ASSESSING INTERNAL CONTAMINATION LEVELS FOR FISSION PRODUCT INHALATION USING A PORTAL MONITOR

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SUMMARY

In the event of a nuclear power plant accident, fission products could be released into the atmosphere potentially affecting the health of local citizens. In order to triage the possibly large number of people impacted, a detection device is needed that can acquire data quickly and that is sensitive to internal contamination. The portal monitor TPM 903B was investigated for use in the event of a fission product release. A list of fission products released from a Pressurized Water Reactor (PWR) was generated and separated into two groups: gamma- and beta-emitting fission products and strictly beta-emitting fission products. Group one fission products—the gamma- and beta-emitting fission products—were used in the previously validated Monte Carlo N-Particle Transport Code (MCNP) model of the portal monitor. Two MIRD anthropomorphic phantom types were implemented in the MCNP model—the Adipose Male and Child phantoms. Dose and Risk Calculation software (DCAL) provided inhalation biokinetic data that were applied to the output of the MCNP modeling to determine the radionuclide concentrations in each organ as a function of time. For each phantom type, these data were used to determine the total body counts associated with each individual gamma-emitting fission product. Corresponding adult and child dose coefficients were implemented to determine the total body counts per 250 mSv. A weighted sum of all of the isotopes involved was performed. The ratio of dose associated with gamma-emitting fission products to the total of all fission products was determined based on corresponding dose coefficients and relative abundance. This ratio was used to project the total body counts corresponding to 250 mSv for the entire fission product release inhalation—including all types of radiation. The developed procedure sheets will be used by first response personnel in the event of a fission product release.

1. INTRODUCTION

Throughout the era of World War II, much progress was made in the understanding of nuclear physics and the investigation of its applications. While WWII may be credited with the capability of using nuclear reactions to create mass destruction with the successful detonation of the atomic bomb, a more peaceful and beneficial application was also developed—nuclear power. With the first nuclear reactor built in Idaho in 1951, the United States began to realize the benefits of this new source of energy [15]. There have always been concerns about the safety of nuclear power plants since their creation. Modern nuclear reactors possess state of the art safety features that mitigate the probability of an accident occurring and releasing hazardous radioactive products into the atmosphere.

There have been several nuclear power plant accidents throughout the history of nuclear power. [15] Now, with more than 100 power plants that contribute to the energy grid in the United States, it is reasonable to consider the possibility of a nuclear power plant accident, albeit small with the advancements in reactor design and safety features. If such an accident were to occur, radioactive material could be released into the atmosphere, potentially affecting the health of local citizens. The main public health concern would be internal contamination via inhalation of the released radioactive material.

Nuclear reactors operate on the principle of controlled nuclear fission. Nuclear fission is defined as, “The splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy,” [10]. The most common fissionable isotopes for nuclear power generation are U-235, U-238, and Pu-239 [6]. Fission occurs in these isotopes when a neutron is absorbed causing an excited nucleus which can split into two different isotopes with the release of kinetic energy, neutrons, and often gamma rays. The isotopes created by the fission reaction are not always the same two isotopes. With the absorption of a neutron by U-235, fission occurs 85% of the time, while neutron capture occurs followed by gamma emission the other 15% of the time. [6] The release of neutrons from the original fission reaction can be absorbed by another fissionable nucleus of U-235 or Pu-239, thus creating a chain reaction. This chain reaction when controlled properly allows for the generation of nuclear power.

The products created from the fission of an isotope are termed fission products. Fission products are neutron rich and undergo beta decay, which is often followed by emission of gamma ray(s), until a stable end product is created [6]. For members of the public, the main concern in a nuclear reactor accident is the internal contamination caused by inhalation of these fission products if released into the atmosphere. In such an emergency, it would be necessary to triage a large number of people in a relatively quick manner to determine those in need of further testing. The methodology of how to respond to such an accident has not been fully explored.

This research focused on assessing the viability of using a radiation detector to determine whether members of the public have fission product internal contamination above a specified dose threshold. This threshold was determined to be a committed effective dose of 250 mSv. The International Commission on Radiation Protection (ICRP) has concluded that a committed effective dose of 250 mSv is within the limit of the lifetime dose of radiation workers when considered as a one-time exposure. The ICRP also determined that a committed effective dose below 250 mSv does not provide any concern for, "…serious deterministic effects." [14] Thermo Scientific's portal monitor, the TPM 903B, was chosen as the radiation detection device for this research because of its availability in the United States, especially in Georgia, and its ability to quickly determine the total body count rate emitted by a potentially contaminated individual.

