54E+03
10.00	5.64E+03	1.30E+05	1.12E+03	8.27E+03
20.00	4.81E+03	1.21E+05	5.28E+02	7.60E+03
30.00	4.44E+03	1.14E+05	2.29E+02	7.03E+03

Table 4.5.2. TPM-903B Child Trigger Levels for Inhalation

Time (days)	Co-60 (cps)	Cs-137 (cps)	I-131 (cps)	Ir-192 (cps)
0.25	1.13E+04	1.73E+05	8.40E+03	1.67E+04
0.50	1.11E+04	1.83E+05	4.73E+03	1.61E+04
1.00	9.59E+03	1.90E+05	1.86E+03	1.42E+04
2.00	7.04E+03	1.87E+05	9.59E+02	1.05E+04
3.00	5.71E+03	1.83E+05	8.63E+02	8.56E+03
4.00	5.08E+03	1.79E+05	8.12E+02	7.71E+03
5.00	4.74E+03	1.77E+05	7.65E+02	7.32E+03
6.00	4.54E+03	1.74E+05	7.19E+02	7.13E+03
7.00	4.39E+03	1.72E+05	6.74E+02	7.01E+03
10.00	4.06E+03	1.68E+05	5.49E+02	6.76E+03
20.00	3.47E+03	1.57E+05	2.53E+02	6.15E+03
30.00	3.20E+03	1.47E+05	1.09E+02	5.64E+03

Table 4.5.3. TPM-903B Conservative Adult Trigger Levels for Ingestion

Time (days)	Co-60 (cps)	Cs-137 (cps)	I-131 (cps)	Ir-192 (cps)
0.25	7.65E+04	5.52E+04	1.43E+04	7.24E+04
0.50	7.81E+04	5.92E+04	7.57E+03	7.06E+04
1.00	6.46E+04	6.17E+04	2.32E+03	5.70E+04
2.00	4.13E+04	6.09E+04	7.59E+02	2.94E+04
3.00	2.96E+04	5.95E+04	6.67E+02	1.50E+04
4.00	2.41E+04	5.84E+04	6.54E+02	9.02E+03
5.00	2.13E+04	5.75E+04	6.40E+02	6.63E+03
6.00	1.96E+04	5.67E+04	6.22E+02	5.67E+03
7.00	1.84E+04	5.61E+04	6.00E+02	5.24E+03
10.00	1.57E+04	5.46E+04	5.22E+02	4.74E+03
20.00	1.12E+04	5.10E+04	2.71E+02	3.92E+03
30.00	9.49E+03	4.79E+04	1.22E+02	3.35E+03

Table 4.5.4. TPM-903B Child Trigger Levels for Ingestion

Time (days)	Co-60 (cps)	Cs-137 (cps)	I-131 (cps)	Ir-192 (cps)
0.25	2.82E+04	9.04E+04	8.12E+03	2.77E+04
0.50	2.85E+04	9.70E+04	4.37E+03	2.71E+04
1.00	2.36E+04	1.01E+05	1.43E+03	3.10E+04
2.00	1.51E+04	9.98E+04	5.48E+02	2.02E+04
3.00	1.08E+04	9.75E+04	4.85E+02	1.08E+04
4.00	8.83E+03	9.56E+04	4.68E+02	6.37E+03
5.00	7.79E+03	9.41E+04	4.51E+02	4.57E+03
6.00	7.16E+03	9.29E+04	4.33E+02	3.83E+03
7.00	6.71E+03	9.19E+04	4.13E+02	3.51E+03
10.00	5.73E+03	8.94E+04	3.51E+02	3.16E+03
20.00	4.10E+03	8.36E+04	1.75E+02	2.61E+03
30.00	3.47E+03	7.84E+04	7.77E+01	2.23E+03

CHAPTER 5: CONCLUSION

The TPM-903B Portal Monitor is a viable first cut screening tool for use in assaying internal contamination following an RDD if the radiation emitted is Co-60, Cs-137, I-131 or Ir-192. The TPM-903B's response to internal contamination of I-131 was modeled at the request of the CDC. The other three gamma emitting isotopes were investigated because they are included in the isotopes of greatest concern for use in an RDD according to a recent NRC/DOE report [22]. However, the fourth gamma emitting isotope listed in the aforementioned report, Am-241, is undetectable when using the TPM-903B, because Am-241's gamma ray energies are below the 60 keV energy cutoff of the TPM-903B. Therefore another method of assaying internal contamination must be used if Am-241 is utilized in an RDD.

The TPM-903B output count rates allow for the identification of individuals in the public who have received greater than or equal to an approximate committed effective dose of 250 mSv through inhalation or ingestion within 30 days of exposure to Co-60, Cs-137 or Ir-192. For I-131, the TPM-903B allows for detection within 20 days of exposure due to I-131's effective half-life. The Adipose Male anthropomorphic phantom consistently gave the most conservative count rates of all the adults. Thus, the trigger levels listed in the procedures sheets for adults are those corresponding to the Adipose Male anthropomorphic phantom to provide more conservative triaging criteria and for simplicity. In conclusion the TPM-903B portal monitor is a useful tool in first cut screening of a large population after a radiological dispersal device.

CHAPTER 6: FUTURE WORK

In addition to evaluating the feasibility of the TPM-903B Portal Monitors as a first cut screening tool, preliminary data were acquired for Canberra’s MiniSentry Transportable Gamma Portal Monitor. Future work includes further evaluation of the MiniSentry to determine trigger levels corresponding to the committed effective dose limit of 250 mSv, for the purpose of MiniSentry procedure sheets. Further evaluation of the MiniSentry is relevant because it is a commercially available portal monitor.

For this work it was assumed that only one radionuclide will be used in an RDD. This may or may not be the case; therefore the development of procedure sheets listing trigger levels for mixed radionuclides would be a germane extension of this work.

Future work also includes evaluating trigger levels using ICRP’s Reference Male phantom and University of Florida’s Reference Male voxel phantom in order to compare the various phantoms. The phantom model type resulting in the most conservative trigger levels would be the preferred model for future work in evaluating first cut screening tools to be used in triaging after an RDD.

APPENDIX A: SAMPLE MCNP INPUT FILE FOR TPM-903B AND SLAB PHANTOM

This is the MCNP5 input file for the benchmark measurement at a thickness of 109 mm on each side of the source holder with a Co-60 source for the TPM-903B at position 3. The other input files for TPM-903B for the benchmark measurements only differed in isotope type, source and PMMA box position, and the thickness of the PMMA.

```
TPM 903B with Co-60 3A12
c +++++++++++++++++
c Cell Cards
c +++++++++++++++++++
c   BC408 Volume
1   1 -1.032      -1 : -2                  imp:p=1
c +++++++++++++++++++
c   Lead Shielding
2   2 -11.3      -3 1 : -4 2               imp:p=1
c +++++++++++++++++++
c   Air in PVC Pipe
3   3 -1.24e-3   -5 1 3 : -6 2 4 : -9       imp:p=1
c +++++++++++++++++++
c   PVC Piping
4   4 -1.32      -7 5 9 : -8 6 9 : -10 9 6 5 imp:p=1
c +++++++++++++++++++
c   Aluminum Feet
5   5 -2.7      -11 : -12                 imp:p=1
c +++++++++++++++++++++
c   PMMA
6   6 -1.19       -13 14:-15                imp:p=1
c +++++++++++++++++++++
c   Air Surrroundings
100 3 -1.24e-3    7 8 10 11 12 -100  13:-14 15      imp:p=1
c +++++++++++++++++++
c   Outside World
101 0            100                      imp:p=0

c ++++++++++++++++
c Surface Cards
c +++++++++++++++++++
c   BC408 Volume
1   RPP  53.45  57.25  -3.75 3.75  0 183
2   RPP -57.25 -53.45  -3.75 3.75  0 183
c +++++++++++++++++
c   Lead Shield
3   RPP  53.45  57.41 -3.91 3.91  0 183
4   RPP -57.41 -53.45 -3.91 3.91  0 183
c ++++++++++++++++++++++++++++++++
c   Air between detector and PVC
5   RCC 55.35    0 -17  0 0 217  4.694
6   RCC -55.35   0 -17  0 0 217  4.694
c +++++++++++++++++++++++
c   PVC Piping on sides
7   RCC 55.35    0 -17  0 0 217  5.25
8   RCC -55.35   0 -17  0 0 217  5.25
c +++++++++++++++++++++
```

```
c   PVC Piping on top
9   RCC -60.044  0  195    120.088 0 0 4.694
10  RCC -60.6    0  195    121.2  0 0 5.25
c ++++++++++++++++++++++
c Aluminum Feet
11  RPP 45.35   65.35  -30 30   -17.61 -17.01
12  RPP -65.35 -45.35  -30 30   -17.61 -17.01
c ++++++++++++++++++++++++++++++++++++++++
c   Air sphere where problem takes place
100 SPH 0 0 90 130
c ++++++++++++++++++++
c   Box source holder
13  BOX -15.25 -23.15 82.41  30.5 0 0  0 46.3 0  0 0 38.85
14  BOX -14.377 -22.2877 83.283 28.754 0 0  0 44.554 0  0 0 37.977
c +++++++++++++++++++++
c   Source Holder
15  RPP -11.15365 11.15365 -14.5 14.5 83.283 113.283

c ++++++++++++++
c Data Cards
c ++++++++++++++
c Materials
M1 1000   0.5246   6000  0.4754                    $ BC408
M2 82000 -1                                    $ Lead
M3 8016 -.232 7014 -.755 6012 -1.2e-4 18000 -1.28e-2 $ Air, NIST
M4 17000 0.166 1000 0.5 6000 0.334                 $PVC
M5 13000 -1                                    $ Aluminum
M6 6000.04p .556 8000.04p 0.296 1000.04p 0.148       $ PMMA
c ++++++++++++++
c Tally
c ++++++++++++++
F8:P 1
E8 0 1e-8 0.005 2000i 1.5
c ++++++++++++++
c Co-60 Source
c ++++++++++++++
sdef par=2 erg=d1 pos=0 -1.23 98.283 rad=d2 ext=d3 axs=0 1 0
si1 l 1.33 1.17
sp1 1 0.99
si2 0 0.357
sp2 -21
si3 0 2.46
mode p
NPS 1e8
phys:p 4j 1
```

APPENDIX B: SAMPLE MCNP INPUT FILE FOR TPM-903B WITH MIRD PHANTOM

This is the MCNP5 input file for the TPM-903B and the Reference Male anthropomorphic phantom with a I-131 source. The other input files differ by phantom type and source isotopes.

```
TPM 903B Reference Male With I-131
c air sphere
1    1 -.001293    -1 (607:-37:606) (-606:601:35) (600:-35) &
              (-615:37:-43:44:4:-616) (37:-608:609) &
              (37:-608:610) 507 508 510 511 512
2    2 -0.2958     ((-2 -4 3):(-2 4)) 5                        $ left lung
3    3 -0.9869     -7 51 -6 (-8:32) 84 101 #2 #24 #28 #58 #59
              (113:115) (114:115) #62 #700                     $ torso insd ribs/lvrtop-shldr
4    3 -0.9869     -7 8 -32 117 113 114 #15 #16 #17 #18 #19 #20 #700
              (-4:-9:116:118:-119) (-4:-9:116:120:-121)        $torso
5    3 -0.9869     -7 8 -117 51 113 114 #9 #13 #14 #700            $ torso
6    3 -0.9869     -7 50 -51 56 84 96 105 106 113 114 #10 #11 #12
              #27 #32 #43 #44 #47 #700                         $ torso
7    3 -0.9869     -7 97 -50 (83:-86:87:-88) 113 114 #30 #33 #38 #39
              #63 #64 #65 #700                                 $ torso abdoman
8    3 -0.9869     -7 37 -97 95 113 114 #31 #33 #38 #65 #66 #700      $ torso abdoman
9    4 -1.4862     8 -9 5 -10                                  $ rib
10   4 -1.4862     8 -9 11 -12                                 $ rib
11   4 -1.4862     8 -9 13 -14                                 $ rib
12   4 -1.4862     8 -9 15 -16                                 $ rib
13   4 -1.4862     8 -9 17 -18                                 $ rib
14   4 -1.4862     8 -9 19 -20                                 $ rib
15   4 -1.4862     8 -9 21 -22                                 $ rib
16   4 -1.4862     8 -9 23 -24                                 $ rib
17   4 -1.4862     8 -9 25 -26                                 $ rib
18   4 -1.4862     8 -9 27 -28                                 $ rib
19   4 -1.4862     8 -9 29 -30                                 $ rib
20   4 -1.4862     8 -9 31 -32                                 $ rib
21   3 -0.9869     ((35 -34):(-33 6 -35)) 102 (84:85)
              #37 #60 #61 #62 #700                             $ head
22   3 -0.9869     -37 38 -39 103 #700                         $ left leg
23   3 -0.9869     -37 38 -40 104 #22 #700                     $ right leg
24   2 -0.2958     ((-41 -4 42):(-41 4)) 5                     $ right lung
25   3 -0.9869     715 -37 43 -44 -4 716 39 40 72 73 #700 #600        $ genitalia
26   3 -0.9869     -47                                         $ brain
27   3 -0.9869     50 -51 -48 -49 #10 #11 #12                  $ liver
28   3 -0.9869     (-52 54):(-53 -54 55)                       $ heart
29   3 -0.9869     -56                                         $ stomach
30   3 -0.9869     138 -57 58 -59                              $ Ascending Colon Wall
31   3 -0.9869     (-63 141 65 -61):(-64 142 37 -65)           $ Sigmoid Colon Wall
32   3 -0.9869     -62 139 66 -67 59                           $ Transverse Colon Wall
33   3 -0.9869     -60 140 61 -59 -83                          $ Descending Colon Wall
35   3 -0.9869     -72                                         $ testicle
36   3 -0.9869     -73                                         $ testicle
37   3 -0.9869     -74 75 -76 6 -77                            $ thyroid
38   4 -1.4862     -82 83 37 -78 80 (79:-81)                   $ pelvis
39   4 -1.4862     -84 78 -85 102                              $ spine
40   3 -0.9869     -83 86 -50 88 -87 #30 #32 #33 #63 #64 #65          $ small int.
41   1 -0.001293   -107 606 -4                                 $ air
42   1 -0.001293   -108 606 -4                                 $ air
```

```
43   3 -0.9869    -92 65                                      $ kidney
44   3 -0.9869    -93 -94                                     $ kidney
45   3 -0.9869    -95                                         $ bladder
46   3 -0.9869    -96                                         $ spleen
47   3 -0.9869    -98 99 (-65:100)                            $ pancreas
48   3 -0.9869    -101                                        $ thymus
49   4 -1.4862    47 -102 #60 #61                             $ skull
50   4 -1.4862    -103 38 -37                                 $ leg bone
51   4 -1.4862    -104 38 -37                                 $ leg bone
52   3 -0.9869    -105 92                                     $ adrenal
53   3 -0.9869    -106 93                                     $ adrenal
54   4 -1.4862    37 -115 -113                                $ arm bone
55   4 -1.4862    37 -115 -114                                $ arm bone
56   4 -1.4862    4 9 -32 -116 117 -118 119                   $ scapulae
57   4 -1.4862    4 9 -32 -116 117 -120 121                   $ scapulae
58   4 -1.4862    -4 -122 -123 124                            $ clavicle
59   4 -1.4862    -4 -122 -125 126                            $ clavicle
60   3 -0.9869    -33 128 129 -130 133 -134 -4 #700           $ eye lense
61   3 -0.9869    -33 128 -131 132 133 -134 -4 #700           $ eye lense
62   3 -0.9869    -77 -137 51                                 $ oesophagus
63   3 -0.9869    -138 58 -59                                 $ Ascending Colon Interior
64   3 -0.9869    -139 66 -67                                 $ Transvers Colon Interior
65   3 -0.9869    -140 61 -59 -83                             $ Decending Colon Interior
66   3 -0.9869    (-141 65 -61) : (-142 37 -65)               $ Sigmoid Colon Interior
600   0          -600 35 34 : -601 33 -35 606 : &             $ Head & Neck
                -606 6 33 -607: -607 7 -6 37 507 508 510 511 512 : &   $ Shoulders & Torso
  (((-46 616) (43 -44) (615 -37)):((615 -45)(610 609)(46 -4)(43 -44))): & $ Genitalia
                -610 40 -37 38 : -609 39 -37 38 : &           $ Legs
                -708 608 -609 : -708 608 -610 : &             $ Feet
                -38 708 -610 40 : -38 708 -609 39
700   5 -1.04     700 35 102 -34 : 701 -33 -35 6 : &          $ Head & Neck
                706 -6 701 -707 : 707 -7 -6 37 114 113 : &    $ Shoulders & Torso
  (((46 -716)(43 -44)(609 610)(715 -37)):((-715 45)(610 609)(46 -4)(43 -44))): & $ Genitalia
                -40 710 -37 38 : -39 709 -37 38 : &           $ Legs
                -38 708 -39 : -38 708 -40                     $ Feet
c ++++++++++++++++++
c   BC408 Volume
c ++++++++++++++++++
501   501 -1.032      -501 : -502
c ++++++++++++++++++
c   Lead Shielding
c ++++++++++++++++++
502   502 -11.3     -503 501 : -504 502
c ++++++++++++++++++
c   Air in PVC Pipe
c ++++++++++++++++++
503   503 -1.24e-3   -505 501 503 : -506 502 504 : -509
c ++++++++++++++++++
c   PVC Piping
c ++++++++++++++++++
504   504 -1.32      -507 505 509 : -508 506 509 : -510 509 506 505
c ++++++++++++++++++
c   Aluminum Feet
c ++++++++++++++++++
505   505 -2.7      -511 : -512
c ++++++++++++++++++++
```

```
67    0             1

1     SO  200
2     SQ  23.04 10.24 1 0 0 0 -576 8.5 0 43.5
3     SQ  23.04 10.24 1 0 0 0 -576 2.5 0 43.5
4     PY  0.0
5     PZ  43.5
6     PZ  70
706   PZ  69.8
606   PZ  70.2
7     SQ  1 4.0 0 0 0 0 -400.0 0 0 0
707   SQ  0.002551 0.010412 0 0 0 0 -1 0 0 0
607   SQ  0.002451 0.00961  0 0 0 0 -1 0 0 0
8     SQ  1 3.15 0 0 0 0 -272.25 0 0 0
9     SQ  1 3.01 0 0 0 0 -289.0 0 0 0
10    PZ  44.9
11    PZ  35.1
12    PZ  36.5
13    PZ  37.9
14    PZ  39.3
15    PZ  40.7
16    PZ  42.1
17    PZ  46.3
18    PZ  47.7
19    PZ  49.1
20    PZ  50.5
21    PZ  51.9
22    PZ  53.3
23    PZ  54.7
24    PZ  56.1
25    PZ  57.5
26    PZ  58.9
27    PZ  60.3
28    PZ  61.7
29    PZ  63.1
30    PZ  64.5
31    PZ  65.9
32    PZ  67.3
33    SQ  100 49 0 0 0 0 -4900 0 0 0
701   SQ  0.021626 0.010412 0 0 0 0 -1 0 0 0
601   SQ  0.01929 0.009612 0 0 0 0 -1 0 0 0
34    SQ  7225 3540.25 4900 0 0 0 -354025 0 0 85.5
700   SQ  0.021626 0.010412 0.014516 0 0 0 -1 0 0 85.5
600   SQ  0.01929 0.009612 0.013212 0 0 0 -1 0 0 85.5
35    PZ  85.5
36    PZ  94
37    PZ  0
38    PZ  -80
708   PZ  -80.215
608   PZ  -80.415
39  601  GQ  5.025 5 0 0 0 -1 -100 0 0 0
709 603  GQ  5.05 5 0 0 0 -1 -100 0 0 0
609 605  GQ  4.963 5 0 0 0 -1 -100 0 0 0
40  600  GQ  5.025 5 0 0 0 1 100 0 0 0
710 602  GQ  5.089 5 0 0 0 1 100 0 0 0
610 604  GQ  4.963 5 0 0 0 1 100 0 0 0
```

```
41    SQ  23.04 10.24 1 0 0 0 -576 -8.5 0 43.5
42    SQ  23.04 10.24 1 0 0 0 -576 -2.5 0 43.5
43    P   10 0 1 -100
44    P   10 0 -1 100
45    PZ  -4.8
715   PZ  -4.6
615   PZ  -5.0
46    P   0 10 1 -100
716   P   0 10.2 1 -100
616   P   0 9.8 1 -100
47    SQ  2.25 1 1.91716 0 0 0 -81 0 0 86.5
48    SQ  64 272.25 0 0 0 0 -17424 0 0 0
49    P   9 7 -7.3256 -315
50    PZ  27
51    PZ  43
52    GQ  45.2 59.9 47.9 17.5 -16.2 34.8 -1632.1 1204.8 -4898.2 124295.2
53    SQ  1 1 1 0 0 0 -25 -1 -3 51
54    P   .6943 -.3237 -.6428 -32.506
55    P   5.2193 -2.4336 -0.916 -59.6345
56    SQ  4 7.11 1 0 0 0 -64 8 -4 35
57    SQ  1 1 0 0 0 0 -6.25 -8.5 -2.36 0
58    PZ  14.45
59    PZ  24
60    GQ  4.54 3.53 .096 0 1.16 -0.166 -77.68 -10.08 -.223 323.52
61    PZ  8.72
62    SQ  0 2.25 6.25 0 0 0 -14.0625 0 -2.36 25.5
63    TY  3 0 8.72 5.72 1.57 1.57
64    TY  3 0 0 3 1.57 1.57
65    PX  3
66    PX  -10.5
67    PX  10.5
68    PX  -20
69    PX  20
70    PY  -30
71    PY  -29
72    SQ  11.9025 8.9401 3.8025 0 0 0 -20.115225 1.3 -8 -2.3
73    SQ  11.9025 8.9401 3.8025 0 0 0 -20.115225 -1.3 -8 -2.3
74    C/Z 0 -6 2.2
75    C/Z 0 -6 1
76    PY  -6
77    PZ  75
78    PZ  22
79    PZ  14
80    PY  -3
81    PY  5
82    C/Z 0 -3 12
83    C/Z 0 -3.8 11.3
84    SQ  6.25 4 0 0 0 0 -25 0 5.5 0
85    PZ  78.5
86    PZ  17
87    PY  2.2
88    PY  -4.86
89    C/Z 0 -11. 0.6350
90    C/Z 0 -11. 0.8636
91    PZ  56.335
92    SQ  1.49 13.44 1 0 0 0 -30.25 6 6 32.5
```

```
93    SQ  1.49 13.44 1 0 0 0 -30.25 -6 6 32.5
94    PX  -3
95    SQ  1 2.0557 2.0557 0 0 0 -24.5818 0 -4.5 8
96    SQ  2.94 9 1 0 0 0 -36 11 3 37
97    PZ  12
98    SQ  1 225 25 0 0 0 -225 0 0 37
99    PX  0
100   PZ  37
101   SQ  1.78 64 1 0 0 0 -16 -2 -6 60.5
102   SQ  2.08 1 1.39 0 0 0 -96.04 0 0 85.5
103   GQ  1 1 .0091 0 0 -.2005 -20 0 1.7857 87.75
104   GQ  1 1 .0091 0 0 .2005 20 0 1.7857 87.75
105   SQ  100 900 9 0 0 0 -225 4.5 6.5 38
106   SQ  100 900 9 0 0 0 -225 -4.5 6.5 38
107   SQ  1.39 .5 2 0 0 0 -70 -6.5 -3 50
108   SQ  1.39 .5 2 0 0 0 -70 6.5 -3 50
109   PX  17
110   PX  6
111   PX  -6
112   PX  -17
113   GQ  503.01 135.24 0 0 0 10.206 -19215 0 -202.0788 183257
114   GQ  503.01 135.24 0 0 0 -10.206 19215 0 -202.0788 183257
115   PZ  69
116   SQ  1 3.7589 0 0 0 0 -361 0 0 0
117   PZ  50.9
118   P   0.25 -1 0 0
119   P   0.8 -1 0 0
120   P   -0.25 -1 0 0
121   P   -0.8 -1 0 0
122   TZ  0 11.1 68.25 20 0.7883 0.7883
123   P   0.89415 1 0 11.1
124   P   7.0342 1 0 11.1
125   P   -0.89415 1 0 11.1
126   P   -7.0342 1 0 11.1
C     2 concentric elliptical cylinders and planes to define eye lenses
127   SQ  100 64 0 0 0 0 -6400 0 0 0
128   SQ  88.36 40.96 0 0 0 0 -3619.2256 0 0 0
129   PX  2
130   PX  4
131   PX  -2
132   PX  -4
133   PZ  82.5
134   PZ  84.5
C     segmenting planes for RBM regions in leg and arm bones
135   PZ  -22.8
136   PZ  52.6
C     Oesophagus
137   SQ 0.16 1.0 0 0 0 0 -0.16 0.5 2.5 0                    $ Oesophagus Exterior
C     Colon Wall
138   SQ 1 1 0 0 0 0 -3.209 -8.5 -2.36 0                     $ Ascending Colon Interior
139   SQ 0 0.9467 3.8927 0 0 0 -3.6854 0 -2.36 25.5
140   GQ 1.796 2.496 0.0674 0 0.818 -0.066 -30.75 -7.12 -0.602 132.2
141   TY 3 0 8.72 5.72 0.91 0.91                             $ Upper Sigmoid Interior
142   TY 3 0 0 3 0.91 0.91                                   $ Lower Sigmoid Interior
c +++++++++++++++
c   BC408 Volume
```

```
501 900 RPP  53.45  57.25  -3.75 3.75  0 183
502 900 RPP -57.25 -53.45  -3.75 3.75  0 183
c +++++++++++++++++
c   Lead Shield
503 900 RPP  53.45  57.41 -3.91 3.91  0 183
504 900 RPP -57.41 -53.45 -3.91 3.91  0 183
c ++++++++++++++++++++++++++++++++
c   Air between detector and PVC
505 900 RCC 55.35    0 -17  0 0 217  4.694
506 900 RCC -55.35   0 -17  0 0 217  4.694
c +++++++++++++++++++++++
c   PVC Piping on sides
507 900 RCC 55.35    0 -17  0 0 217  5.25
508 900 RCC -55.35   0 -17  0 0 217  5.25
c +++++++++++++++++++++
c   PVC Piping on top
509 900 RCC -60.044  0  195    120.088 0 0 4.694
510 900 RCC -60.6    0  195    121.2  0 0 5.25
c ++++++++++++++++++++++
c Aluminum Feet
511 900 RPP 45.35   65.35  -30 30   -17.61 -17.01
512 900 RPP -65.35 -45.35  -30 30   -17.61 -17.01

C Data Cards
tr600 -0.1
tr601 0.1
tr602 -0.15
tr603 0.15
tr604 -0.051
tr605 0.051
tr900 0 0 -64 0 1 0 1 0 0 0 0 1
c VOL   0 9.89817E3 5.12539E4 7.01171E3 4.12839E3 3.75367E4 4.1204E4 &
c      3.96266E4 3.42787E2 3.43057E2 3.41728E2 3.41505E2 3.3914E2 &
c      3.38905E2 3.37704E2 3.38854E2 3.36585E2 3.35548E2 3.34261E2 &
c      3.3525E2 1.09049E4 5.26806E4 5.19336E4 9.87788E3 8.35231E2 &
c      8.24983E3 1.08532E4 3.48665E3 2.39203E3 5.46974E2 4.19631E2 &
c      7.21861E2 5.2306E2 1.1077E2 1.11655E2 1.72154E2 3.63227E3 &
c      5.17342E3 6.31233E3 0 0 8.49751E2 8.55366E2 1.48895E3 1.04544E3 &
c      3.58882E2 1.45325E2 4.77509E3 8.25008E3 8.23095E3 5.80561E1 &
c      5.70516E1 2.81453E3 2.80523E3 5.80932E2 5.89508E2 1.56404E2 &
c      1.56141E2 1.09588E1 1.10836E1 2.31698E2 5.781E2 7.58053E2 &
c      6.152E2 2.15848E2 1.23531E4 1.09131E4 1.6059E4 1.6059E4 &
c      1.6059E4 1.6059E4 23.9241 9.2379 53.9171 10.2532 28.10780 &
c      23.9241 9.2379 53.9171 10.2532 28.1078 23.9241 9.2379 53.9171 &
c      10.2532 28.1078 23.9241 9.2379 53.9171 10.2532 28.1078 0
IMP:P 1 71R 0
C
C Sources
SDEF  PAR=2  ERG=D1  CEL=D2  RAD=fcel=D3  &
      POS=fcel=D4  EXT=fcel=D5  AXS=fcel=D6
SI1 L 0.029458 0.722893 0.0297792 0.080183 0.284298 0.636973 0.36448
SP1 0.013568 0.01752 0.025171 0.025448 0.058825 0.07057 0.788898
C Left Lung, Right Lung, Stomach, Small Int., Heart, Ascending Colon,
C Sigmoid Colon, Transvers Colon, Descending Colon, Bladder,
C Body Tissue (3, 4, 5, 6, 7, 8, 21, 22, 23, 25), Thyroid
SI2 L 2 24 29 40 28 30 31 32 33 45 3 4 5 6 7 8 21 22 23 25 37
```

```
SP2 D 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
DS3 S 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
DS4 L 8.5 0 43.4   -8.5 0 43.4   8 -4 35   0 -3.8 11.3   -1 -3 51   &
      -8.5 -2.36 14.35   5 0 -0.1   -10.6 -2.36 25.5   8.72 0 8.52  &
      0 -4.5 8   0 0 42.9   0 0 50.8   0 0 42.9   0 0 26.9          &
      0 0 11.9   0 0 -0.1   0 0 69.9   10.5 0 -80.1   -10.5 0 -80.1 &
      0 -8 -4.9   0 -6 69.9
DS5 S 30 31 0 32 0 33 34 35 36 0 37 38 39 40 41 42 43 44 45 46 47
DS6 L 0 0 1   0 0 1   0 0 0   0 0 1   0 0 0   0 0 1   0 0 1 &
      1 0 0   0 0 1   0 0 0   0 0 1   0 0 1   0 0 1   0 0 1 &
      0 0 1   0 0 1   0 0 1   0 0 1   0 0 1   0 0 1   0 0 1
SI7  0 7.6
SP7  -21 1
SI8  0 7.6
SP8  -21 1
SI9  0 8.2
SP9  -21 2
SI10 0 11.4
SP10 -21 1
SI11 0 8.2
SP11 -21 2
SI12 0 2.6
SP12 -21 1
SI13 0 7.1
SP13 -21 1
SI14 0 3.85
SP14 -21 1
SI15 0 4
SP15 -21 1
SI16 0 5.2
SP16 -21 2
SI17 0 20.2
SP17 -21 1
SI18 0 20.3
SP18 -21 1
SI19 0 20.3
SP19 -21 1
SI20 0 20.3
SP20 -21 1
SI21 0 20.3
SP21 -21 1
SI22 0 20.3
SP22 -21 1
SI23 0 10.1
SP23 -21 1
SI24 0 11
SP24 -21 1
SI25 0 11
SP25 -21 1
SI26 0 8.1
SP26 -21 1
SI27 0 2.2
SP27 -21 1
SI30 0 24.6
SP30 -21 0
SI31 0 24.6
```

```
SP31 -21 0
SI32 0 10.2
SP32 -21 0
SI33 0 9.75
SP33 -21 0
SI34 0 8.92
SP34 -21 0
SI35 0 21.2
SP35 -21 0
SI36 0 16
SP36 -21 0
SI37 0 27.2
SP37 -21 0
SI38 0 16.6
SP38 -21 0
SI39 0 8.1
SP39 -21 0
SI40 0 16.2
SP40 -21 0
SI41 0 15.2
SP41 -21 0
SI42 0 12.2
SP42 -21 0
SI43 0 24.2
SP43 -21 0
SI44 0 80.2
SP44 -21 0
SI45 0 80.2
SP45 -21 0
SI46 0 5
SP46 -21 0
SI47 0 5.2
SP47 -21 0
C
c ++++++++++++++
c Tally
F8:P 501
E8 0 1e-8 0.005 2000i 1.5
FT8 SCX 2
c ++++++++++++++
C Material Cards
C      THIS IS THE COMPOSITION FOR AIR
M1    7014 -.7558 8016 -.2314 18000 -.0128
C     THIS IS THE COMPOSITION FOR LUNG TISSUE
M2    1001 -.1021
      6012 -.1001
      7014 -.0280
      8016 -.7596
     11023 -.0019
     15031 -.0008
     16032 -.0023
     17000 -.0027
     19000 -.0020
     20000 -.0001
     26000 -.0004
C       THE COMPOSITION FOR TOTAL BODY MINUS SKELETON AND LUNGS
```

```
M3    1001 -.1047
      6012 -.2302
      7014 -.0234
      8016 -.6321
     11023 -.0013
     12000 -.0002
     15031 -.0024
     16032 -.0022
     17000 -.0014
     19000 -.0021
C      THE COMPOSITION FOR SKELETAL TISSUE
M4    1001 -.0704
      6012 -.2279
      8016 -.4856
      7014 -.0387
     11023 -.0032
     12000 -.0011
     15031 -.0694
     16032 -.0017
     17000 -.0014
     19000 -.0015
     20000 -.0991
c      Adult Tissues (Density = 1.04 g/cc)
M5       1001  -0.10454
         6012  -0.22663
         7014  -0.02490
         8016  -0.63525
        11023  -0.00112
        12000  -0.00013
        14000  -0.00030
        15031  -0.00134
        16032  -0.00204
        17000  -0.00133
        19000  -0.00208
        20000  -0.00024
        26000  -0.00005
        30000  -0.00003
        37085  -0.000007217
        37087  -0.000002783
        40000  -0.00001
c Materials
M501 1000   0.5246   6000  0.4754                      $ BC408
M502 82000 -1                                     $ Lead
M503 8016 -.232 7014 -.755 6012 -1.2e-4 18000 -1.28e-2 $ Air, NIST
M504 17000 0.166 1000 0.5 6000 0.334                   $PVC
M505 13000 -1                                     $ Aluminum
lost 50
c STOP NPS 1E8 F38 0.01
NPS 4E9
RAND GEN=2 SEED=1561615651
PHYS:P 4J 1
PRINT
MODE P
```