2. ASSUMPTIONS

Several assumptions were made in the completion of this research. The validity of these assumptions relies on the underlying principle that the results of this research will only be used as a first cut screening tool. Only an initial assessment of the level of absorbed dose in an individual is intended to be drawn from the detector reading. The trigger levels reported herein are meant to identify individuals who need further, more accurate methods of testing to determine the individual's dose and if some remedial action should be taken.

One of the assumptions made was that the reactor releasing the fission products is a uranium-fueled Pressurized Water Reactor (PWR), which had operated at 1000MWe for three years causing all of the fuel to be at the end of its lifetime. While most operating reactors replace 1/3 of the fuel at a time, it is assumed here that all of the fuel has been in the reactor for the fuel lifetime of three years with the fission product concentrations proportional to this. The assumption makes the results an over-estimation. The majority of reactors operating in the United States are PWR's, thereby making it a reasonable representative system to study. [13]

Another assumption made was that the fission product amounts released from the reactor were proportional to their relative amounts in the fuel at the end of the fuel cycle. Element specific fission product's release fractions were taken from NUREG document 1465 [11]. These release fractions were applied to the fuel isotopic inventory to generate the release terms. Also, it was assumed that the fission products released into the atmosphere were inhaled in the relative concentrations predicted by their core activity and ex-vessel release fraction.

3. DETECTOR SPECIFICATIONS

The TPM 903B is a scintillation detector, utilizing two BC408 plastic scintillators to produce a readout in counts per second [7]. Each BC408 plastic scintillator has dimensions of 7.5 cm x 180 cm x 3.6 cm, equal to a total detector volume of 10.6 liters [12]. Each plastic scintillator is surrounded on three sides by 1.6 mm of lead shielding [5] to minimize detection of background radiation. The TPM 903B is shown in Figure 3.1. The detector structure has two pillars, each containing one organic plastic scintillator, connected by a crossover with PVC piping used as the encasement material. Each pillar is 213 cm tall with a diameter of 4.5 cm. The crossover creates 84 cm of space between each pillar. [12]

Figure 3.1 TPM 903B Portal Monitor [5]

4. METHODOLOGY

Four main steps describe the general method used in this research. First, the fission products of concern were identified. Next, using the MCNP model of the detector and biokinetic data for two general phantom types—the adipose male and child—the detector reading, i.e. count rates, for the gamma-emitting fission products was established. Then, the non-gamma emitting fission products' contributions to the individual's dose were determined. Finally, the total body count rate, in counts per second as registered by the detector, corresponding to a committed effective dose of 250 mSv was calculated.

Accident Scenario

While the methodology used in this research can be applied to any reactor accident scenario, it was important to define a specific accident scenario to focus this research. First, the specific reactor in question was defined: a uranium-fueled, pressurized light water reactor (PWR), operating at 1000 MW_e, with a fuel lifetime of three years. A severe core melt accident occurring at the end of the fuel lifetime resulting in an ex-vessel release was applied to the reactor in question to investigate the fission products released.

Determination of Fission Products

To begin to assess the ability of the portal monitor to detect fission product internal contamination, a list of fission products needed to be developed. The book *Nuclear Chemical Engineering* [1] lists fission product concentrations in spent fuel. The fission products associated with the reactor investigated in this research—a uranium-fueled PWR operating at 1000MWe with a three-year fuel lifetime—are listed in Table 8.1 of the reference. The fission products contained in this list are displayed in Table 4.1. The activity at the end of the fuel lifetime for each of these fission products is also documented in the reference [1].

Table 4.1 Fission products present at fuel discharge

Ag-110	Ce-144	Eu-156	Nb-95m	Rb-86	Sb-126m	Sr-89	Te-129
Ag-110m	Cs-134	H-3	Nd-147	Rh-103m	Se-79	Sr-90	Te-129m
Ag-111	Cs-135	I-129	Pd-107	Rh-106	Sm-151	Tb-160	Xe-131m
Ba-137m	Cs-136	I-131	Pm-147	Ru-103	Sn-117m	Tc-99	Xe-133
Ba-140	Cs-137	Kr-85	Pm-148	Ru-106	Sn-119m	Te-123m	Y-90
Cd-113m	Eu-152	La-140	Pm-148m	Sb-124	Sn-123	Te-125m	Y-91
Cd-115m	Eu-154	Nb-93m	Pr-143	Sb-125	Sn-125	Te-127	Zr-93
Ce-141	Eu-155	Nb-95	Pr-144	Sb-126	Sn-126	Te-127m	Zr-95

Next, it was important to determine the release fractions of each of these fission products from a PWR core during the accident scenario. The PWR release fractions used in this research were obtained from the U.S. Nuclear Regulatory Commission's final report number 1465, "Accident Source Terms for Light-Water Nuclear Power Plants," [11]. The fission products from Table 4.1 were compared with the atmospheric release fractions for each fission product. The atmospheric release fractions of the fission products are displayed in Table 4.2 for an ex-vessel release. These release fractions were considered to be fractions of the core isotopic inventory that would be released. The fission products from Table 4.1 that were not listed in Table 4.2 were eliminated by drawing the conclusion that they are not released into the atmosphere, and thus are not a concern for internal contamination. The list of fission products released into the atmosphere is shown in Table 4.3.

Table 4.2 Fission product release fractions. Releases are fractions of core activities.

Nuclide	Ex-Vessel release
I, Br	0.25
Cs, Rb	0.35
Te, Sb, Se	0.25
Ba, Sr	0.1
Ru, Rh, Pd, Mo, Tc, Co	0.0025
La, Zr, Nd, Eu, Nb, Pm, Pr, Sm, Y, Cm, Am	0.005
Ce, Pu, Np	0.005

Releases are Fractions of Core Inventory. Source: NUREG-1465

Table 4.3 List of released fission products

Ba-140	Eu-155	Pm-147	Sb-126m	Te-127
Ba-137m	Eu-156	Pm-148m	Sb-126	Te-129m
Ce-141	I-129	Pm-148	Se-79	Te-129
Ce-144	I-131	Pr-143	Sr-89	Y-90
Cs-134	La-140	Pr-144	Sr-90	Y-91
Cs-135	Nb-93m	Rb-86	Sm-151	Zr-93
Cs-136	Nb-95m	Rh-103m	Tc-99	Zr-95
Cs-137	Nb-95	Rh-106	Te-123m	
Eu-152	Nd-147	Sb-124	Te-125m	
Eu-154	Pd-107	Sb-125	Te-127m	

A toxicity index was developed to eliminate those isotopes that would not be significant contributors to the dose. Use of the toxicity index was motivated by the realization that the most *toxic* fission products would be responsible for driving the individual's dose. The toxicity index used in this research is defined in Equation 4.1. Any fission product with a toxicity index of less than 10^{-14} was assumed to not be a major dose contributor and thus, eliminated from the list of isotopes of concern.

$$T.I. = RF * A * DC \tag{4.1}$$

where *RF* represents the release fraction, *A* represents the activity and *DC* represents the dose coefficient. The computed toxicity indexes for each fission product are displayed in Table 4.4 and Table 4.5 for the adipose male and child phantoms, respectively. The toxicity indexes for the adult were computed using the ICRP 72 adult dose coefficients for public inhalation, while the child toxicity indexes were computed using the ICRP 72 public inhalation dose coefficients for a 10-year-old child. These dose coefficients were extracted from the software Radiological Toolbox [8]. The list of the fission products of concern, after elimination of those below the cutoff, is displayed in Table 4.6.

Table 4.4 Computed toxicity indexes for the adipose male

Isotope	Toxicity Index	Isotope	Toxicity Index
Ba-140	1.41E-12	**Rb-86**	1.55E-15
Ce-141	2.56E-13	**Rh-103m**	7.98E-17
Ce-144	2.85E-12	**Rh-106**	----
Cs-134	5.51E-12	**Ru-103**	8.86E-14
Cs-135	6.70E-19	**Ru-106**	8.69E-13
Cs-136	2.48E-13	**Sb-124**	6.32E-15
Cs-137/Ba-137m	1.69E-12	**Sb-125**	1.01E-13
Eu-152	2.55E-17	**Sb-126m**	1.04E-18
Eu-154	1.80E-14	**Sb-126**	3.86E-16
Eu-155	2.51E-15	**Se-79**	2.50E-18
Eu-156	3.73E-14	**Sm-151**	2.43E-16
I-129	3.24E-18	**Sr-89**	6.98E-13
I-131	1.55E-11	**Sr-90**	1.80E-12
La-140	8.01E-14	**Tc-99**	1.39E-18
Nb-93m	1.27E-20	**Te-123m**	5.91E-18
Nb-95m	1.19E-15	**Te-125m**	2.56E-14
Nb-95	1.20E-13	**Te-127m**	2.77E-13
Nd-147	6.83E-14	**Te-127**	2.27E-14
Pd-107	6.67E-23	**Te-129m**	9.16E-13
Pm-147	2.42E-14	**Te-129**	3.02E-14
Pm-148m	1.08E-14	**Y-90**	5.87E-15
Pm-148	2.12E-14	**Y-91**	4.04E-13
Pr-143	1.40E-13	**Zr-93**	9.17E-19
Pr-144	9.77E-16	**Zr-95**	3.19E-13