APPENDIX C: MIRD PHANTOM COUNT RATE PER 250 mSv

Table C.1. CPS per 250 mSv for Reference Male Inhaled Co-60

Total Body Count		
Co-60		**cps per 250 mSv**
Days following exposure	1	1.44E+04
	2	1.04E+04
	3	8.40E+03
	4	7.42E+03
	5	6.92E+03
	6	6.61E+03
	7	6.40E+03
	8	6.22E+03
	9	6.06E+03
	10	5.93E+03
	20	5.07E+03
	30	4.66E+03

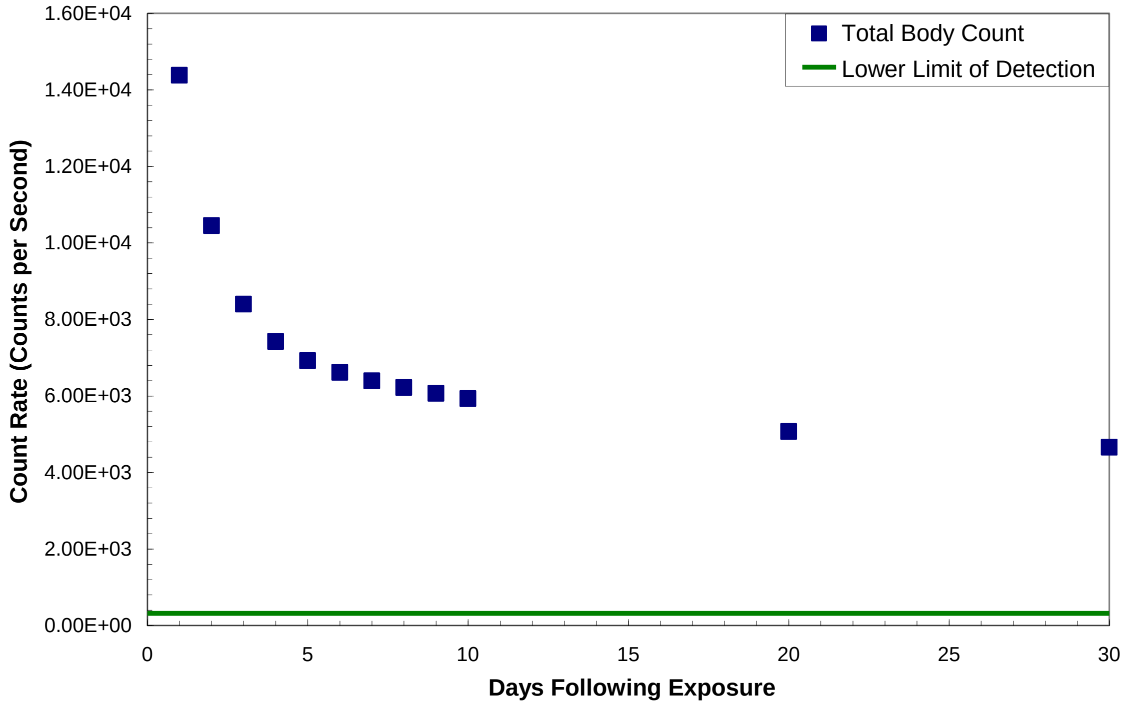

Figure C.1. CPS per 250 mSv for Reference Male Inhaled Co-60

Table C.2. CPS per 250 mSv for Reference Male Inhaled Cs-137

Total Body Count		
Cs-137		**cps per 250 mSv**
Days following exposure	1	1.40E+05
	2	1.38E+05
	3	1.35E+05
	4	1.33E+05
	5	1.30E+05
	6	1.29E+05
	7	1.27E+05
	8	1.26E+05
	9	1.25E+05
	10	1.24E+05
	20	1.16E+05
	30	1.09E+05

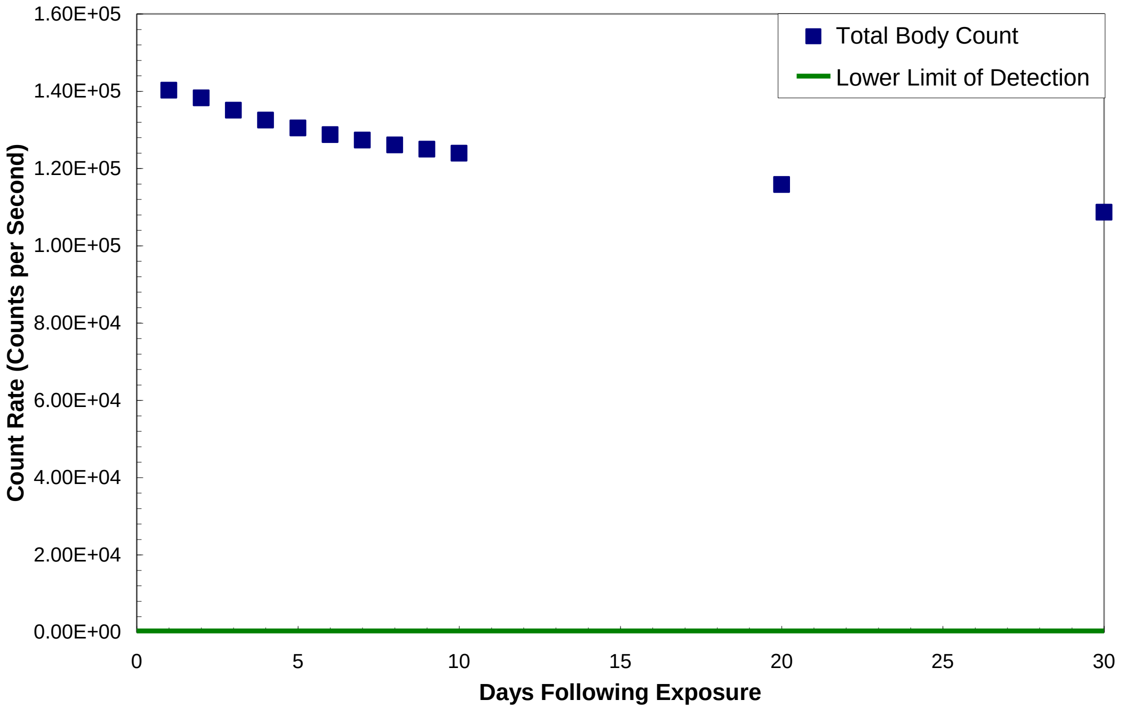

Figure C.2. CPS per 250 mSv for Reference Male Inhaled Cs-137

Table C.3. CPS per 250 mSv for Reference Male Inhaled I-131

Total Body Count		
I-131		**cps per 250 mSv**
Days following exposure	1	4.44E+03
	2	2.34E+03
	3	2.11E+03
	4	1.98E+03
	5	1.86E+03
	6	1.75E+03
	7	1.63E+03
	8	1.53E+03
	9	1.42E+03
	10	1.33E+03
	20	6.08E+02
	30	2.60E+02

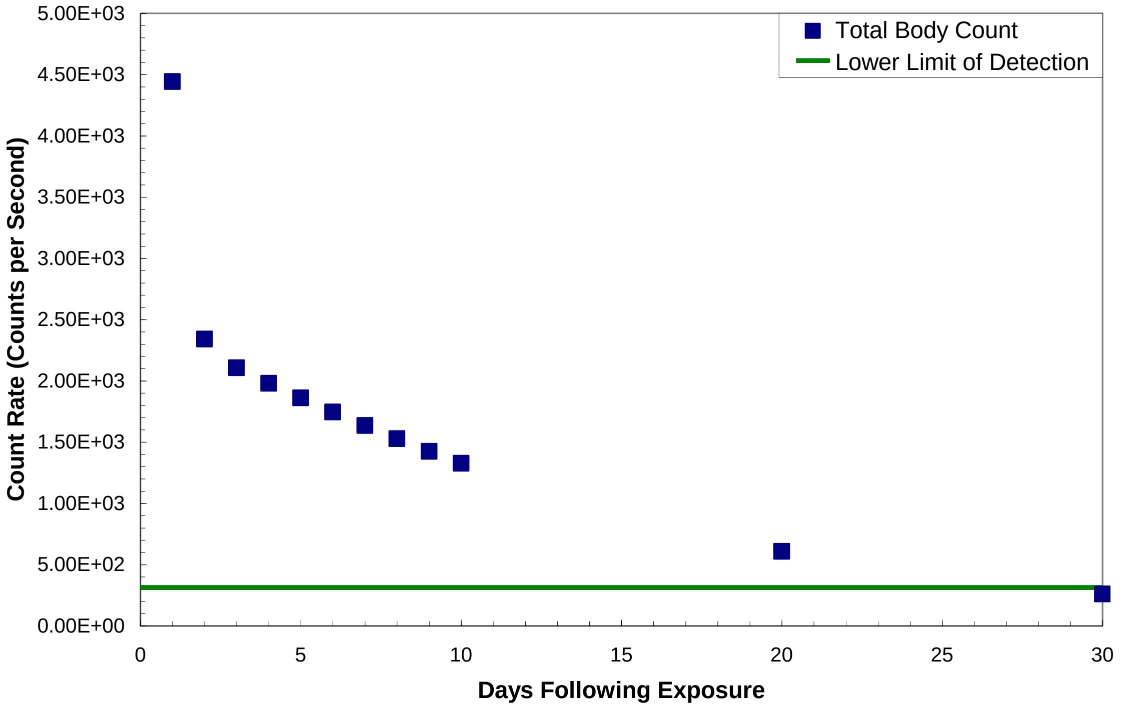

Figure C.3. CPS per 250 mSv for Reference Male Inhaled I-131

Table C.4. CPS per 250 mSv for Reference Male Inhaled Ir-192

Total Body Count		
Ir-192		**cps per 250 mSv**
Days following exposure	1	1.98E+04
	2	1.45E+04
	3	1.17E+04
	4	1.05E+04
	5	9.96E+03
	6	9.68E+03
	7	9.51E+03
	8	9.38E+03
	9	9.27E+03
	10	9.17E+03
	20	8.30E+03
	30	7.59E+03

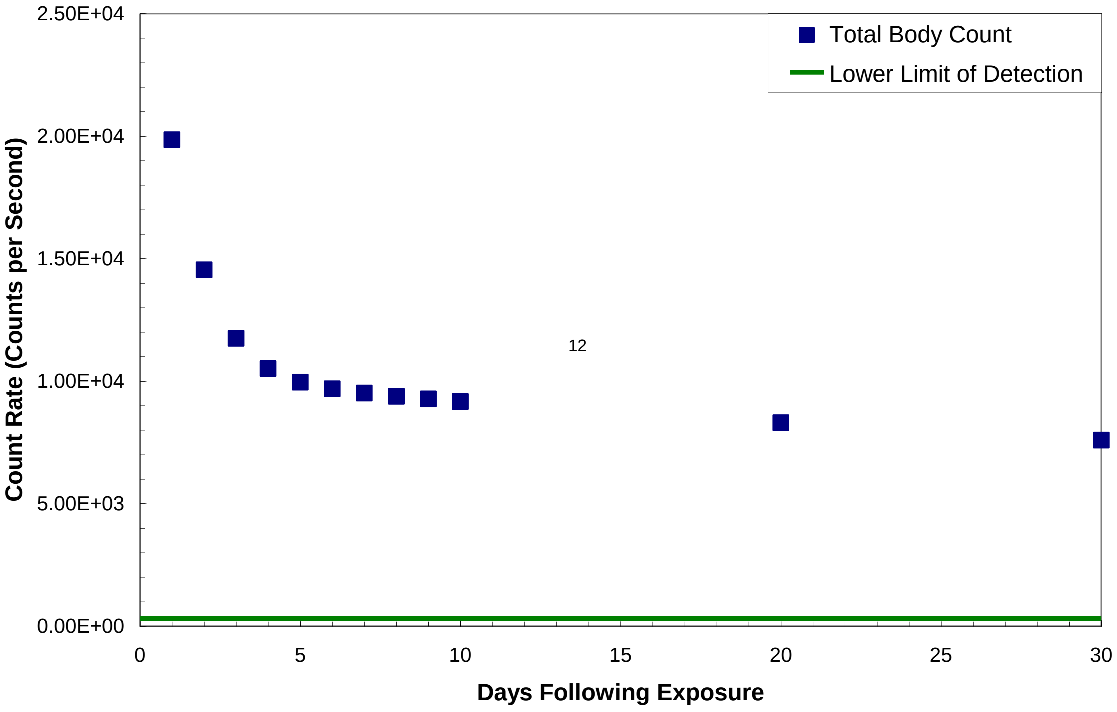

Figure C.4. CPS per 250 mSv for Reference Male Inhaled Ir-192

Table C.5. CPS per 250 mSv for Reference Female Inhaled Co-60

Total Body Count		
Co-60		**cps per 250 mSv**
Days following exposure	1	1.42E+04
	2	1.04E+04
	3	8.41E+03
	4	7.46E+03
	5	6.97E+03
	6	6.66E+03
	7	6.44E+03
	8	6.26E+03
	9	6.10E+03
	10	5.96E+03
	20	5.10E+03
	30	4.69E+03