Table 4.5 Computed toxicity indexes for the child

Isotope	Toxicity Index	Isotope	Toxicity Index
Ba-140	3.37E-12	**Rb-86**	3.34E-15
Ce-141	3.58E-13	**Rh-103m**	1.27E-16
Ce-144	3.92E-12	**Rh-106**	----
Cs-134	4.42E-12	**Ru-103**	1.24E-13
Cs-135	5.92E-19	**Ru-106**	1.20E-12
Cs-136	4.14E-13	**Sb-124**	9.48E-15
Cs-137/Ba-137m	1.36E-12	**Sb-125**	1.43E-13
Eu-152	2.97E-17	**Sb-126m**	1.91E-18
Eu-154	2.21E-14	**Sb-126**	7.04E-16
Eu-155	3.34E-15	**Se-79**	4.71E-18
Eu-156	5.81E-14	**Sm-151**	2.73E-16
I-129	6.02E-18	**Sr-89**	1.60E-12
I-131	3.97E-11	**Sr-90**	3.08E-12
La-140	1.46E-13	**Tc-99**	1.98E-18
Nb-93m	1.76E-20	**Te-123m**	8.42E-18
Nb-95m	1.76E-15	**Te-125m**	3.62E-14
Nb-95	1.67E-13	**Te-127m**	4.11E-13
Nd-147	9.97E-14	**Te-127**	4.19E-14
Pd-107	1.39E-22	**Te-129m**	1.36E-12
Pm-147	3.36E-14	**Te-129**	5.31E-14
Pm-148m	1.57E-14	**Y-90**	1.06E-14
Pm-148	3.57E-14	**Y-91**	5.90E-13
Pr-143	2.10E-13	**Zr-93**	3.76E-19
Pr-144	1.85E-15	**Zr-95**	4.51E-13

Table 4.6 Fission products below toxicity index cutoff

Fission Products of Concern	
Ba-137m/Cs-137	Pr-143
Ba-140	Rh-106
Ce-141	Ru-103
Ce-144	Ru-106
Cs-134	Sb-125
Cs-136	Sr-89
Eu-154	Sr-90
Eu-156	Te-125m
I-131	Te-127
La-140	Te-127m
Nb-95	Te-129
Nd-147	Te-129m
Pm-147	Y-90
Pm-148	Y-91
Pm-148m	Zr-95

The list of fission products of concern was examined to determine whether any daughter products exist. Several parent daughter relationships were found. The parent daughter relationships are displayed in Equations 4.2 to 4.19.

$$Ba-140 \longrightarrow La-140 \quad (4.2)$$

$$Ce-144 \longrightarrow \mathrm{Pr}-144 \quad (4.3)$$

$$Eu-152 \longrightarrow Gd-152 \quad (4.4)$$

$$I-131 \longrightarrow Xe-131m \quad (4.5)$$

$$Nb-95m \longrightarrow Nb-95 \quad (4.6)$$

$$Nd-147 \longrightarrow Pm-147 \longrightarrow Sm-147 \quad (4.7)$$

$$Pm-148m \longrightarrow Pm-148 \quad (4.8)$$

$$Ru-103 \longrightarrow Rh-103m \quad (4.9)$$

$$Ru-106 \longrightarrow Rh-106 \quad (4.10)$$

$$Sb-125 \longrightarrow Te-125m \quad (4.11)$$

$$Sb-126m \longrightarrow Sb-126 \quad (4.12)$$

$$Sr-90 \longrightarrow Y-90 \quad (4.13)$$

$$Te-127m \longrightarrow Te-127 \quad (4.14)$$

$$Te-129m \longrightarrow Te-129 \longrightarrow I-129 \quad (4.15)$$

$$Te-129m \longrightarrow I-129 \quad (4.16)$$

$$Zr-93 \longrightarrow Nb-93m \quad (4.17)$$

$$Zr-95 \longrightarrow Nb-95m \quad (4.18)$$

$$Zr-95 \longrightarrow Nb-95 \quad (4.19)$$

Rh-106 decays away before counts can be registered at 0.25 days so its gamma energies are only considered in its buildup from the decay of Ru-106. Te-127m does have gamma energies above the energy and intensity cutoffs; however, no response was detected in the simulated detector model. This is because the gamma energy was just above the 40 keV energy cutoff but still below the 60 keV detector energy cutoff with a very low intensity. Te-127m was not ignored though because its daughter product, Te-127, is also a gamma emitter. Y-90 is only used in the child analysis because it did not meet the toxicity index cutoff when computed for the adipose male.