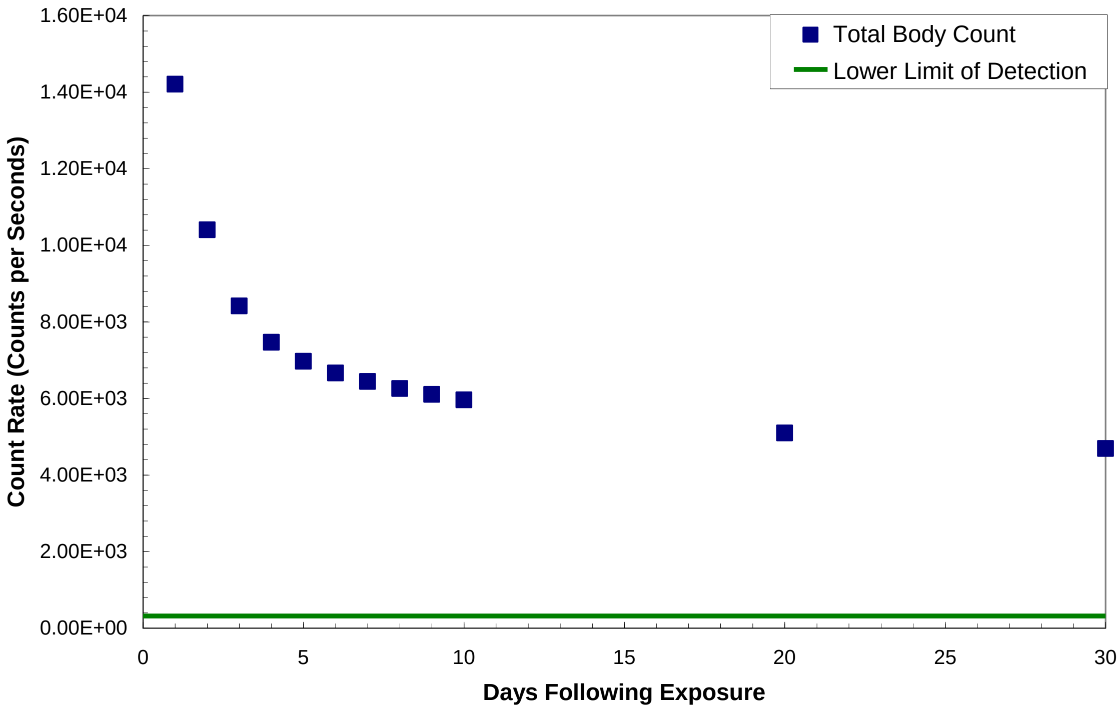

Figure C.5. CPS per 250 mSv for Reference Female Inhaled Co-60

Table C.6. CPS per 250 mSv for Reference Female Inhaled Cs-137

Total Body Count		
Cs-137		**cps per 250 mSv**
Days following exposure	1	1.48E+05
	2	1.46E+05
	3	1.43E+05
	4	1.40E+05
	5	1.38E+05
	6	1.36E+05
	7	1.34E+05
	8	1.33E+05
	9	1.32E+05
	10	1.31E+05
	20	1.22E+05
	30	1.15E+05

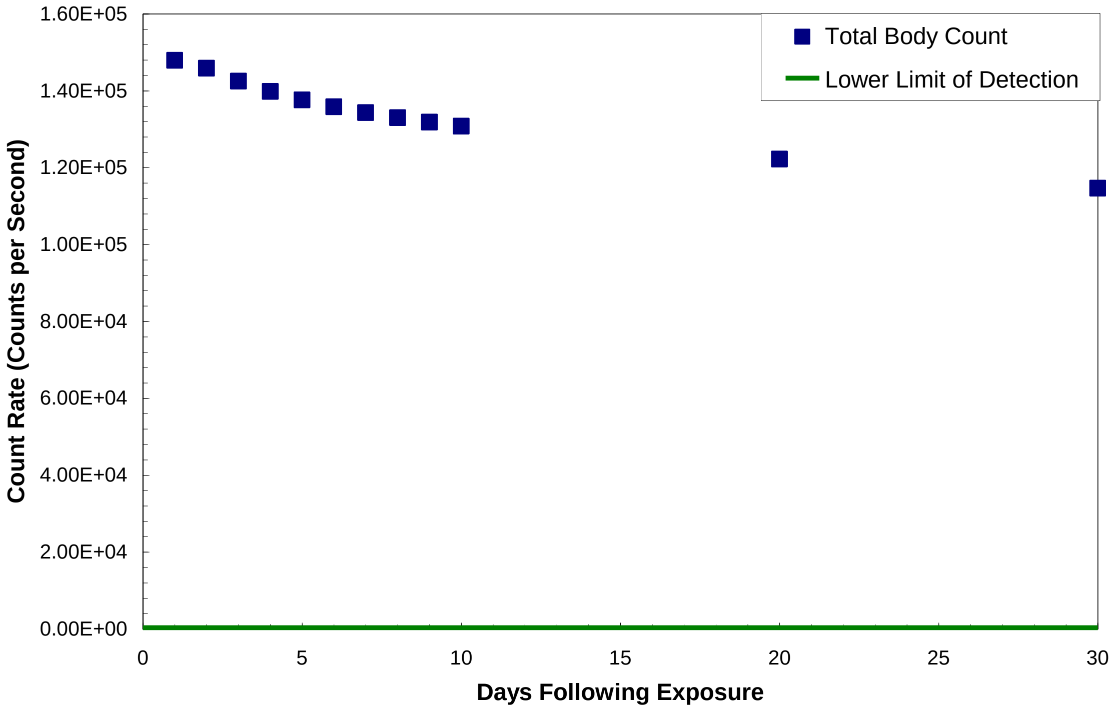

Figure C.6. CPS per 250 mSv for Reference Female Inhaled Cs-137

Table C.7. CPS per 250 mSv for Reference Female Inhaled I-131

Total Body Count		
I-131		**cps per 250 mSv**
Days following exposure	1	4.49E+03
	2	2.29E+03
	3	2.06E+03
	4	1.94E+03
	5	1.83E+03
	6	1.72E+03
	7	1.62E+03
	8	1.51E+03
	9	1.51E+03
	10	1.32E+03
	20	6.10E+02
	30	2.62E+02

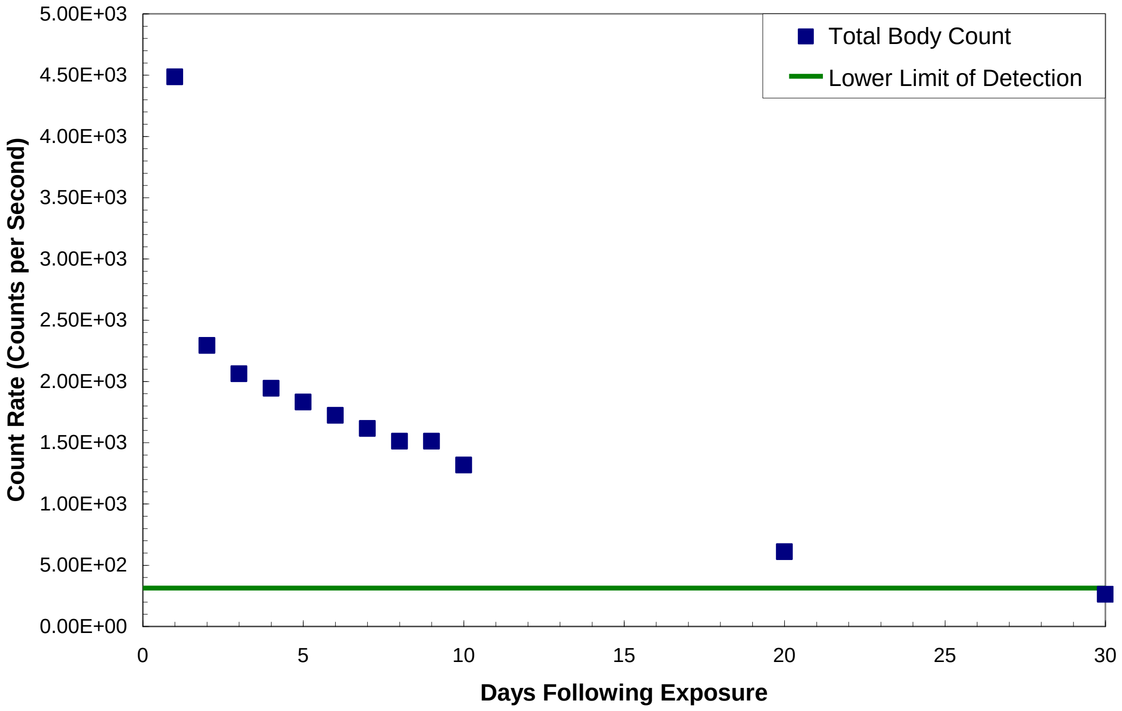

Figure C.7. CPS per 250 mSv for Reference Female Inhaled I-131

Table C.8. CPS per 250 mSv for Reference Female Inhaled Ir-192

Total Body Count		
Ir-192		**cps per 250 mSv**
Days following exposure	1	1.96E+04
	2	1.45E+04
	3	1.18E+04
	4	1.06E+04
	5	1.01E+04
	6	9.80E+03
	7	9.63E+03
	8	9.51E+03
	9	9.40E+03
	10	9.30E+03
	20	8.46E+03
	30	7.77E+03

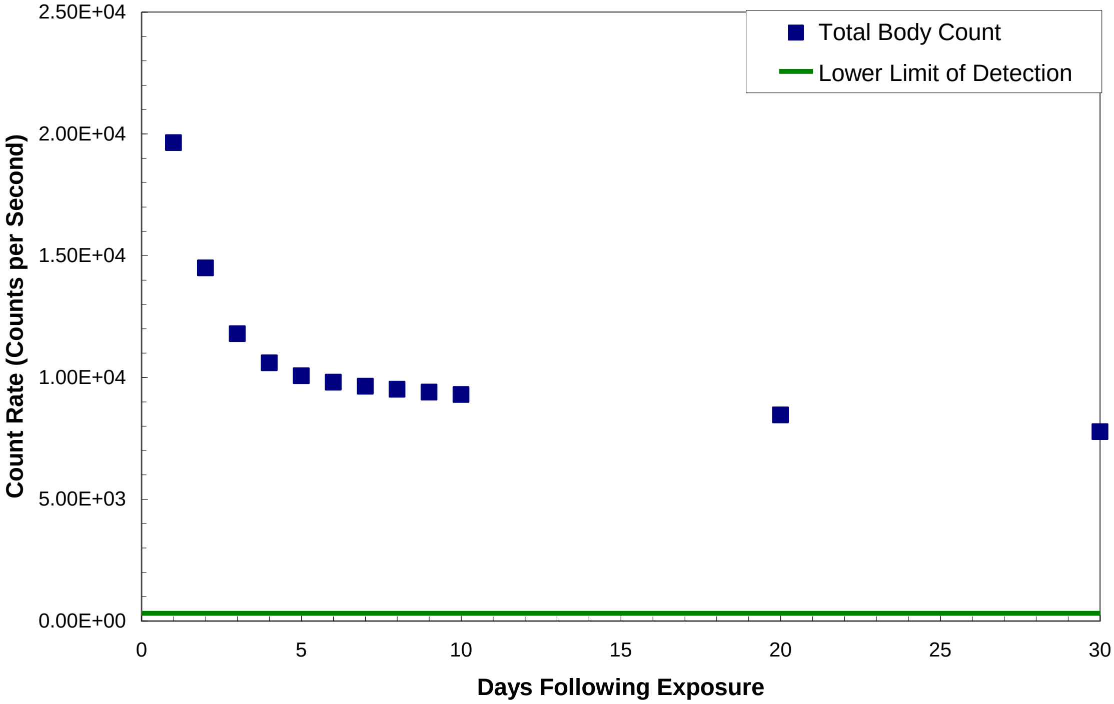

Figure C.8. CPS per 250 mSv for Reference Female Inhaled Ir-192

Table C.9. CPS per 250 mSv for Adipose Male Inhaled Co-60

Total Body Count		
Co-60		**cps per 250 mSv**
Days following exposure	1	1.27E+04
	2	9.52E+03
	3	7.85E+03
	4	7.03E+03
	5	6.59E+03
	6	6.31E+03
	7	6.10E+03
	8	5.93E+03
	9	5.77E+03
	10	5.64E+03
	20	4.81E+03
	30	4.44E+03

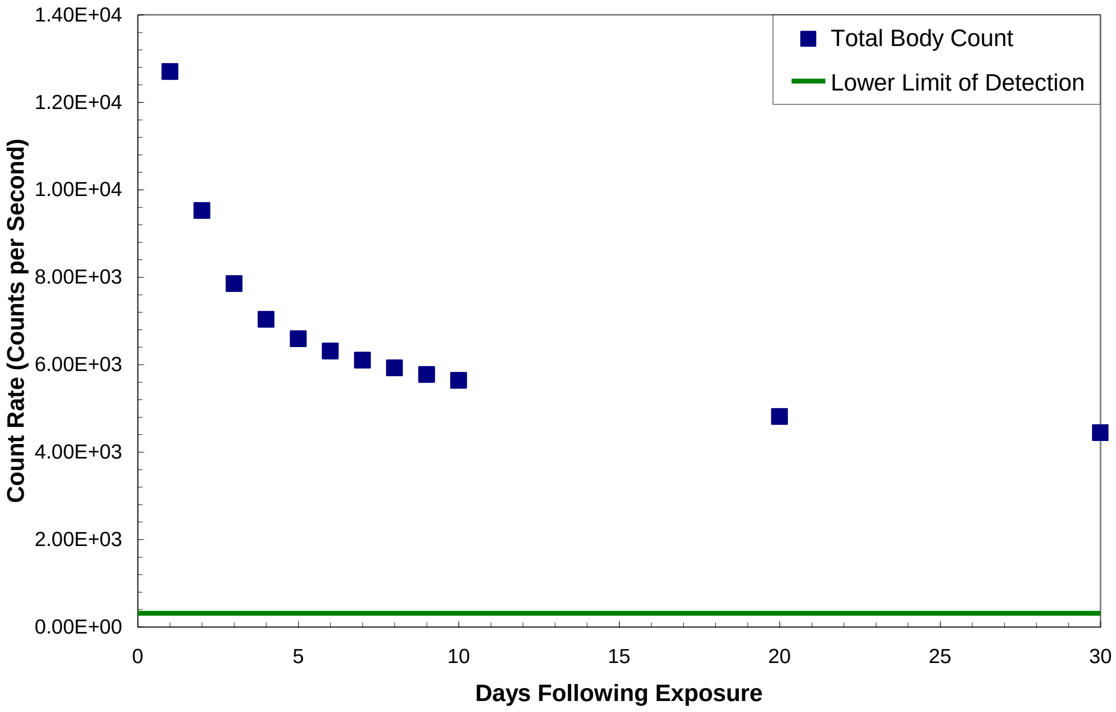

Figure C.9. CPS per 250 mSv for Adipose Male Inhaled Co-60

Table C.10. CPS per 250 mSv for Adipose Male Inhaled Cs-137

Total Body Count		
Cs-137		**cps per 250 mSv**
Days following exposure	1	1.47E+05
	2	1.45E+05
	3	1.41E+05
	4	1.39E+05
	5	1.36E+05
	6	1.35E+05
	7	1.33E+05
	8	1.32E+05
	9	1.31E+05
	10	1.30E+05
	20	1.21E+05
	30	1.14E+05

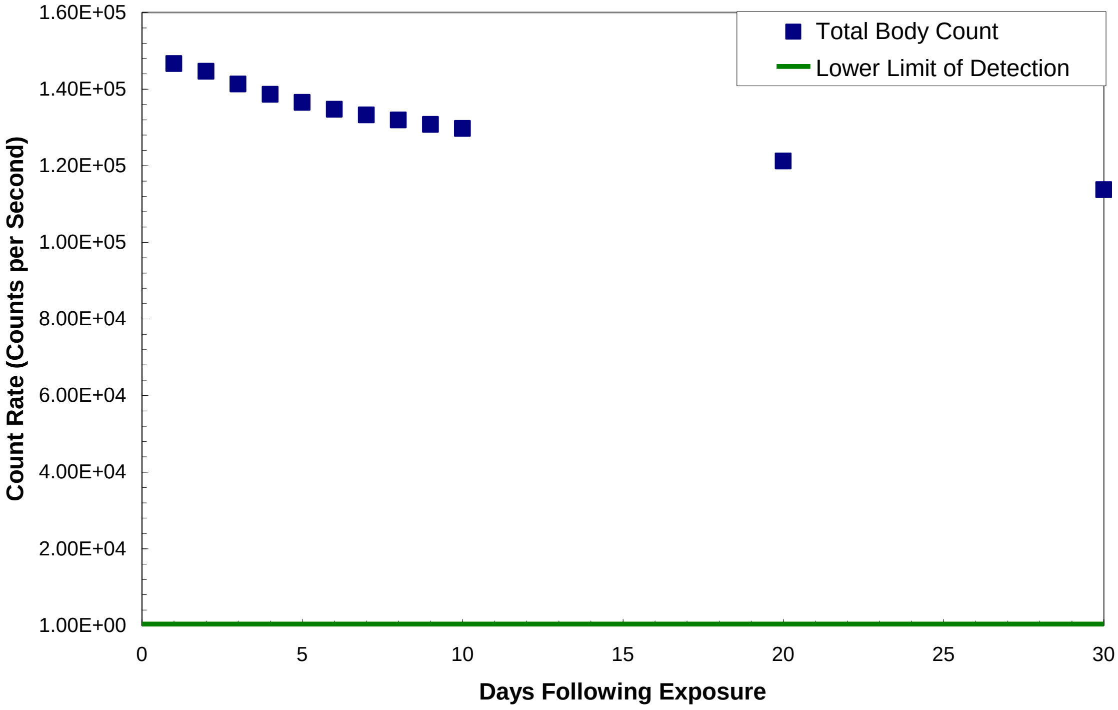

Figure C.10. CPS per 250 mSv for Adipose Male Inhaled Cs-137

Table C.11. CPS per 250 mSv for Adipose Male Inhaled I-131

Total Body Count		
I-131		**cps per 250 mSv**
Days following exposure	1	3.93E+03
	2	1.89E+03
	3	1.69E+03
	4	1.61E+03
	5	1.52E+03
	6	1.44E+03
	7	1.36E+03
	8	1.27E+03
	9	1.20E+03
	10	1.12E+03
	20	5.28E+02
	30	2.29E+02

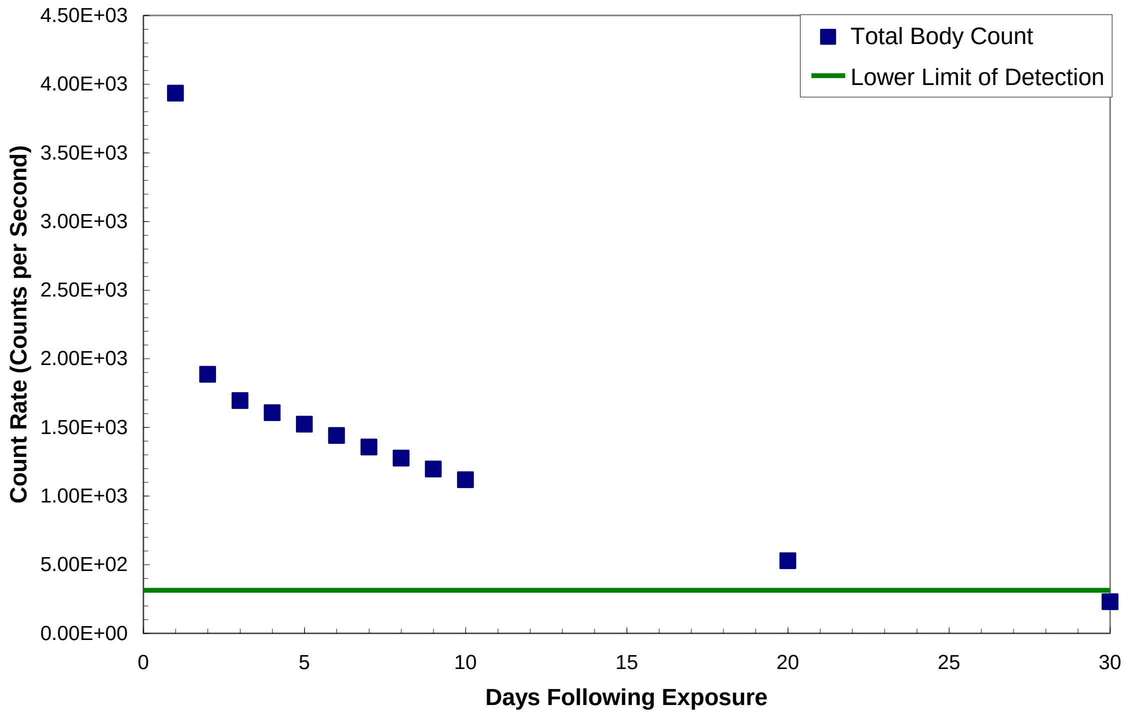

Figure C.11. CPS per 250 mSv for Adipose Male Inhaled I-131

Table C.12. CPS per 250 mSv for Adipose Male Inhaled Ir-192

Total Body Count		
Ir-192		**cps per 250 mSv**
Days following exposure	1	1.57E+04
	2	1.21E+04
	3	1.01E+04
	4	9.27E+03
	5	8.87E+03
	6	8.67E+03
	7	8.54E+03
	8	8.44E+03
	9	8.35E+03
	10	8.27E+03
	20	7.60E+03
	30	7.03E+03

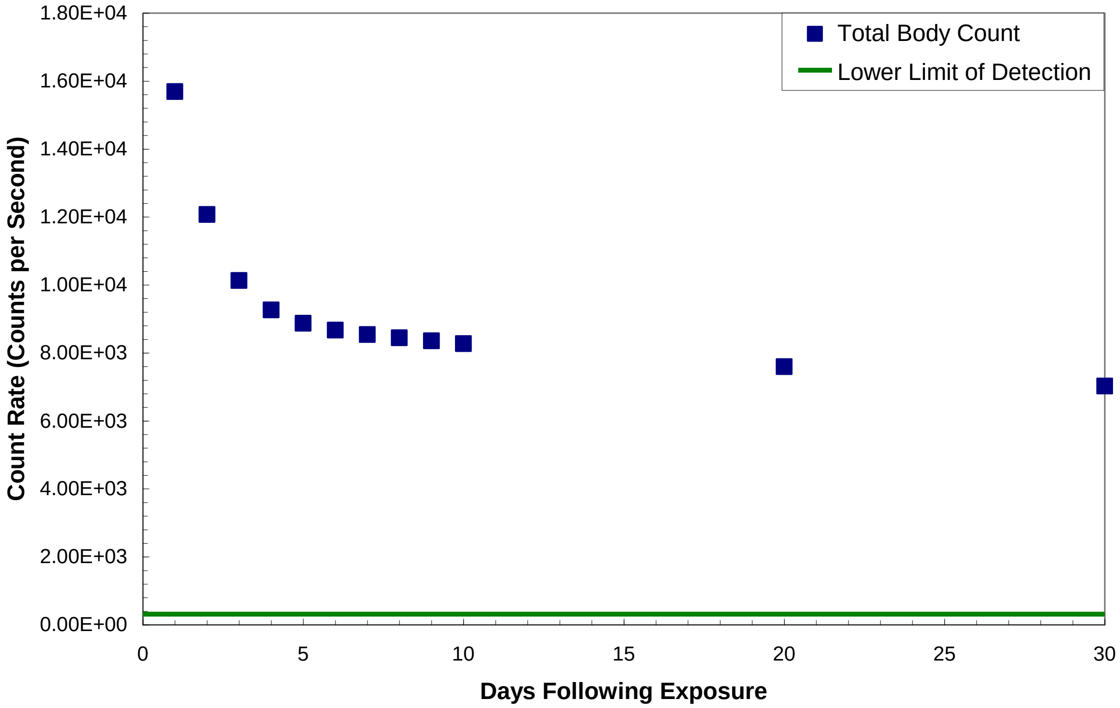

Figure C.12. CPS per 250 mSv for Adipose Male Inhaled Ir-192

Table C.13. CPS per 250 mSv for Adipose Female Inhaled Co-60

Total Body Count		
Co-60		**cps per 250 mSv**
Days following exposure	1	1.28E+04
	2	9.69E+03
	3	8.03E+03
	4	7.22E+03
	5	6.77E+03
	6	6.48E+03
	7	6.26E+03
	8	6.08E+03
	9	5.93E+03
	10	5.79E+03
	20	4.94E+03
	30	4.56E+03

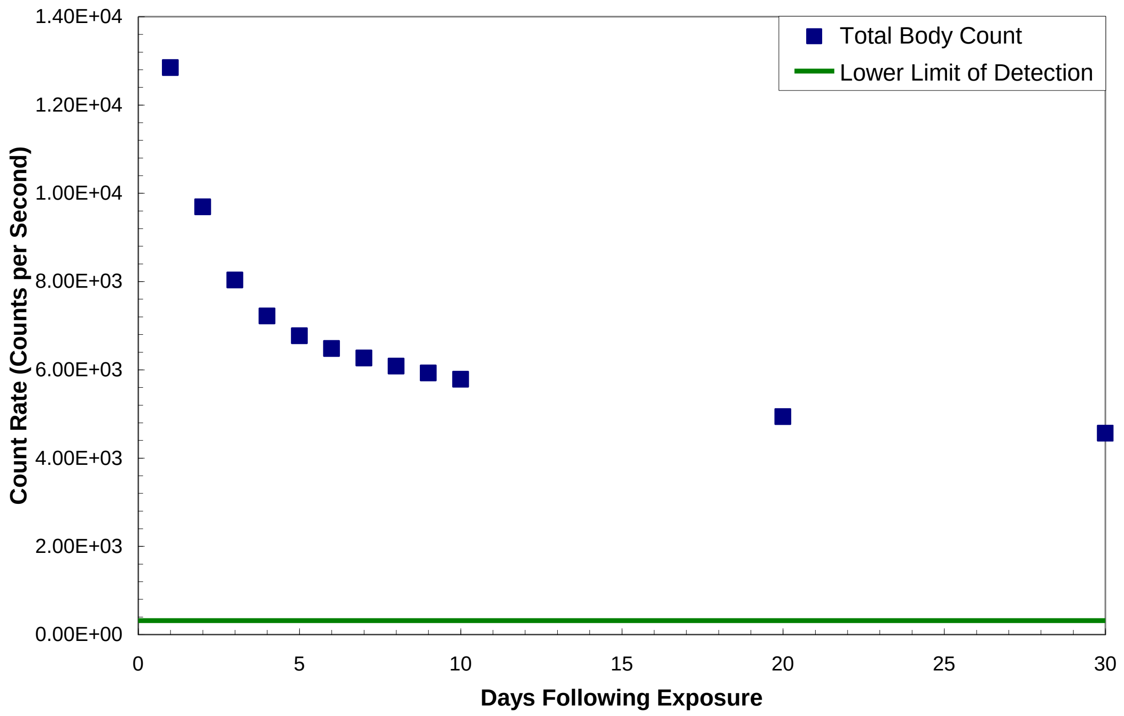

Figure C.13. CPS per 250 mSv for Adipose Female Inhaled Co-60

Table C.14. CPS per 250 mSv for Adipose Female Inhaled Cs-137

Total Body Count		
Cs-137		**cps per 250 mSv**
Days following exposure	1	1.57E+05
	2	1.54E+05
	3	1.51E+05
	4	1.48E+05
	5	1.46E+05
	6	1.44E+05
	7	1.42E+05
	8	1.41E+05
	9	1.40E+05
	10	1.38E+05
	20	1.29E+05
	30	1.21E+05

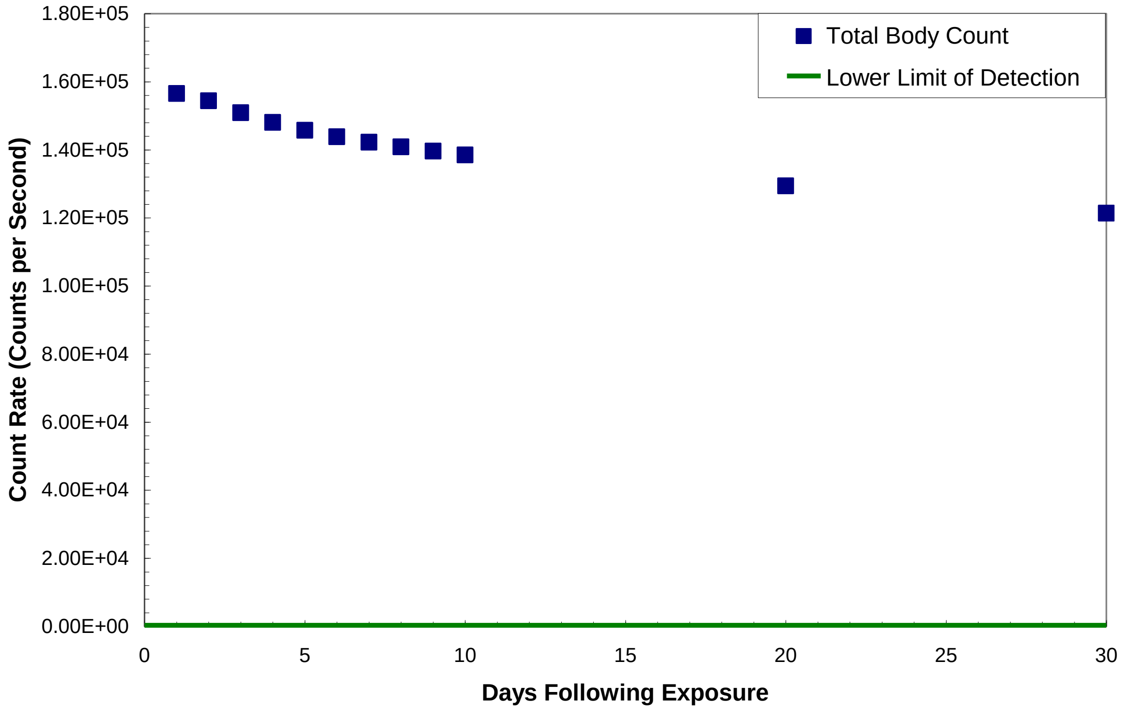

Figure C.14. CPS per 250 mSv for Adipose Female Inhaled Cs-137

Table C.15. CPS per 250 mSv for Adipose Female Inhaled I-131

Total Body Count		
I-131		cps per 250 mSv
Days following exposure	1	4.10E+03
	2	1.91E+03
	3	1.72E+03
	4	1.63E+03
	5	1.55E+03
	6	1.47E+03
	7	1.39E+03
	8	1.31E+03
	9	1.23E+03
	10	1.15E+03
	20	5.47E+02
	30	2.38E+02

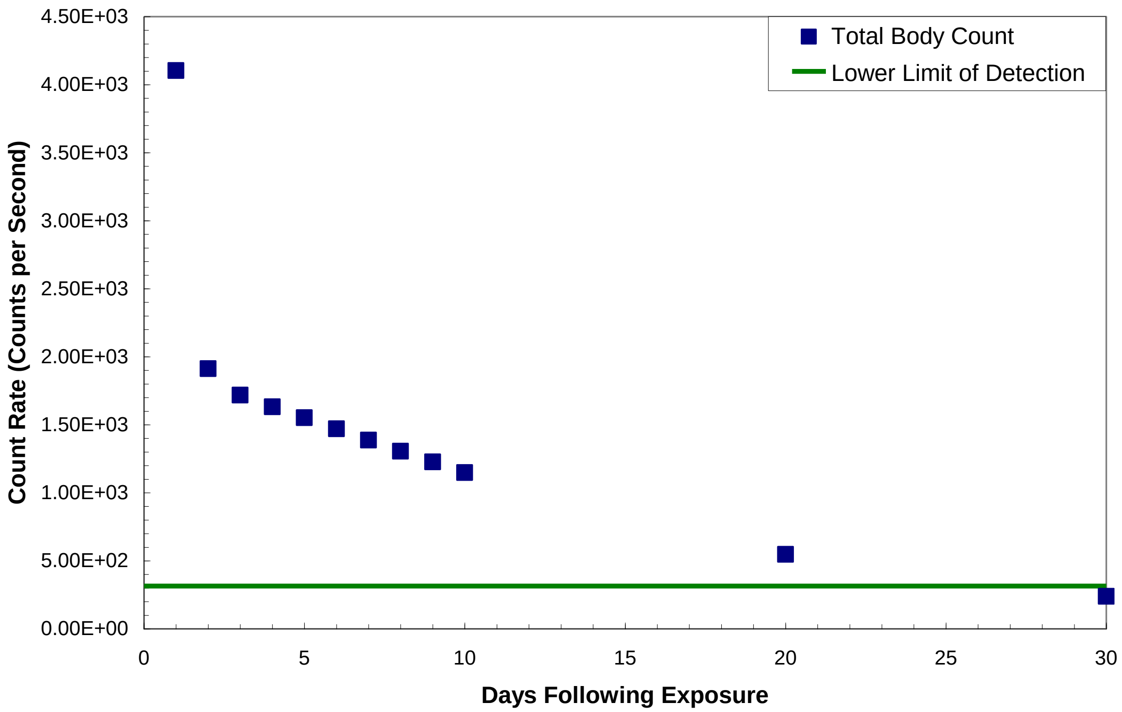

Figure C.15. CPS per 250 mSv for Adipose Female Inhaled I-131

Table C.16. CPS per 250 mSv for Adipose Female Inhaled Ir-192

Total Body Count		
Ir-192		**cps per 250 mSv**
Days following exposure	1	1.65E+04
	2	1.27E+04
	3	1.07E+04
	4	9.83E+03
	5	9.42E+03
	6	9.21E+03
	7	9.08E+03
	8	8.97E+03
	9	8.88E+03
	10	8.80E+03
	20	8.10E+03
	30	7.50E+03

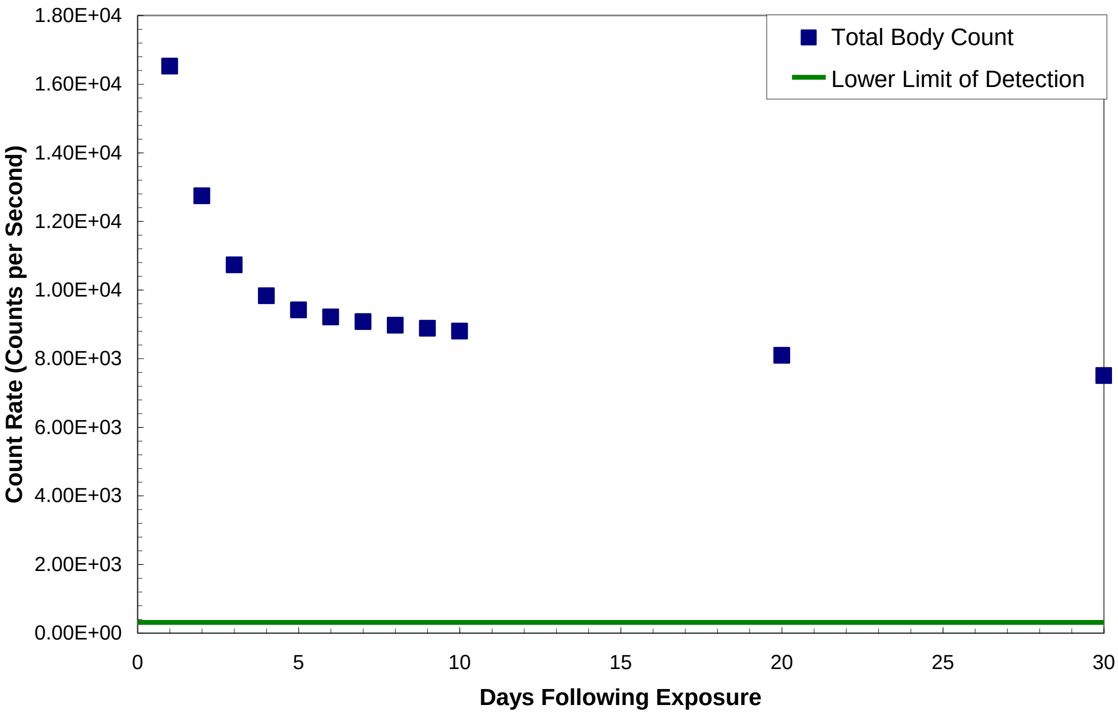

Figure C.16. CPS per 250 mSv for Adipose Female Inhaled Ir-192

Table C.17. CPS per 250 mSv for Post Menopausal Adipose Female Inhaled Co-60

Total Body Count		
Co-60		**cps per 250 mSv**
Days following exposure	1	1.30E+04
	2	9.67E+03
	3	7.92E+03
	4	7.08E+03
	5	6.62E+03
	6	6.34E+03
	7	6.13E+03
	8	5.95E+03
	9	5.80E+03
	10	5.67E+03
	20	4.84E+03
	30	4.47E+03

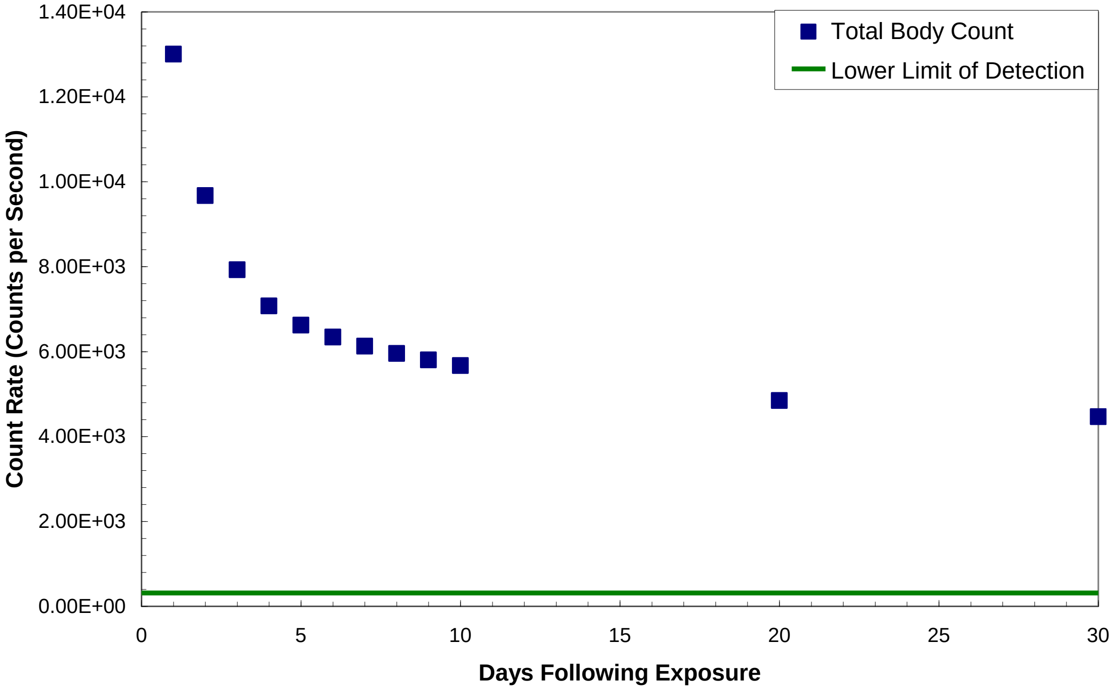

Figure C.17. CPS per 250 mSv for Post Menopausal Adipose Female Inhaled Co-60

Table C.18. CPS per 250 mSv for Post Menopausal Adipose Female Inhaled Cs-137

Total Body Count		
Cs-137		**cps per 250 mSv**
Days following exposure	1	1.48E+05
	2	1.46E+05
	3	1.42E+05
	4	1.40E+05
	5	1.37E+05
	6	1.36E+05
	7	1.34E+05
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	9	1.32E+05
	10	1.31E+05
	20	1.22E+05
	30	1.14E+05

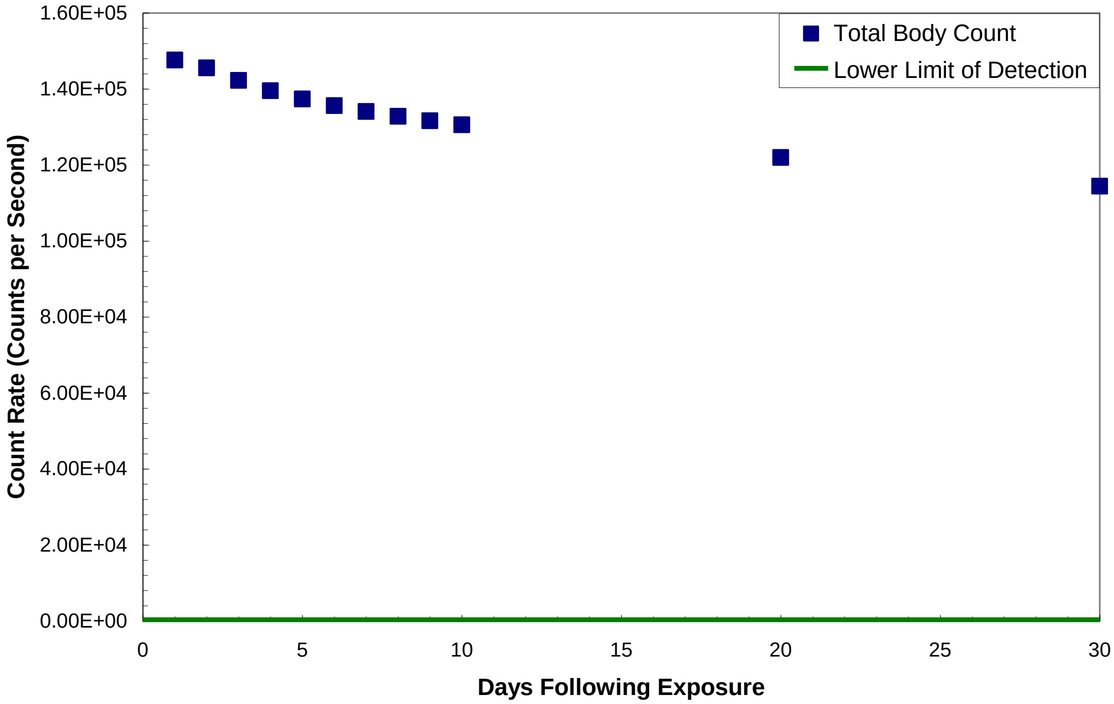

Figure C.18. CPS per 250 mSv for Post Menopausal Adipose Female Inhaled Cs-137

Table C.19. CPS per 250 mSv for Post Menopausal Adipose Female Inhaled I-131

Total Body Count		
I-131		**cps per 250 mSv**
Days following exposure	1	4.02E+03
	2	2.01E+03
	3	1.81E+03
	4	1.71E+03
	5	1.62E+03
	6	1.52E+03
	7	1.43E+03
	8	1.34E+03
	9	1.25E+03
	10	1.17E+03
	20	5.46E+02
	30	2.35E+02

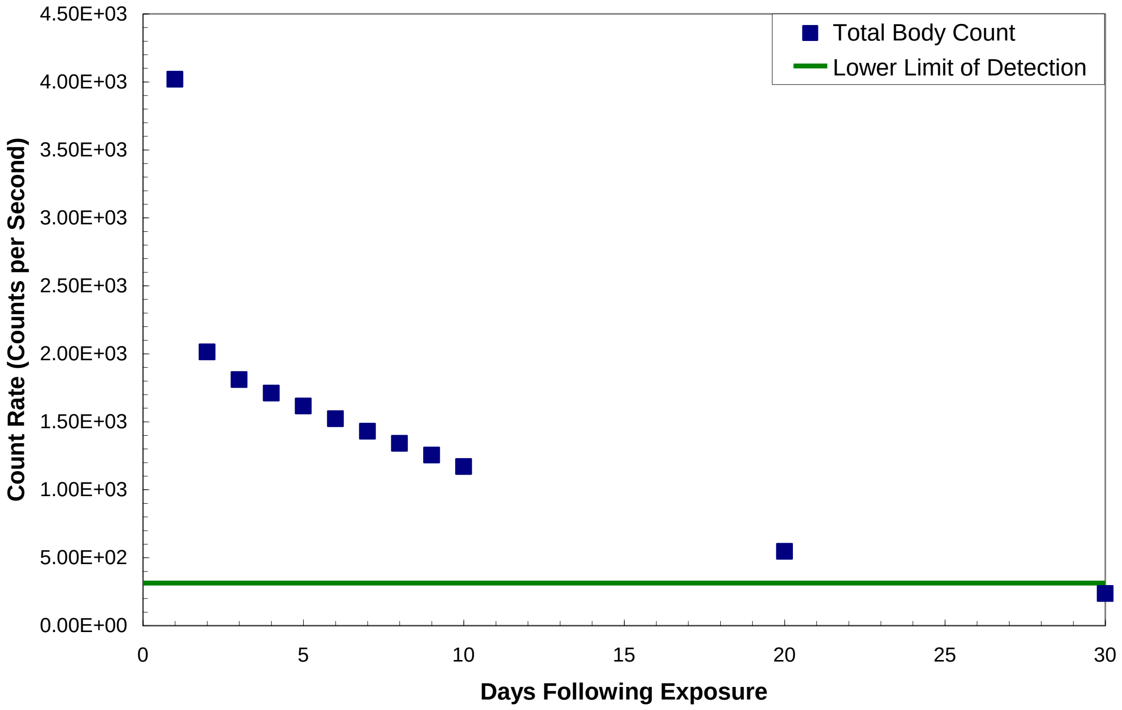

Figure C.19. CPS per 250 mSv for Post Menopausal Adipose Female Inhaled I-131

Table C.20. CPS per 250 mSv for Post Menopausal Adipose Female Inhaled Ir-192

Total Body Count		
Ir-192		**cps per 250 mSv**
Days following exposure	1	1.62E+04
	2	1.23E+04
	3	1.03E+04
	4	9.32E+03
	5	8.90E+03
	6	8.69E+03
	7	8.55E+03
	8	8.45E+03
	9	8.36E+03
	10	8.27E+03
	20	7.56E+03
	30	6.97E+03

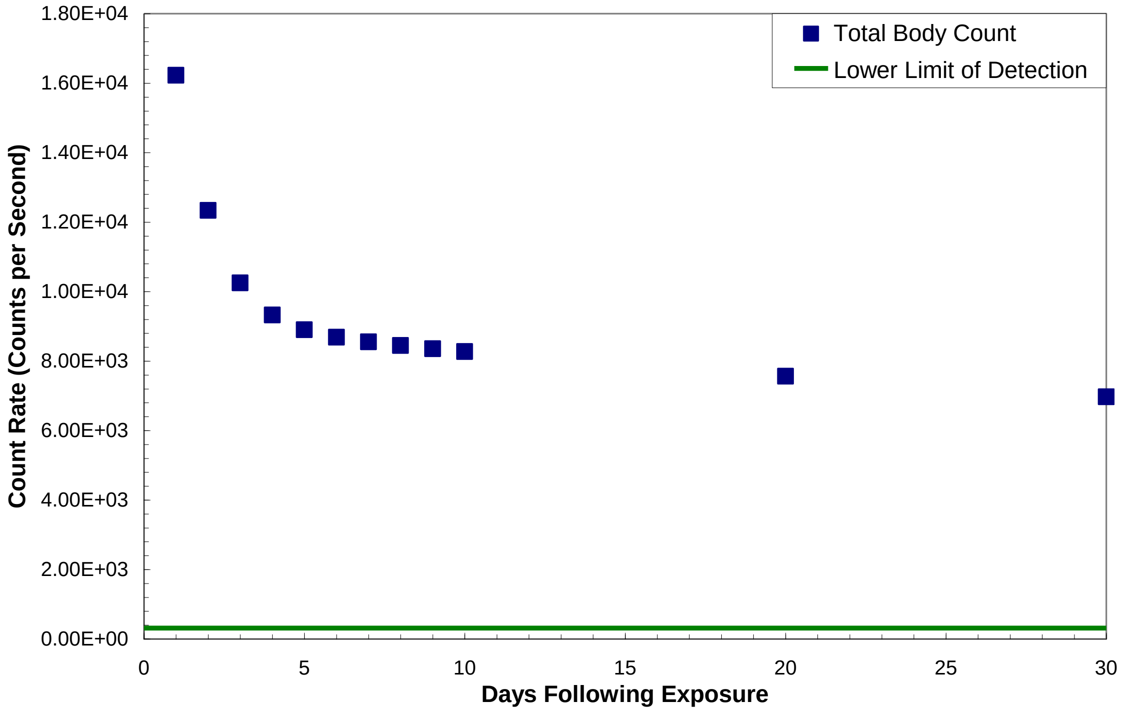

Figure C.20. CPS per 250 mSv for Post Menopausal Adipose Female Inhaled Ir-192

Table C.21. CPS per 250 mSv for 10-year-old Child Inhaled Co-60

Total Body Count		
Co-60		**cps per 250 mSv**
Days following exposure	1	9.59E+03
	2	7.04E+03
	3	5.71E+03
	4	5.08E+03
	5	4.74E+03
	6	4.54E+03
	7	4.39E+03
	8	4.26E+03
	9	4.16E+03
	10	4.06E+03
	20	3.47E+03
	30	3.20E+03

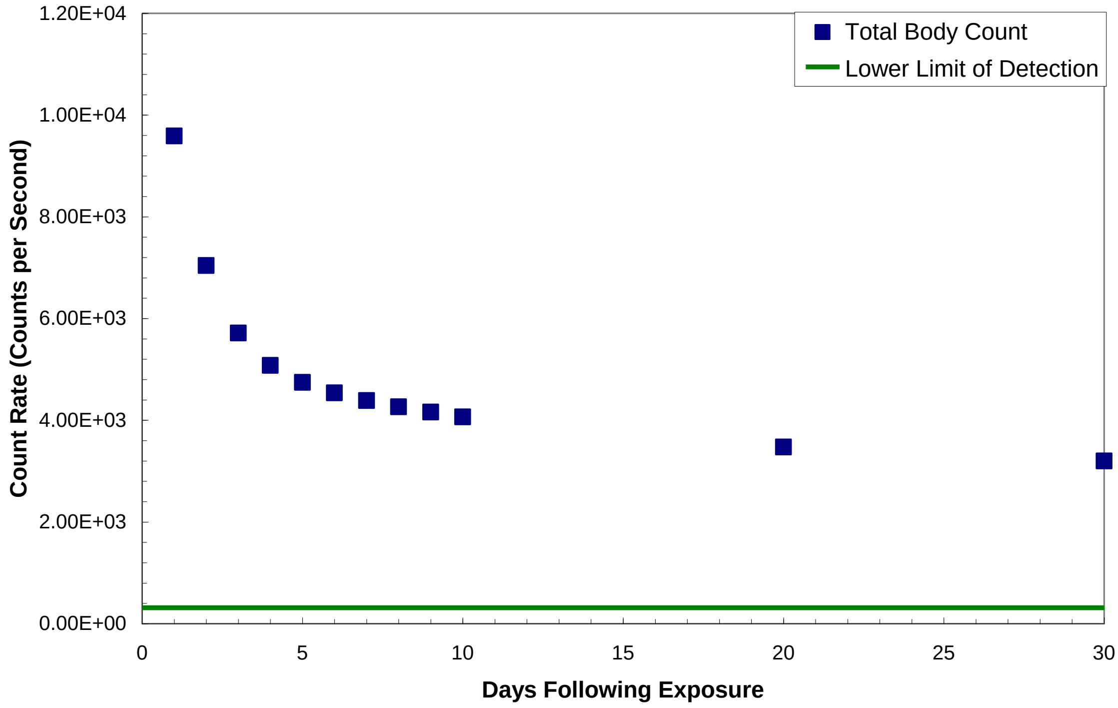

Figure C.21. CPS per 250 mSv for 10-year-old Child Inhaled Co-60

Table C.22. CPS per 250 mSv for 10-year-old Child Inhaled Cs-137

Total Body Count		
Cs-137		**cps per 250 mSv**
Days following exposure	1	1.90E+05
	2	1.87E+05
	3	1.83E+05
	4	1.79E+05
	5	1.77E+05
	6	1.74E+05
	7	1.72E+05
	8	1.71E+05
	9	1.69E+05
	10	1.68E+05
	20	1.57E+05
	30	1.47E+05

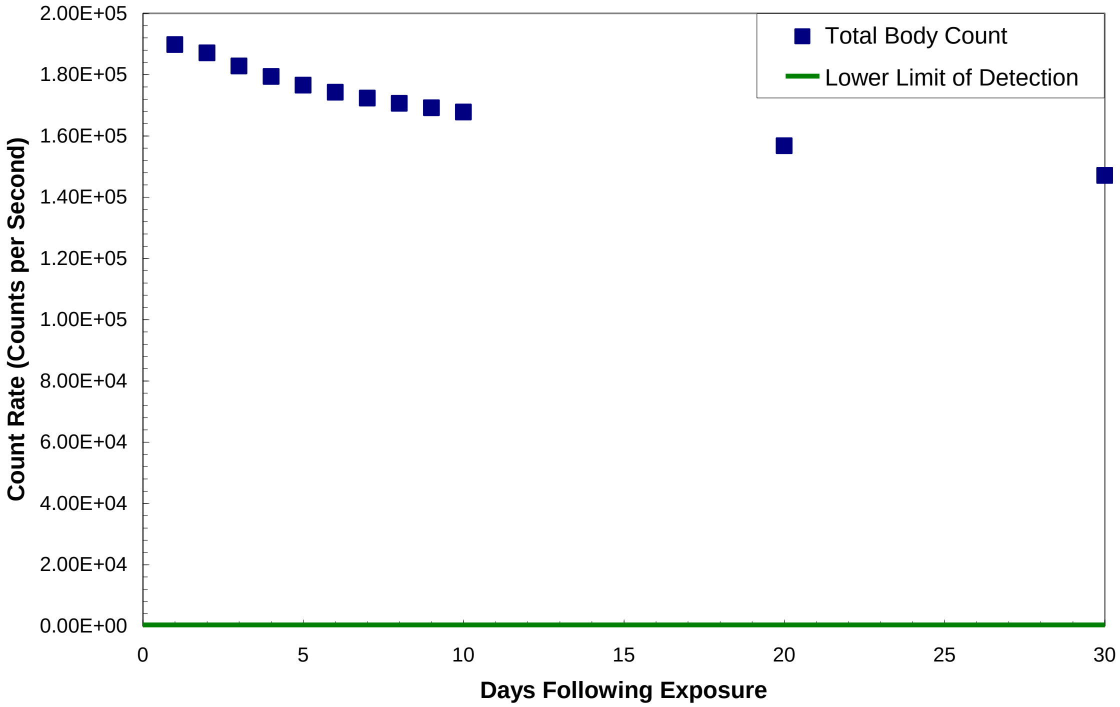

Figure C.22. CPS per 250 mSv for 10-year-old Child Inhaled Cs-137

Table C.23. CPS per 250 mSv for 10-year-old Child Inhaled I-131

Total Body Count		
I-131		**cps per 250 mSv**
Days following exposure	1	1.86E+03
	2	9.59E+02
	3	8.63E+02
	4	8.12E+02
	5	7.65E+02
	6	7.19E+02
	7	6.74E+02
	8	6.31E+02
	9	5.89E+02
	10	5.49E+02
	20	2.53E+02
	30	1.09E+02

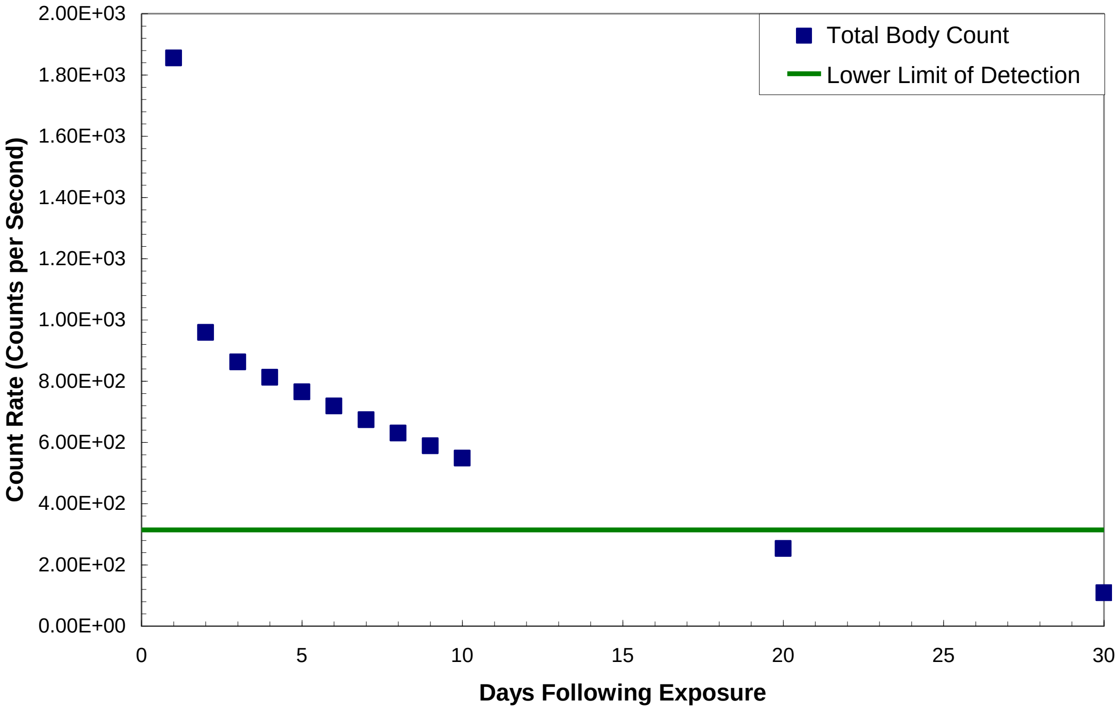

Figure C.23. CPS per 250 mSv for 10-year-old Child Inhaled I-131

Table C.24. CPS per 250 mSv for 10-year-old Child Inhaled Ir-192

Total Body Count		
Ir-192		**cps per 250 mSv**
Days following exposure	1	1.42E+04
	2	1.05E+04
	3	8.56E+03
	4	7.71E+03
	5	7.32E+03
	6	7.13E+03
	7	7.01E+03
	8	6.92E+03
	9	6.84E+03
	10	6.76E+03
	20	6.15E+03
	30	5.64E+03

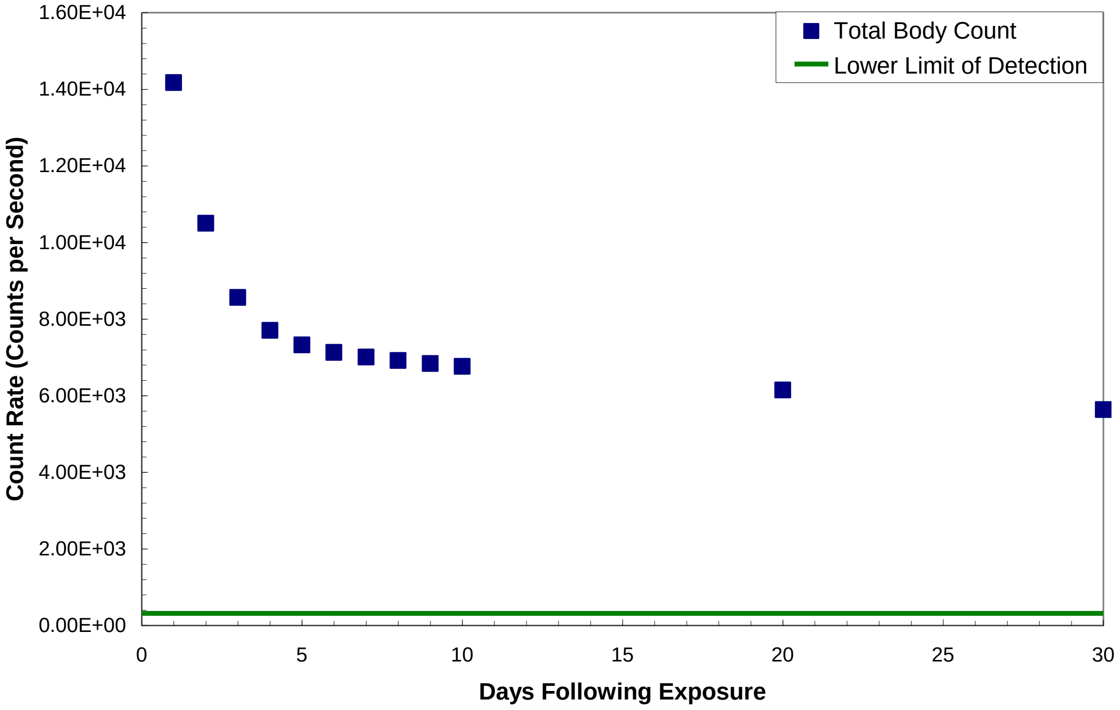

Figure C.24. CPS per 250 mSv for 10-year-old Child Inhaled Ir-192

Table C.25. CPS per 250 mSv for Reference Male Ingested Co-60

Total Body Count		
Co-60		**cps per 250 mSv**
Days following exposure	1	7.73E+04
	2	4.84E+04
	3	3.38E+04
	4	2.71E+04
	5	2.37E+04
	6	2.17E+04
	7	2.03E+04
	8	1.91E+04
	9	1.82E+04
	10	1.73E+04
	20	1.24E+04
	30	1.05E+04

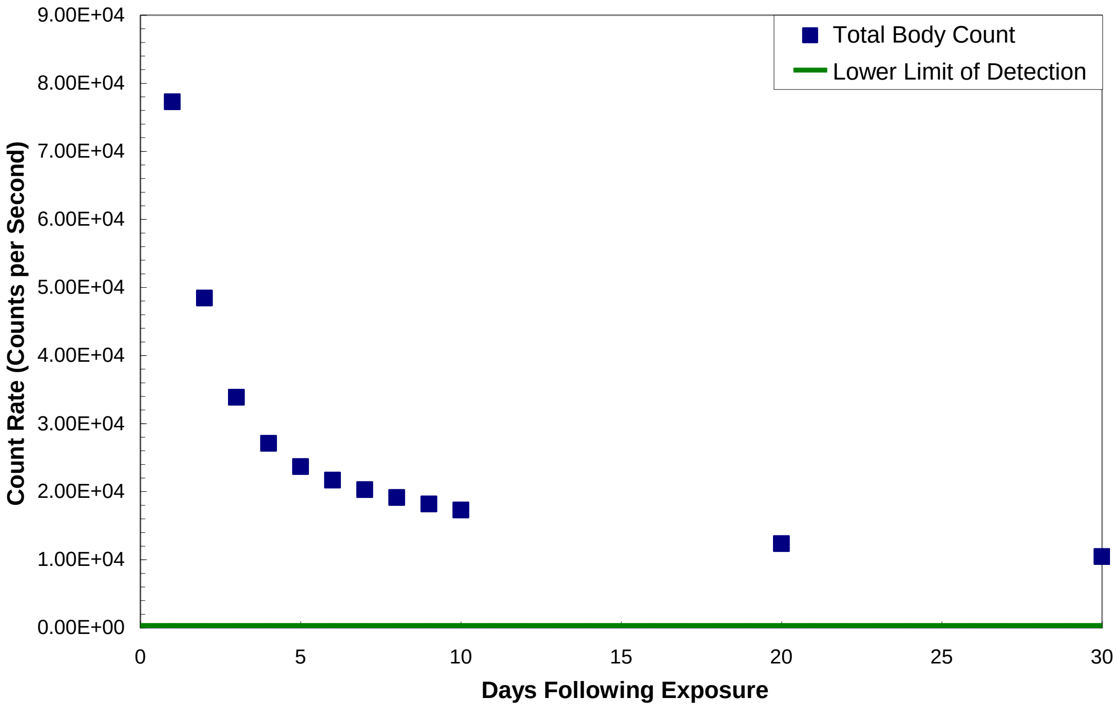

Figure C.25. CPS per 250 mSv for Reference Male Ingested Co-60

Table C.26. CPS per 250 mSv for Reference Male Ingested Cs-137

Total Body Count		
Cs-137		cps per 250 mSv
Days following exposure	1	7.11E+04
	2	7.02E+04
	3	6.86E+04
	4	6.73E+04
	5	6.62E+04
	6	6.53E+04
	7	6.46E+04
	8	6.40E+04
	9	6.34E+04
	10	6.29E+04
	20	5.88E+04
	30	5.52E+04

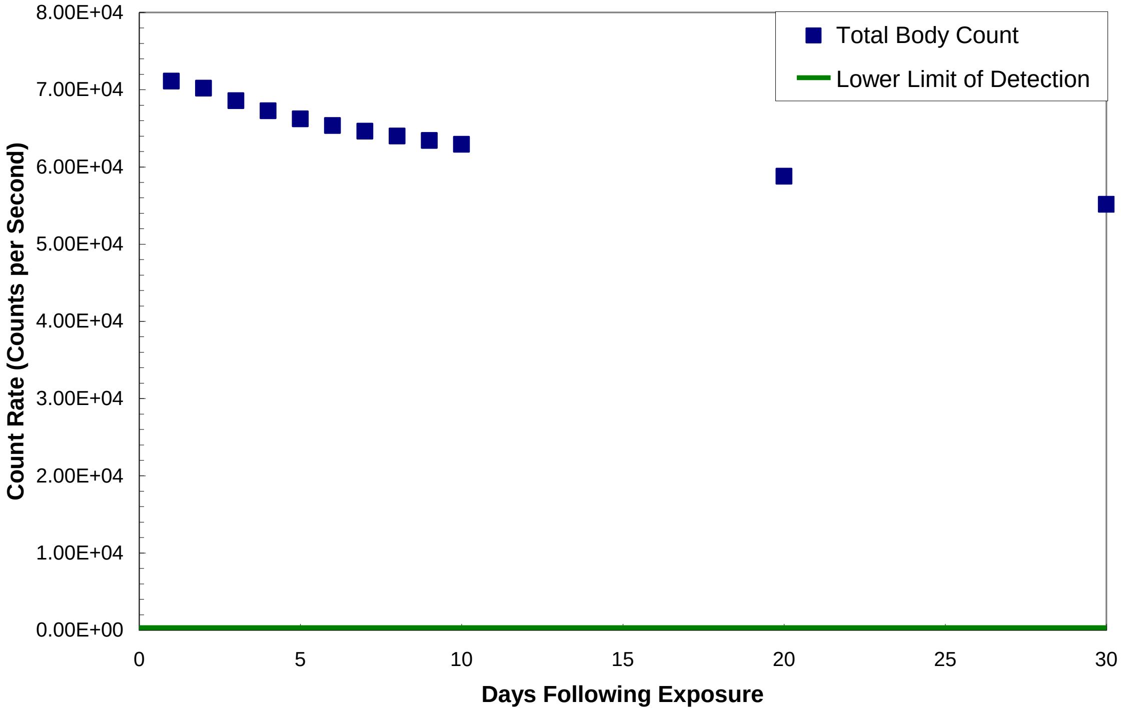

Figure C.26. CPS per 250 mSv for Reference Male Ingested Cs-137

Table C.27. CPS per 250 mSv for Reference Male Ingested I-131

Total Body Count		
I-131		**cps per 250 mSv**
Days following exposure	1	3.08E+03
	2	1.20E+03
	3	1.06E+03
	4	1.02E+03
	5	9.84E+02
	6	9.42E+02
	7	8.98E+02
	8	8.53E+02
	9	8.07E+02
	10	7.61E+02
	20	3.77E+02
	30	1.67E+02

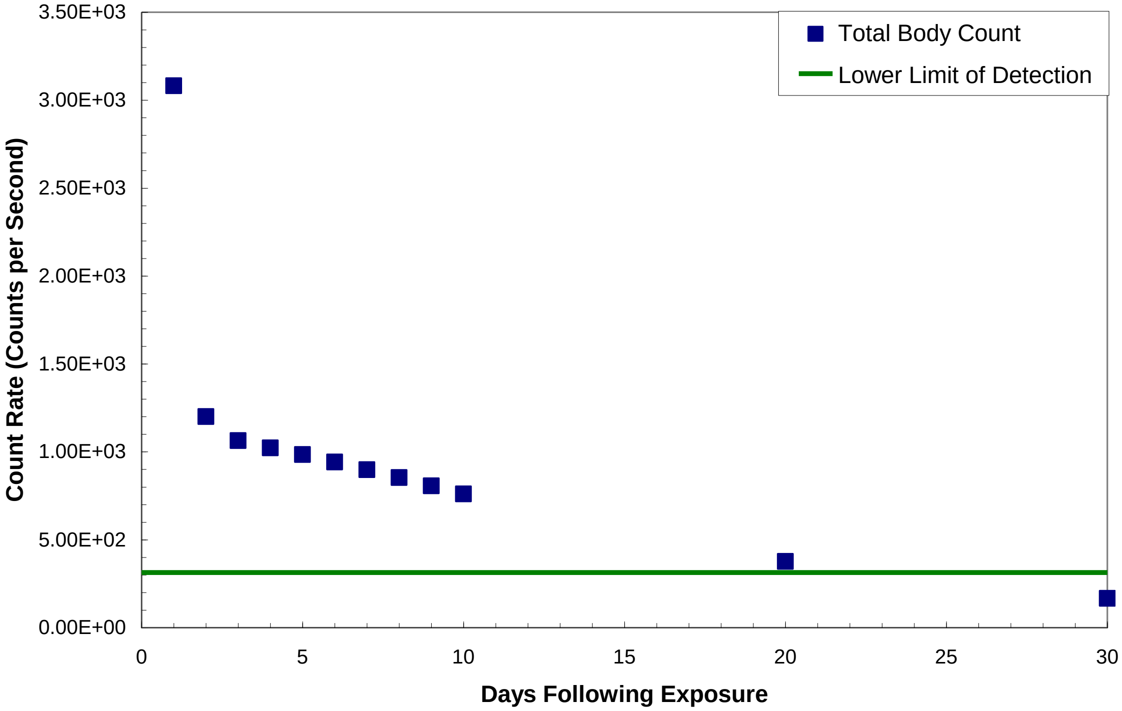

Figure C.27. CPS per 250 mSv for Reference Male Ingested I-131

Table C.28. CPS per 250 mSv for Reference Male Ingested Ir-192

Total Body Count		
Ir-192		**cps per 250 mSv**
Days following exposure	1	9.00E+04
	2	4.43E+04
	3	2.15E+04
	4	1.21E+04
	5	8.38E+03
	6	6.92E+03
	7	6.29E+03
	8	5.97E+03
	9	5.78E+03
	10	5.63E+03
	20	4.65E+03
	30	3.98E+03

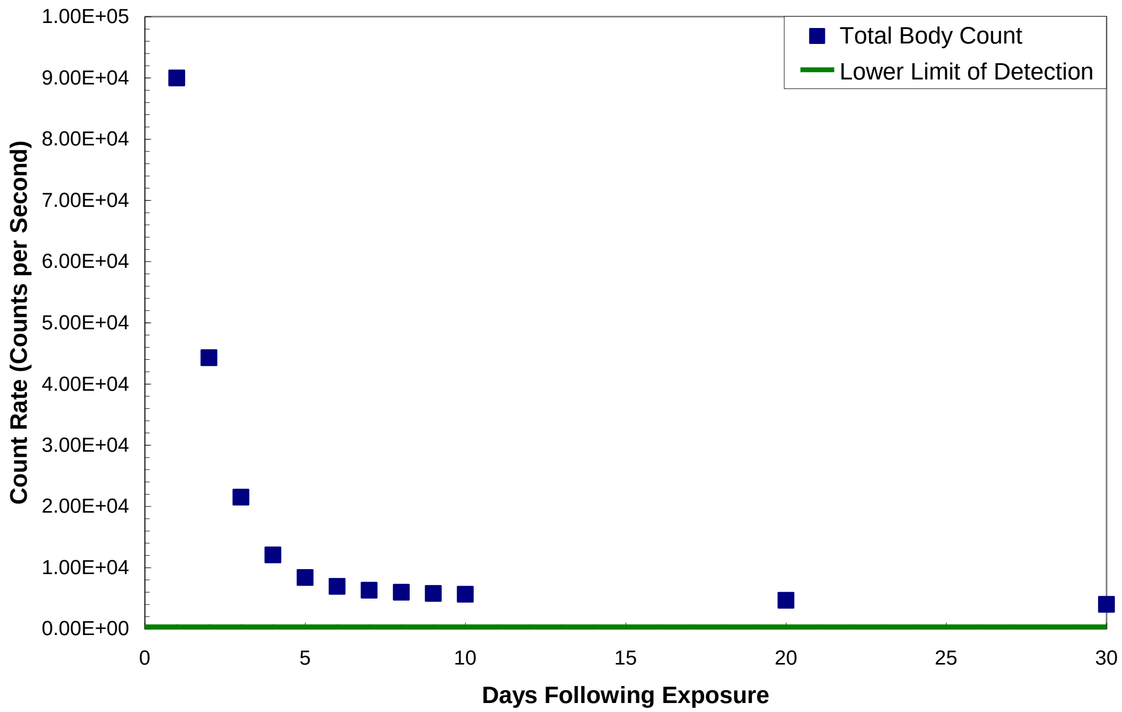

Figure C.28. CPS per 250 mSv for Reference Male Ingested Ir-192

Table C.29. CPS per 250 mSv for Reference Female Ingested Co-60

Total Body Count		
Co-60		cps per 250 mSv
Days following exposure	1	7.72E+04
	2	4.92E+04
	3	3.49E+04
	4	2.83E+04
	5	2.49E+04
	6	2.28E+04
	7	2.14E+04
	8	2.02E+04
	9	1.92E+04
	10	1.83E+04
	20	1.31E+04
	30	1.11E+04

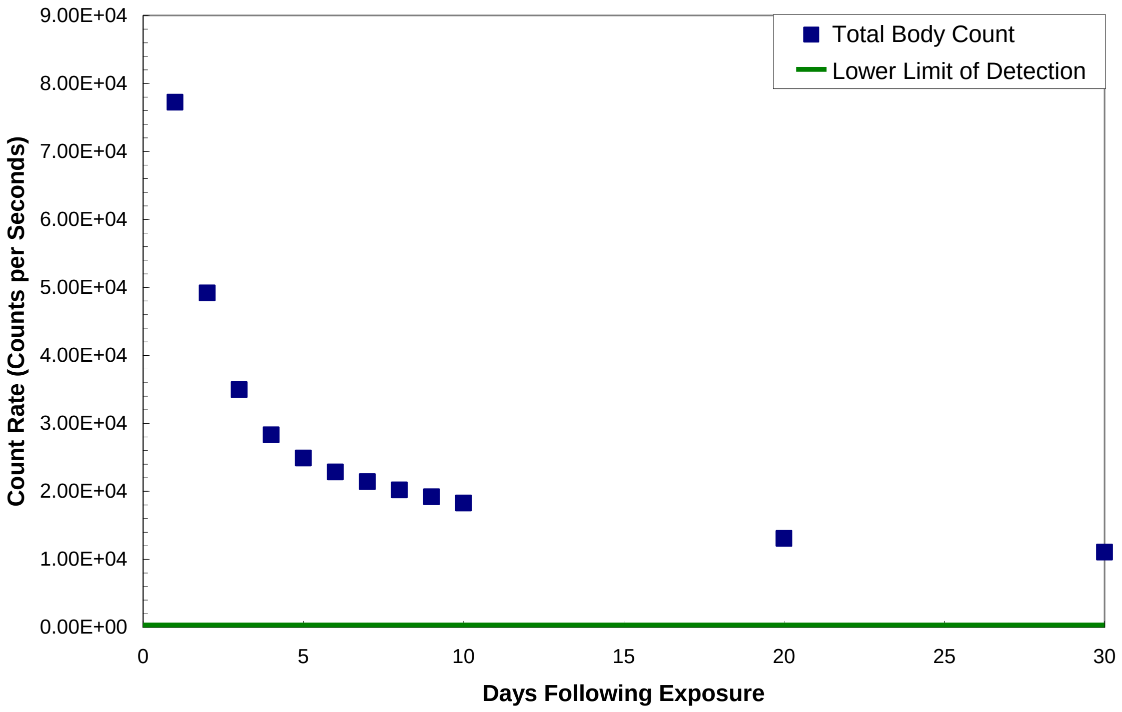

Figure C.29. CPS per 250 mSv for Reference Female Ingested Co-60

Table C.30. CPS per 250 mSv for Reference Female Ingested Cs-137

Total Body Count		
Cs-137		**cps per 250 mSv**
Days following exposure	1	7.54E+04
	2	7.45E+04
	3	7.28E+04
	4	7.14E+04
	5	7.03E+04
	6	6.93E+04
	7	6.86E+04
	8	6.79E+04
	9	6.73E+04
	10	6.68E+04
	20	6.24E+04
	30	5.85E+04

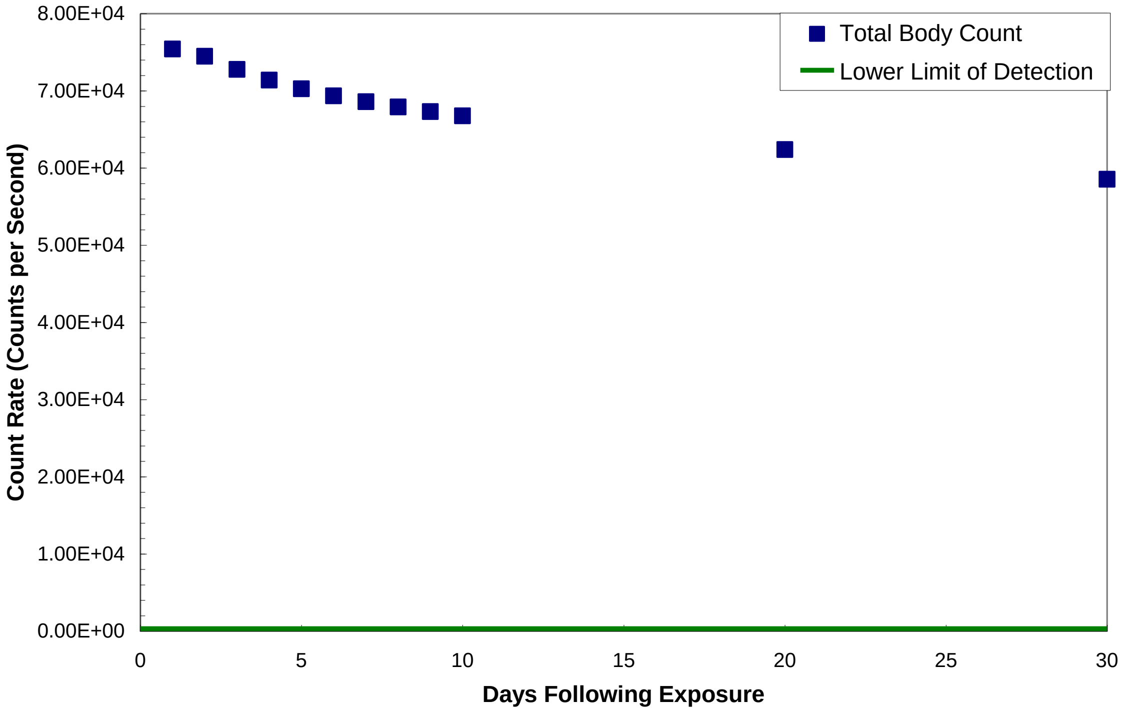

Figure C.30. CPS per 250 mSv for Reference Female Ingested Cs-137

Table C.31. CPS per 250 mSv for Reference Female Ingested I-131

Total Body Count		
I-131		**cps per 250 mSv**
Days following exposure	1	3.22E+03
	2	1.22E+03
	3	1.08E+03
	4	1.04E+03
	5	1.00E+03
	6	9.63E+02
	7	9.20E+02
	8	8.75E+02
	9	8.75E+02
	10	7.83E+02
	20	3.91E+02
	30	1.74E+02

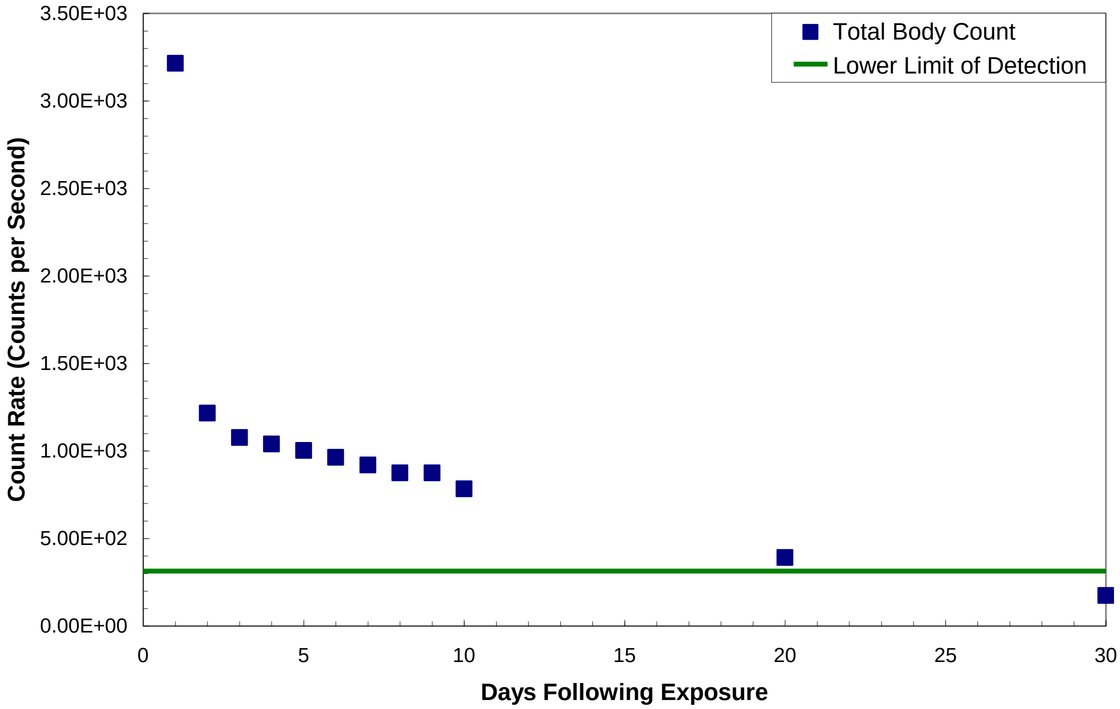

Figure C.31. CPS per 250 mSv for Reference Female Ingested I-131

Table C.32. CPS per 250 mSv for Reference Female Ingested Ir-192

Total Body Count		
Ir-192		**cps per 250 mSv**
Days following exposure	1	8.96E+04
	2	4.44E+04
	3	2.18E+04
	4	1.25E+04
	5	8.82E+03
	6	7.35E+03
	7	6.72E+03
	8	6.40E+03
	9	6.20E+03
	10	6.04E+03
	20	4.99E+03
	30	4.27E+03

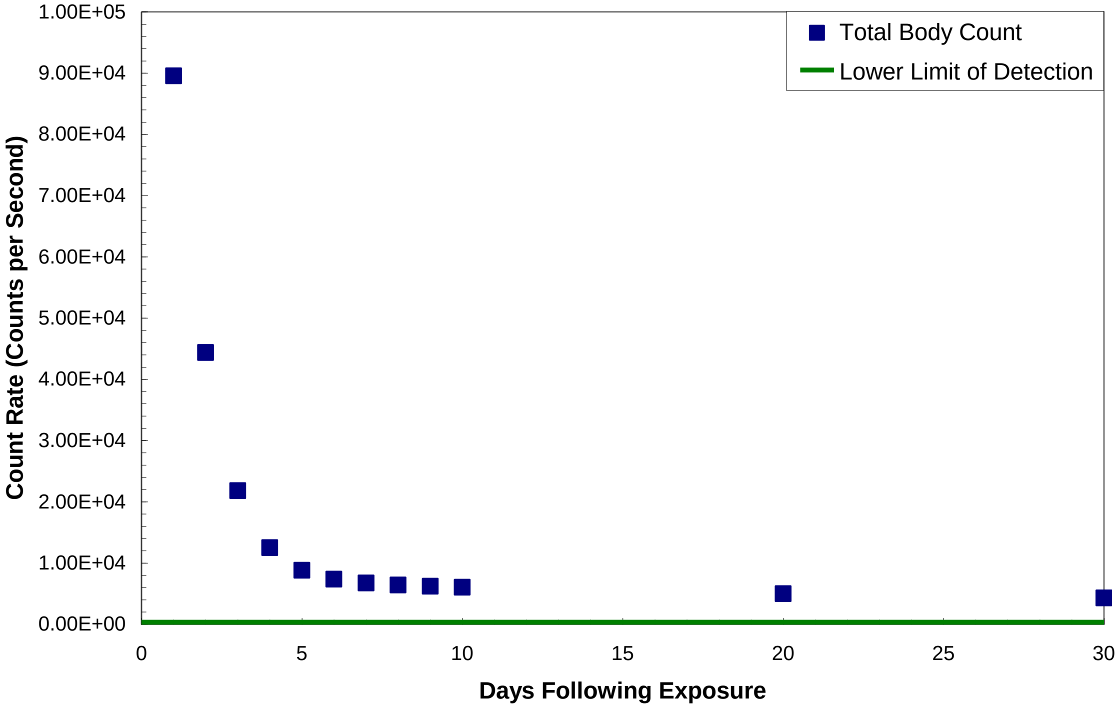

Figure C.32. CPS per 250 mSv for Reference Female Ingested Ir-192

Table C.33. CPS per 250 mSv for Adipose Male Ingested Co-60

Total Body Count		
Co-60		**cps per 250 mSv**
Days following exposure	1	6.46E+04
	2	4.13E+04
	3	2.96E+04
	4	2.41E+04
	5	2.13E+04
	6	1.96E+04
	7	1.84E+04
	8	1.73E+04
	9	1.65E+04
	10	1.57E+04
	20	1.12E+04
	30	9.49E+03

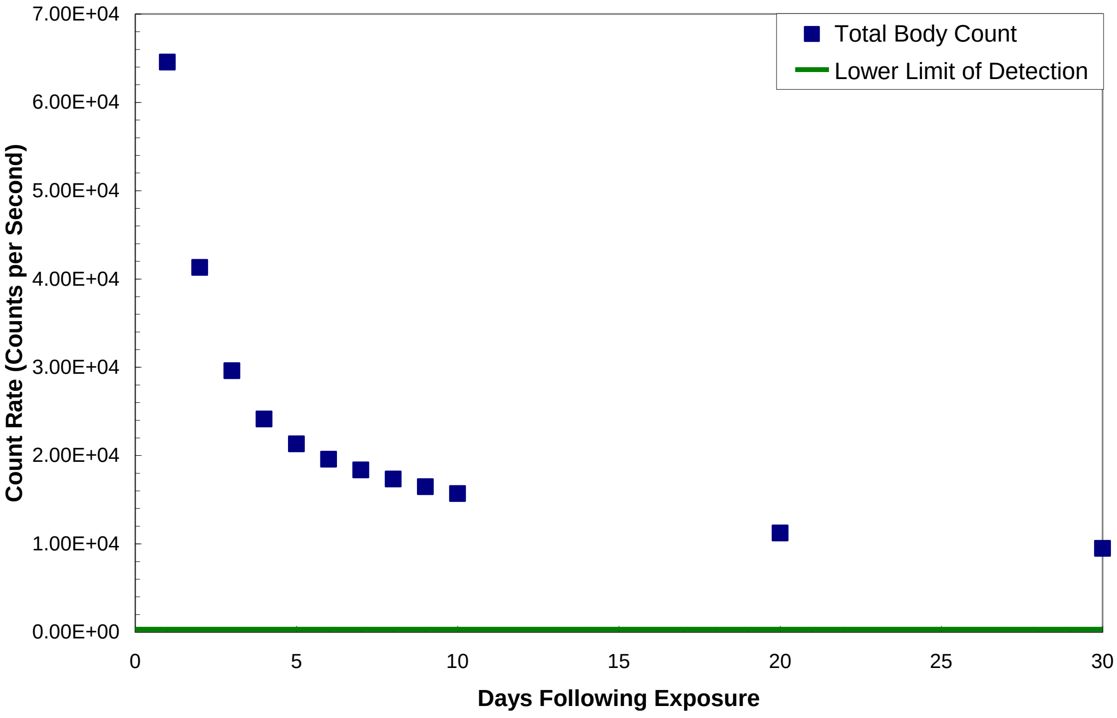

Figure C.33. CPS per 250 mSv for Adipose Male Ingested Co-60

Table C.34. CPS per 250 mSv for Adipose Male Ingested Cs-137

Total Body Count		
Cs-137		**cps per 250 mSv**
Days following exposure	1	6.17E+04
	2	6.09E+04
	3	5.95E+04
	4	5.84E+04
	5	5.75E+04
	6	5.67E+04
	7	5.61E+04
	8	5.55E+04
	9	5.50E+04
	10	5.46E+04
	20	5.10E+04
	30	4.79E+04

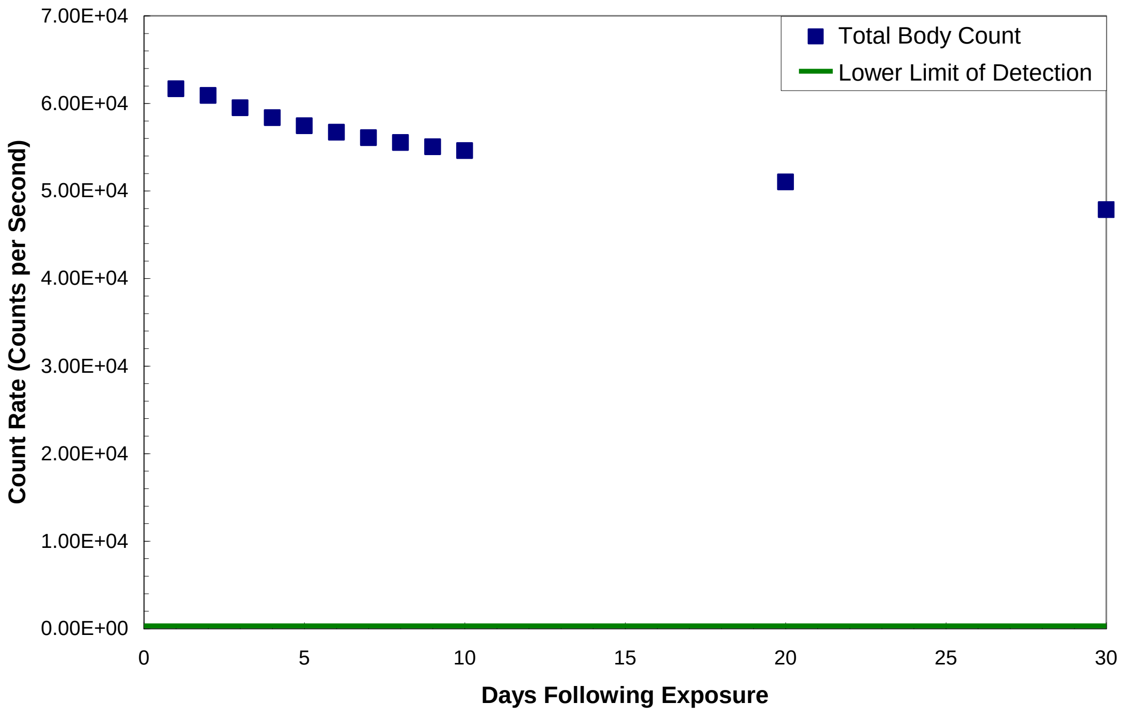

Figure C.34. CPS per 250 mSv for Adipose Male Ingested Cs-137

Table C.35. CPS per 250 mSv for Adipose Male Ingested I-131

Total Body Count		
I-131		cps per 250 mSv
Days following exposure	1	2.32E+03
	2	7.59E+02
	3	6.67E+02
	4	6.54E+02
	5	6.40E+02
	6	6.22E+02
	7	6.00E+02
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	9	5.50E+02
	10	5.22E+02
	20	2.71E+02
	30	1.22E+02

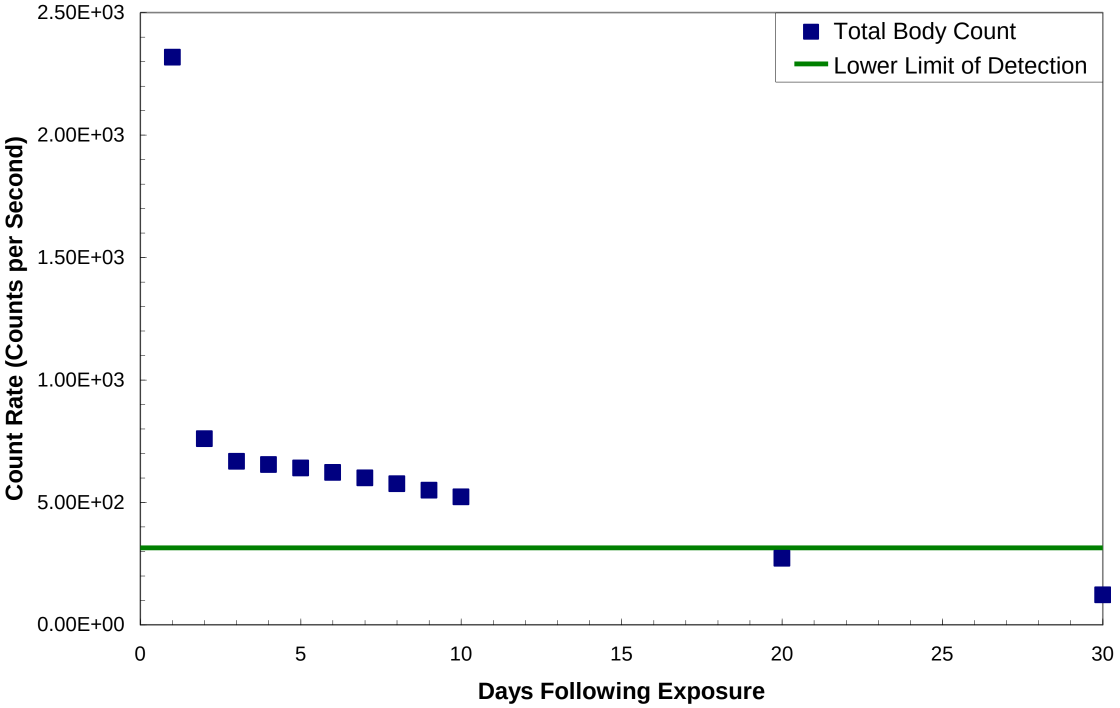

Figure C.35. CPS per 250 mSv for Adipose Male Ingested I-131

Table C.36. CPS per 250 mSv for Adipose Male Ingested Ir-192

Total Body Count		
Ir-192		cps per 250 mSv
Days following exposure	1	5.70E+04
	2	2.94E+04
	3	1.50E+04
	4	9.02E+03
	5	6.63E+03
	6	5.67E+03
	7	5.24E+03
	8	5.01E+03
	9	4.86E+03
	10	4.74E+03
	20	3.92E+03
	30	3.35E+03

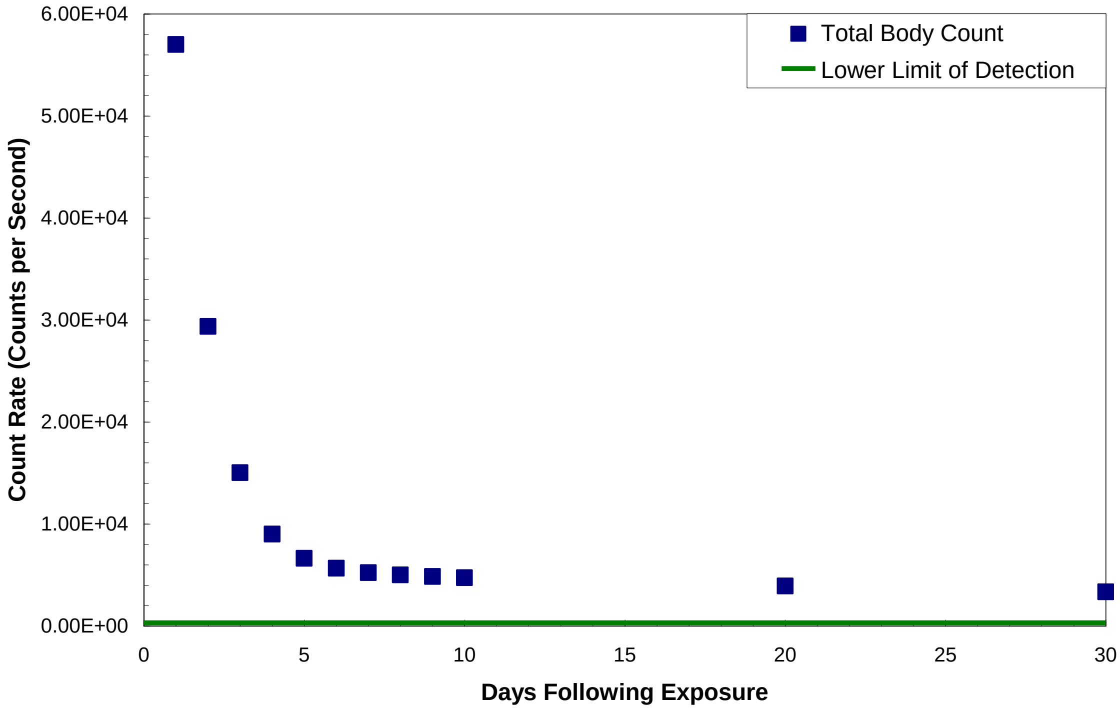

Figure C.36. CPS per 250 mSv for Adipose Male Ingested Ir-192

Table C.37. CPS per 250 mSv for Adipose Female Ingested Co-60

Total Body Count		
Co-60		**cps per 250 mSv**
Days following exposure	1	6.97E+04
	2	4.72E+04
	3	3.56E+04
	4	3.00E+04
	5	2.69E+04
	6	2.49E+04
	7	2.34E+04
	8	2.21E+04
	9	2.10E+04
	10	2.00E+04
	20	1.43E+04
	30	1.21E+04

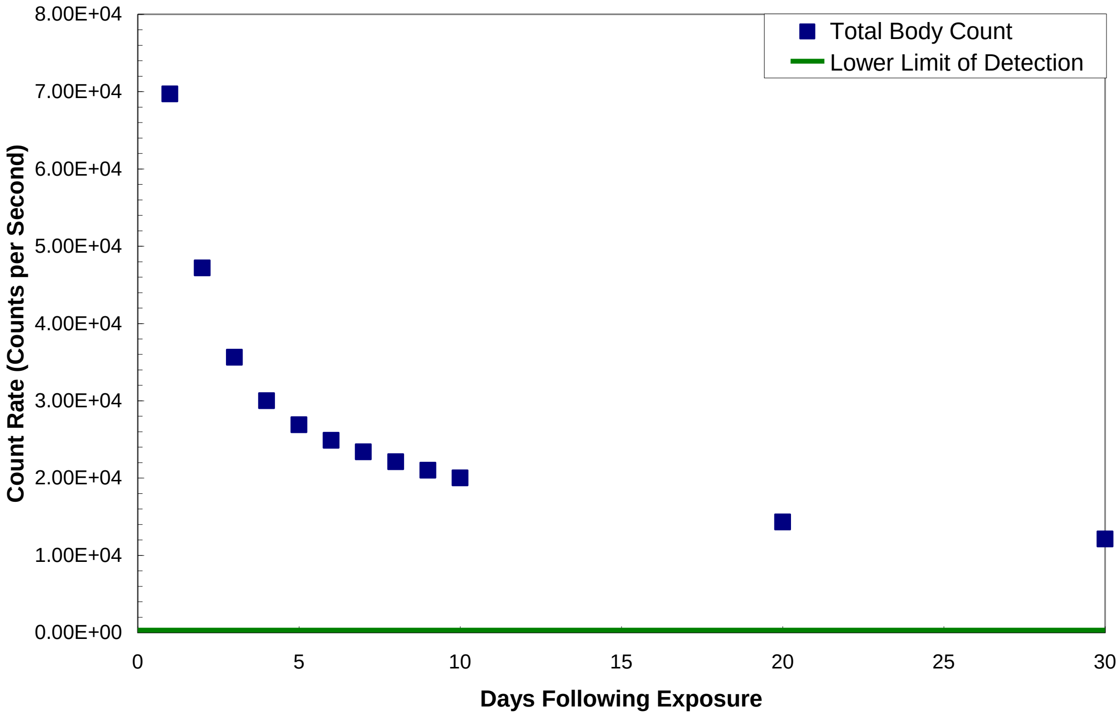

Figure C.37. CPS per 250 mSv for Adipose Female Ingested Co-60

Table C.38. CPS per 250 mSv for Adipose Female Ingested Cs-137

Total Body Count		
Cs-137		**cps per 250 mSv**
Days following exposure	1	8.08E+04
	2	7.98E+04
	3	7.80E+04
	4	7.65E+04
	5	7.53E+04
	6	7.43E+04
	7	7.35E+04
	8	7.28E+04
	9	7.22E+04
	10	7.16E+04
	20	6.69E+04
	30	6.27E+04

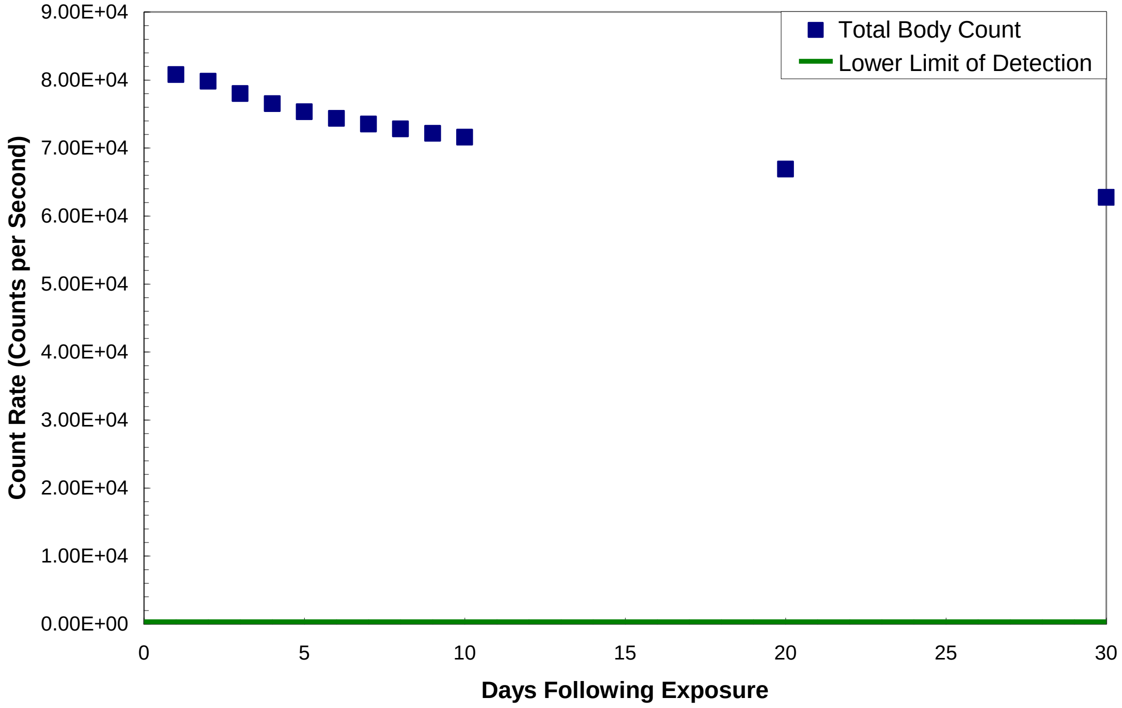

Figure C.38. CPS per 250 mSv for Adipose Female Ingested Cs-137

Table C.39. CPS per 250 mSv for Adipose Female Ingested I-131

Total Body Count		
I-131		**cps per 250 mSv**
Days following exposure	1	3.14E+03
	2	1.07E+03
	3	9.44E+02
	4	9.23E+02
	5	9.01E+02
	6	8.73E+02
	7	8.41E+02
	8	8.06E+02
	9	7.68E+02
	10	7.29E+02
	20	3.76E+02
	30	1.69E+02

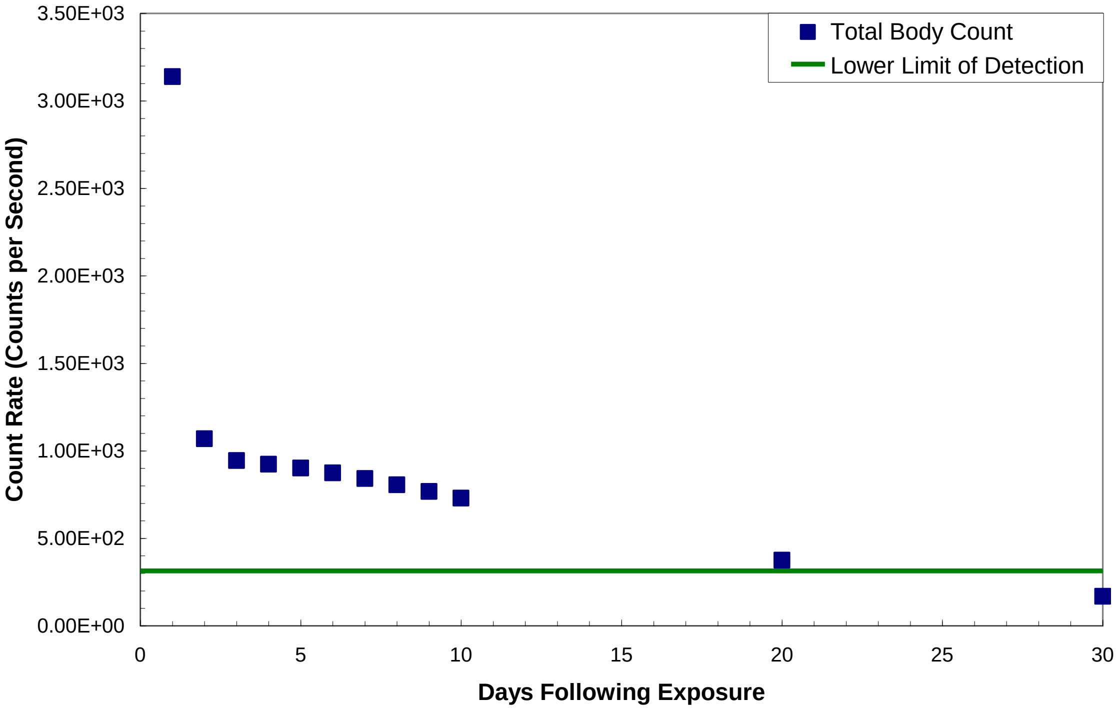

Figure C.39. CPS per 250 mSv for Adipose Female Ingested I-131

Table C.40. CPS per 250 mSv for Adipose Female Ingested Ir-192

Total Body Count		
Ir-192		cps per 250 mSv
Days following exposure	1	6.29E+04
	2	3.30E+04
	3	1.76E+04
	4	1.12E+04
	5	8.62E+03
	6	7.55E+03
	7	7.05E+03
	8	6.78E+03
	9	6.58E+03
	10	6.43E+03
	20	5.32E+03
	30	4.55E+03

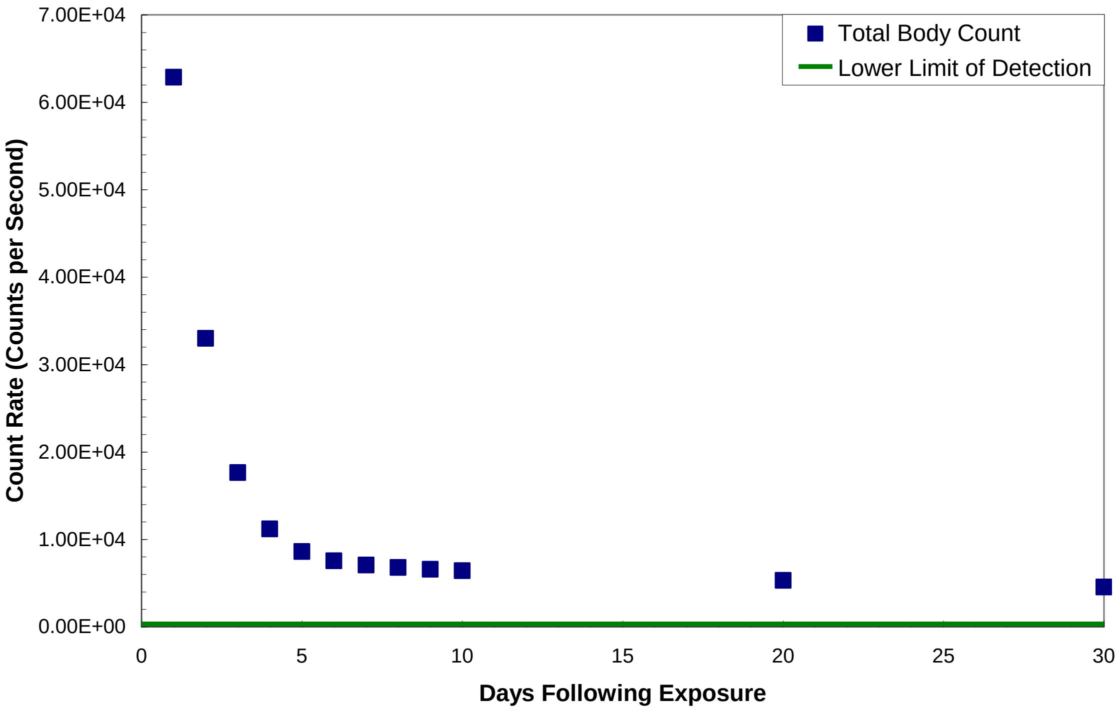

Figure C.40. CPS per 250 mSv for Adipose Female Ingested Ir-192

Table C.41. CPS per 250 mSv for Post Menopausal Adipose Female Ingested Co-60

Total Body Count		
Co-60		**cps per 250 mSv**
Days following exposure	1	6.88E+04
	2	4.53E+04
	3	3.33E+04
	4	2.76E+04
	5	2.45E+04
	6	2.26E+04
	7	2.12E+04
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	20	1.30E+04
	30	1.10E+04

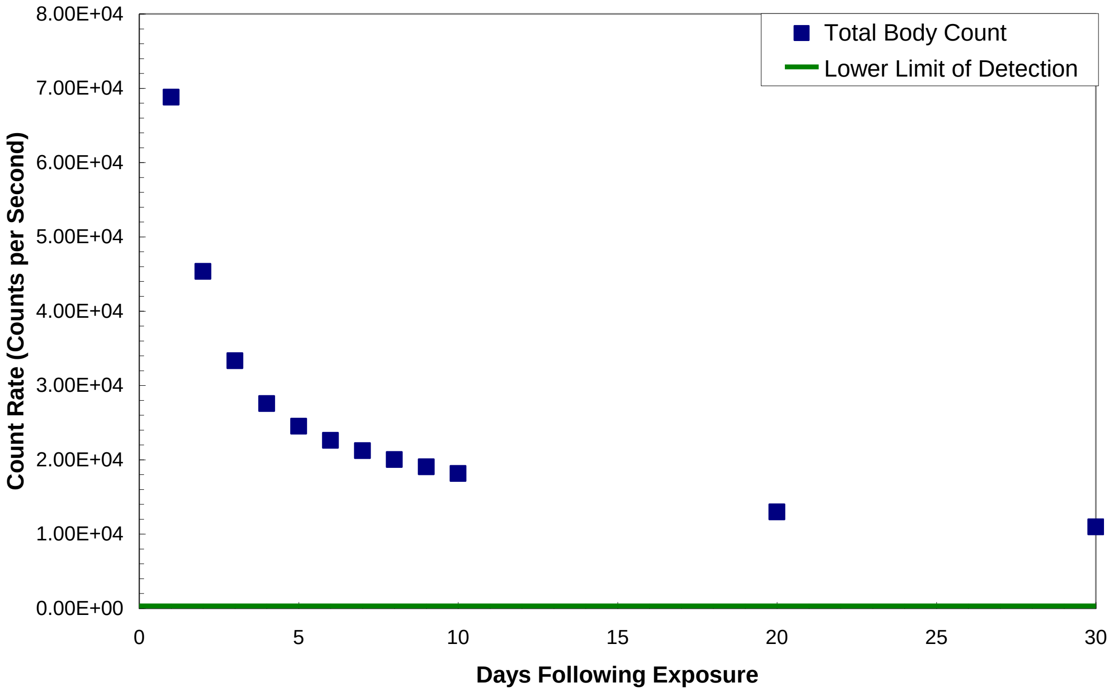

Figure C.41. CPS per 250 mSv for Post Menopausal Adipose Female Ingested Co-60

Table C.42. CPS per 250 mSv for Post Menopausal Adipose Female Ingested Cs-137

Total Body Count		
Cs-137		**cps per 250 mSv**
Days following exposure	1	7.56E+04
	2	7.47E+04
	3	7.30E+04
	4	7.16E+04
	5	7.05E+04
	6	6.96E+04
	7	6.88E+04
	8	6.81E+04
	9	6.75E+04
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	20	6.26E+04
	30	5.87E+04

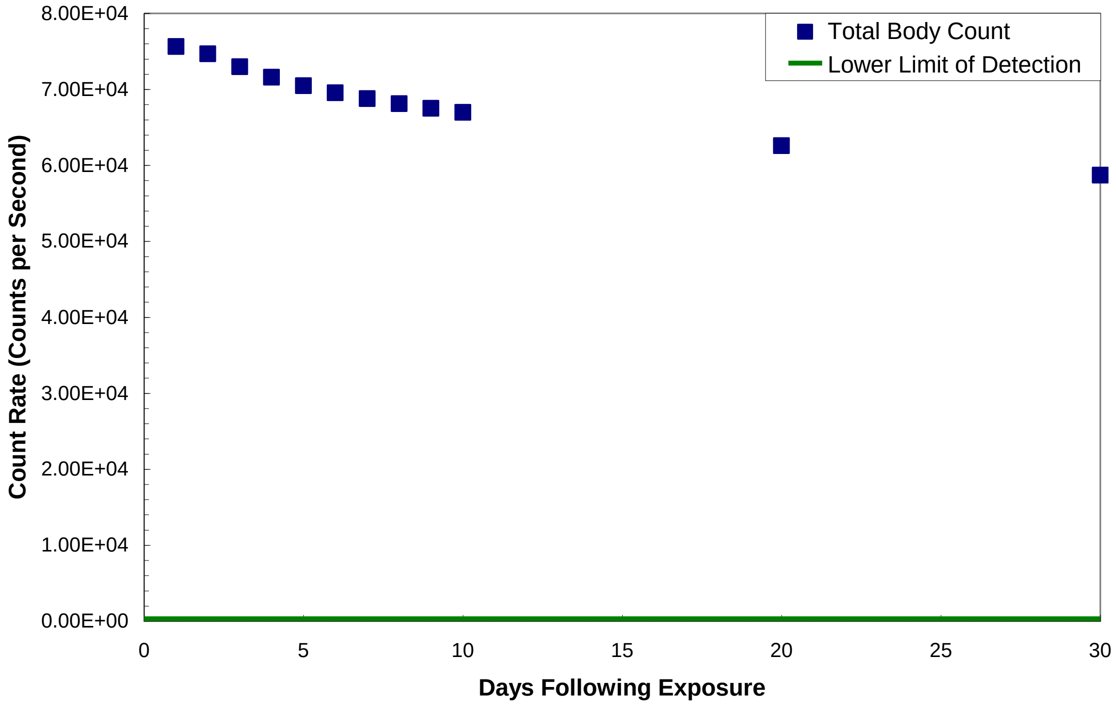

Figure C.42. CPS per 250 mSv for Post Menopausal Adipose Female Ingested Cs-137

Table C.43. CPS per 250 mSv for Post Menopausal Adipose Female Ingested I-131

Total Body Count		
I-131		**cps per 250 mSv**
Days following exposure	1	2.97E+03
	2	1.12E+03
	3	9.92E+02
	4	9.59E+02
	5	9.27E+02
	6	8.91E+02
	7	8.52E+02
	8	8.11E+02
	9	7.69E+02
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	20	3.64E+02
	30	1.62E+02

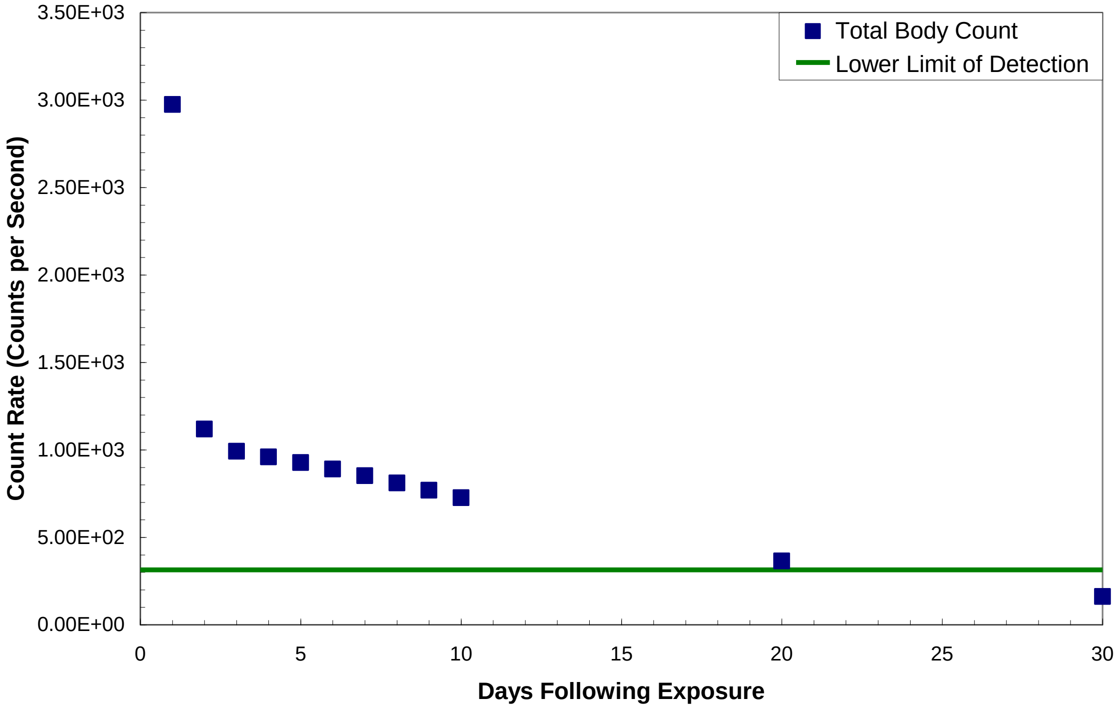

Figure C.43. CPS per 250 mSv for Post Menopausal Adipose Female Ingested I-131

Table C.44. CPS per 250 mSv for Post Menopausal Adipose Female Ingested Ir-192

Total Body Count		
Ir-192		cps per 250 mSv
Days following exposure	1	6.30E+04
	2	3.27E+04
	3	1.70E+04
	4	1.04E+04
	5	7.79E+03
	6	6.72E+03
	7	6.23E+03
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	10	5.66E+03
	20	4.68E+03
	30	4.00E+03

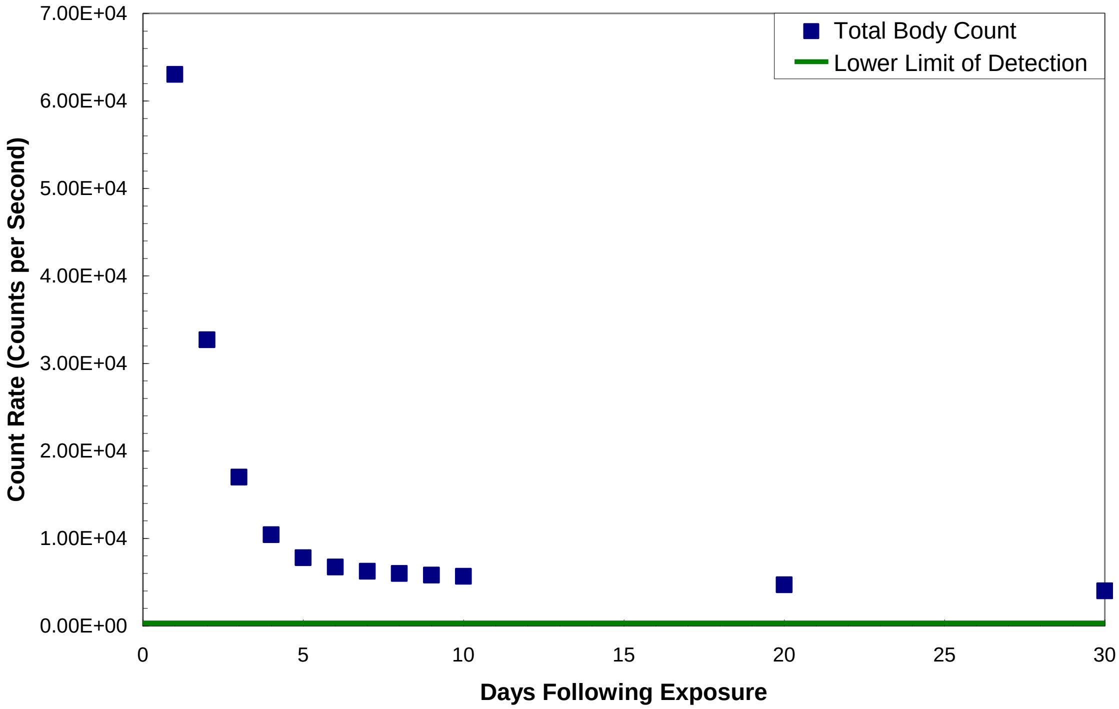

Figure C.44. CPS per 250 mSv for Post Menopausal Adipose Female Ingested Ir-192

Table C.45. CPS per 250 mSv for 10-year-old Child Ingested Co-60

Total Body Count		
Co-60		**cps per 250 mSv**
Days following exposure	1	2.36E+04
	2	1.51E+04
	3	1.08E+04
	4	8.83E+03
	5	7.79E+03
	6	7.16E+03
	7	6.71E+03
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	9	6.02E+03
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	20	4.10E+03
	30	3.47E+03

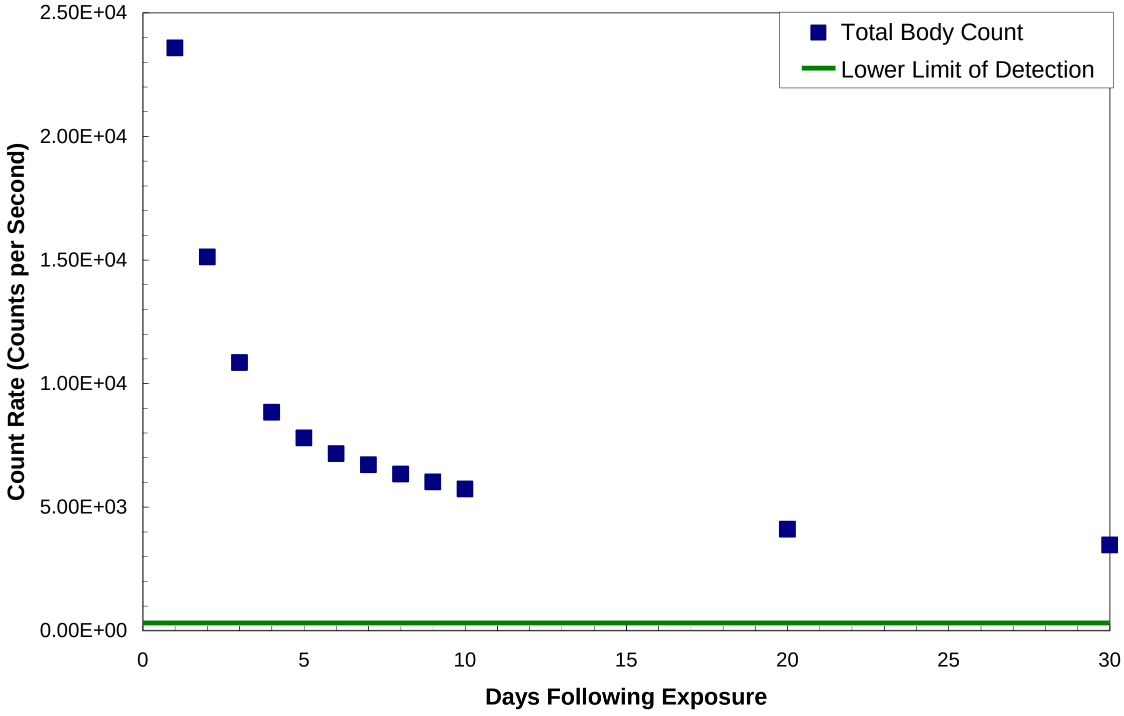

Figure C.45. CPS per 250 mSv for 10-year-old Child Ingested Co-60

Table C.46. CPS per 250 mSv for 10-year-old Child Ingested Cs-137

Total Body Count		
Cs-137		**cps per 250 mSv**
Days following exposure	1	1.01E+05
	2	9.98E+04
	3	9.75E+04
	4	9.56E+04
	5	9.41E+04
	6	9.29E+04
	7	9.19E+04
	8	9.10E+04
	9	9.02E+04
	10	8.94E+04
	20	8.36E+04
	30	7.84E+04

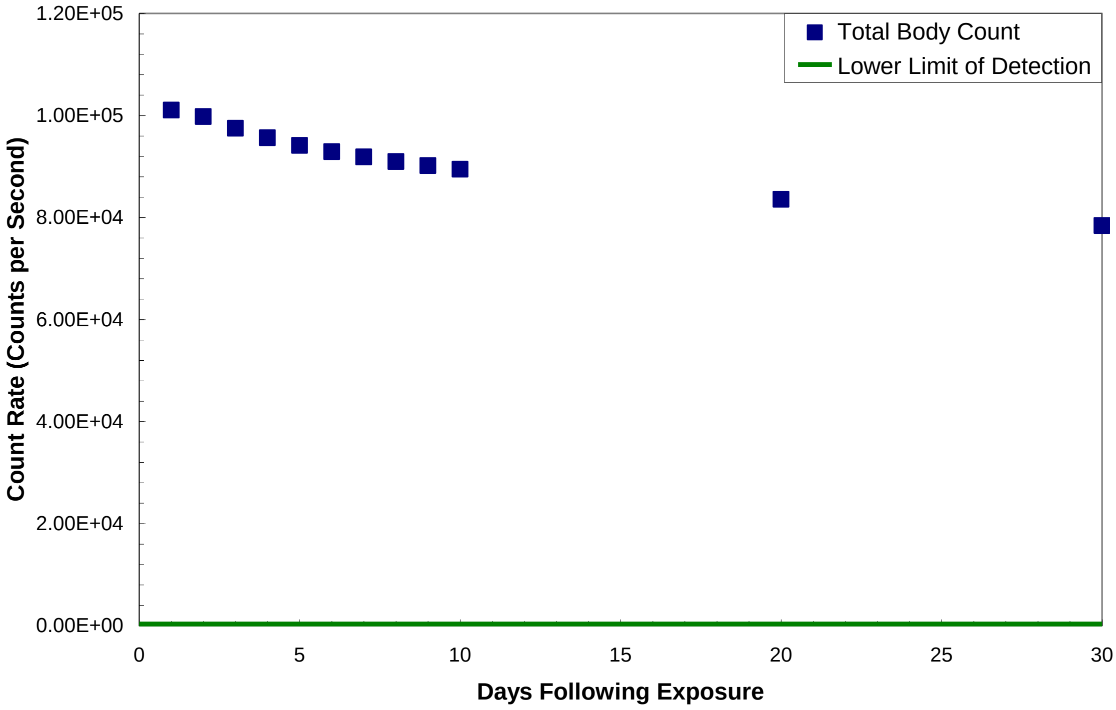

Figure C.46. CPS per 250 mSv for 10-year-old Child Ingested Cs-137

Table C.47. CPS per 250 mSv for 10-year-old Child Ingested I-131

Total Body Count		
I-131		**cps per 250 mSv**
Days following exposure	1	1.43E+03
	2	5.48E+02
	3	4.85E+02
	4	4.68E+02
	5	4.51E+02
	6	4.33E+02
	7	4.13E+02
	8	3.93E+02
	9	3.72E+02
	10	3.51E+02
	20	1.75E+02
	30	7.77E+01

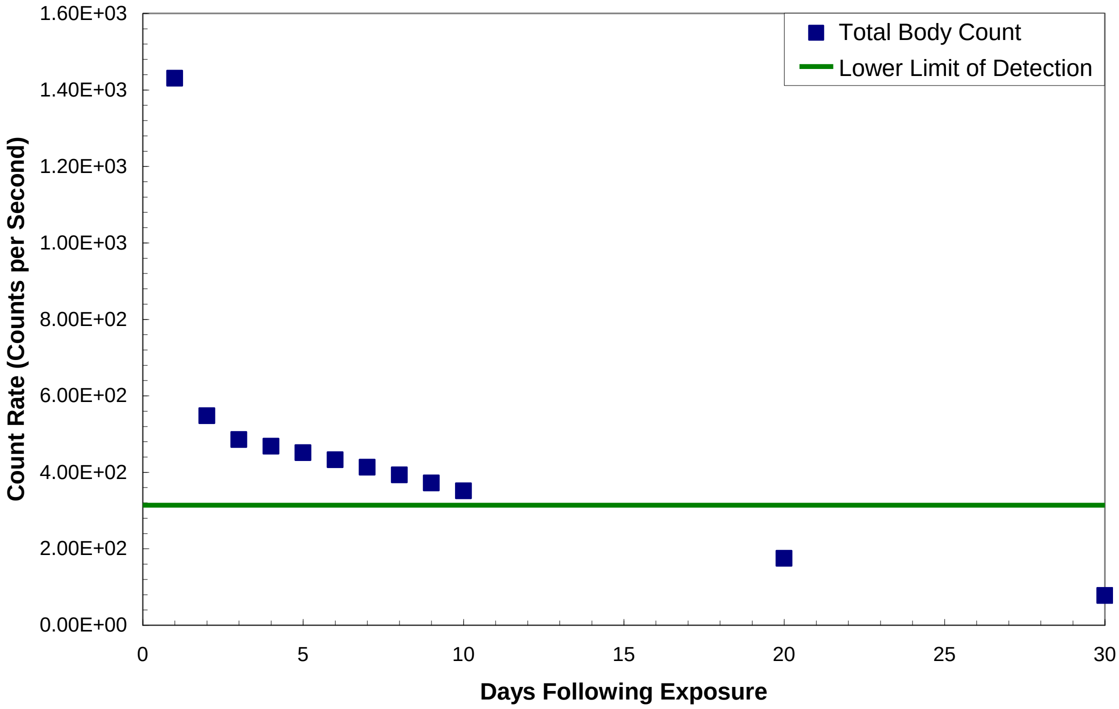

Figure C.47. CPS per 250 mSv for 10-year-old Child Ingested I-131

Table C.48. CPS per 250 mSv for 10-year-old Child Ingested Ir-192

Total Body Count		
Ir-192		**cps per 250 mSv**
Days following exposure	1	3.10E+04
	2	2.02E+04
	3	1.08E+04
	4	6.37E+03
	5	4.57E+03
	6	3.83E+03
	7	3.51E+03
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	9	3.24E+03
	10	3.16E+03
	20	2.61E+03
	30	2.23E+03

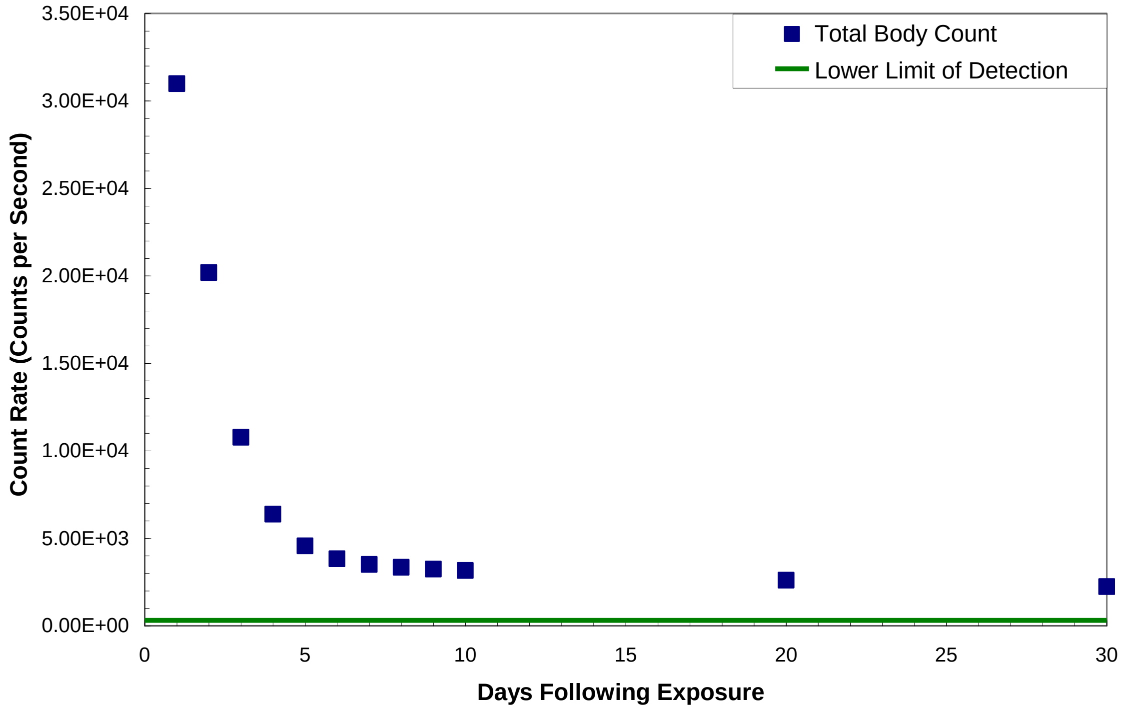

Figure C.48. CPS per 250 mSv for 10-year-old Child Ingested Ir-192

APPENDIX D: PROCEDURE SHEETS

TPM-903B (Adult with Inhaled Radioactivity)

Basic Operation

- Attach aluminum feet to bottom of the PVC pipes.
- String cables through top PVC pipe and place on top of the two sides.
- Connect the cables to the bottom side of the display unit.
- Connect the portal monitor to AC power or D-cell batteries and turn on.
- The background will automatically be acquired once the portal monitor is turned on. Record the background value.
- Calibrate the portal monitor, following the instructions listed in the manual.
- Set the background count parameter to 20 seconds and turn off the occupation alarm by setting the nsigma parameter to n=99.
- Have the victims form a line at least 15 feet from the portal monitor.
- Have each victim stand sideways inside the center of the portal monitor, facing the display unit.
- Once victim enters the portal monitor manually set the mode to background mode by pushing the # button. After the victim has been in the portal monitor for approximately one minute write down the count rate.
- After a count rate has been obtained, subtract the background count from the number on the display and compare the result to the proper trigger level.

Trigger Levels if Inhaled

Time (days)	Co-60 (cps)	Cs-137 (cps)	I-131 (cps)	Ir-192 (cps)
0.25	1.47E+04	1.33E+05	1.91E+04	1.80E+04
0.50	1.45E+04	1.41E+05	1.06E+04	1.76E+04
1.00	1.27E+04	1.47E+05	3.93E+03	1.57E+04
2.00	9.52E+03	1.45E+05	1.89E+03	1.21E+04
3.00	7.85E+03	1.41E+05	1.69E+03	1.01E+04
4.00	7.03E+03	1.39E+05	1.61E+03	9.27E+03
5.00	6.59E+03	1.36E+05	1.52E+03	8.87E+03
6.00	6.31E+03	1.35E+05	1.44E+03	8.67E+03
7.00	6.10E+03	1.33E+05	1.36E+03	8.54E+03
10.00	5.64E+03	1.30E+05	1.12E+03	8.27E+03
20.00	4.81E+03	1.21E+05	5.28E+02	7.60E+03
30.00	4.44E+03	1.14E+05	2.29E+02	7.03E+03

TPM-903B (Adult with Ingested Radioactivity)

Basic Operation

- Attach aluminum feet to bottom of the PVC pipes.
- String cables through top PVC pipe and place on top of the two sides.
- Connect the cables to the bottom side of the display unit.
- Connect the portal monitor to AC power or D-cell batteries and turn on.
- The background will automatically be acquired once the portal monitor is turned on. Record the background value.
- Calibrate the portal monitor, following the instructions listed in the manual.
- Set the background count parameter to 20 seconds and turn off the occupation alarm by setting the nsigma parameter to n=99.
- Have the victims form a line at least 15 feet from the portal monitor.
- Have each victim stand sideways inside the center of the portal monitor, facing the display unit.
- Once victim enters the portal monitor manually set the mode to background mode by pushing the # button. After the victim has been in the portal monitor for approximately one minute write down the count rate.
- After a count rate has been obtained, subtract the background count from the number on the display and compare the result to the proper trigger level.

Trigger Levels if Ingested

Time (days)	Co-60 (cps)	Cs-137 (cps)	I-131 (cps)	Ir-192 (cps)
0.25	7.65E+04	5.52E+04	1.43E+04	7.24E+04
0.50	7.81E+04	5.92E+04	7.57E+03	7.06E+04
1.00	6.46E+04	6.17E+04	2.32E+03	5.70E+04
2.00	4.13E+04	6.09E+04	7.59E+02	2.94E+04
3.00	2.96E+04	5.95E+04	6.67E+02	1.50E+04
4.00	2.41E+04	5.84E+04	6.54E+02	9.02E+03
5.00	2.13E+04	5.75E+04	6.40E+02	6.63E+03
6.00	1.96E+04	5.67E+04	6.22E+02	5.67E+03
7.00	1.84E+04	5.61E+04	6.00E+02	5.24E+03
10.00	1.57E+04	5.46E+04	5.22E+02	4.74E+03
20.00	1.12E+04	5.10E+04	2.71E+02	3.92E+03
30.00	9.49E+03	4.79E+04	1.22E+02	3.35E+03

TPM-903B (Child with Inhaled Radioactivity)

Basic Operation

- Attach aluminum feet to bottom of the PVC pipes.
- String cables through top PVC pipe and place on top of the two sides.
- Connect the cables to the bottom side of the display unit.
- Connect the portal monitor to AC power or D-cell batteries and turn on.
- The background will automatically be acquired once the portal monitor is turned on. Record the background value.
- Calibrate the portal monitor, following the instructions listed in the manual.
- Set the background count parameter to 20 seconds and turn off the occupation alarm by setting the nsigma parameter to n=99.
- Have the victims form a line at least 15 feet from the portal monitor.
- Have each victim stand sideways inside the center of the portal monitor, facing the display unit.
- Once victim enters the portal monitor manually set the mode to background mode by pushing the # button. After the victim has been in the portal monitor for approximately one minute write down the count rate.
- After a count rate has been obtained, subtract the background count from the number on the display and compare the result to the proper trigger level.

Trigger Levels if Inhaled

Time (days)	Co-60 (cps)	Cs-137 (cps)	I-131 (cps)	Ir-192 (cps)
0.25	1.13E+04	1.73E+05	8.40E+03	1.67E+04
0.50	1.11E+04	1.83E+05	4.73E+03	1.61E+04
1.00	9.59E+03	1.90E+05	1.86E+03	1.42E+04
2.00	7.04E+03	1.87E+05	9.59E+02	1.05E+04
3.00	5.71E+03	1.83E+05	8.63E+02	8.56E+03
4.00	5.08E+03	1.79E+05	8.12E+02	7.71E+03
5.00	4.74E+03	1.77E+05	7.65E+02	7.32E+03
6.00	4.54E+03	1.74E+05	7.19E+02	7.13E+03
7.00	4.39E+03	1.72E+05	6.74E+02	7.01E+03
10.00	4.06E+03	1.68E+05	5.49E+02	6.76E+03
20.00	3.47E+03	1.57E+05	2.53E+02	6.15E+03
30.00	3.20E+03	1.47E+05	1.09E+02	5.64E+03

TPM-903B (Child with Ingested Radioactivity)

Basic Operation

- Attach aluminum feet to bottom of the PVC pipes.
- String cables through top PVC pipe and place on top of the two sides.
- Connect the cables to the bottom side of the display unit.
- Connect the portal monitor to AC power or D-cell batteries and turn on.
- The background will automatically be acquired once the portal monitor is turned on. Record the background value.
- Calibrate the portal monitor, following the instructions listed in the manual.
- Set the background count parameter to 20 seconds and turn off the occupation alarm by setting the nsigma parameter to n=99.
- Have the victims form a line at least 15 feet from the portal monitor.
- Have each victim stand sideways inside the center of the portal monitor, facing the display unit.
- Once victim enters the portal monitor manually set the mode to background mode by pushing the # button. After the victim has been in the portal monitor for approximately one minute write down the count rate.
- After a count rate has been obtained, subtract the background count from the number on the display and compare the result to the proper trigger level.

Trigger Levels if Ingested

Time (days)	Co-60 (cps)	Cs-137 (cps)	I-131 (cps)	Ir-192 (cps)
0.25	2.82E+04	9.04E+04	8.12E+03	2.77E+04
0.50	2.85E+04	9.70E+04	4.37E+03	2.71E+04
1.00	2.36E+04	1.01E+05	1.43E+03	3.10E+04
2.00	1.51E+04	9.98E+04	5.48E+02	2.02E+04
3.00	1.08E+04	9.75E+04	4.85E+02	1.08E+04
4.00	8.83E+03	9.56E+04	4.68E+02	6.37E+03
5.00	7.79E+03	9.41E+04	4.51E+02	4.57E+03
6.00	7.16E+03	9.29E+04	4.33E+02	3.83E+03
7.00	6.71E+03	9.19E+04	4.13E+02	3.51E+03
10.00	5.73E+03	8.94E+04	3.51E+02	3.16E+03
20.00	4.10E+03	8.36E+04	1.75E+02	2.61E+03
30.00	3.47E+03	7.84E+04	7.77E+01	2.23E+03

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