Each parent daughter relationship was examined to determine whether the daughter product emits gamma rays above the 40 keV energy cutoff and the 0.5% intensity cutoff. Those daughter products that were found to be non-gamma emitters or gamma-emitters with energies and/or intensities below energy and/or intensity cutoffs were not considered in the parent analysis. Equations 4.20 to 4.28 show the parent daughter relationships with gamma-emitting daughter products, with gamma rays being emitted above the energy and intensity cutoffs.

$$Ba-140 \longrightarrow La-140 \quad (4.20)$$

$$Ce-144 \longrightarrow \mathrm{Pr}-144 \quad (4.21)$$

$$Nb-95m \longrightarrow Nb-95 \quad (4.22)$$

$$Pm-148m \longrightarrow Pm-148 \quad (4.23)$$

$$Ru-106 \longrightarrow Rh-106 \quad (4.24)$$

$$Te-127m \longrightarrow Te-127 \quad (4.25)$$

$$Te-129m \longrightarrow Te-129 \quad (4.26)$$

$$Zr-95 \longrightarrow Nb-95m \quad (4.27)$$

$$Zr-95 \longrightarrow Nb-95 \quad (4.28)$$

Next, it was important to separate the list of fission products into groups based on the types of radiation that they emit. Group 1, as seen in Table 4.7, consisted of fission products that are gamma-emitters themselves or that have a daughter product that is a gamma emitter. The remaining fission products were placed in Group 2, as seen in Table 4.8. This separation based on gamma-emission was performed because the portal monitor is only sensitive to gamma radiation. All other types of radiation emitted are not detected by the portal monitor and must be included in a different manner to arrive at the TPM 903B count rate for a 250 mSv committed effective dose. Fission products in Group 2 will be considered separately.

Table 4.7 Group 1 fission products

Group 1 Fission Products
Ba-140/La-140
Ce-141
Ce-144/Pr-144
Cs-134
Cs-136
Cs-137/Ba-137m
Eu-154
Eu-156
I-131
La-140
Nd-147
Nb-95
Nb-95m/Nb-95
Pm-148
Pm-148m/Pm-148
Ru-103
Ru-106/Rh-106
Sb-125
Te-127
Te-127m/Te-127
Te-129
Te-129m/Te-129
Zr-95/Nb-95m/Nb-95

Table 4.8 Group 2 fission products

Group 2 Fission Products
Sr-89
Sr-90
Y-90
Y-91
Pr-143
Pm-147

Group 1 Fission Products

The count rates for the gamma-emitting fission products in Group 1 were simulated individually in the MCNP model of the detector by inputting each fission products' gamma energy and intensity. Thermo Scientific, the manufacturer of the TPM-903B portal monitor, reports that the cutoff energy for its plastic scintillator is 60 keV [12]. This manufacturer's specification was validated in previous research [7]. To be conservative, the energy cutoff for gamma rays was fixed at 40 keV. The cutoff for the gamma ray intensity was established at 0.05%. The gamma rays below the energy and/or intensity cutoffs were eliminated. Because none of the gamma rays emitted from Te-125m were above the energy and intensity cutoffs, Te-125m was eliminated from Group 1. Te-125m does not have any radioactive daughter products and does not emit any other type of radiation, so it was not placed in Group 2 and eliminated completely from the list of fission products of concern. The fission product gamma spectra used in the MCNP model are displayed in Table 4.9.

Table 4.9 Gamma spectrums used in MCNP model for each fission product

Fission Product	Intensity	Energy (MeV)
Ba-140	0.2439, 0.0621, 0.043, 0.0315, 0.0193	0.537274, 0.162609, 0.30485, 0.423722, 0.437575
Ce-141	0.48, 0.0174874, 0.00900864, 0.00702144	0.14544, 0.0407484, 0.0406532, 0.0417924
Ce-144	0.108, 0.016416, 0.0106958, 0.00550999	0.13353, 0.0801199, 0.0407484, 0.0406532
Cs-134	0.976, 0.854, 0.1543, 0.0873, 0.0838, 0.0304, 0.018, 0.0146, 0.01	0.604699, 0.795845, 0.569315, 0.801932, 0.563227, 1.36515, 1.16794, 0.47535, 1.03857
Cs-136	0.997002, 0.797202, 0.467532, 0.197802, 0.135864, 0.126873, 0.124875, 0.0747252, 0.0631368, 0.0461538, 0.0097902, 0.0062937, 0.005994, 0.005994	0.8185, 1.04807, 0.34057, 1.23534, 0.17656 0.27365, 0.06691, 0.15322, 0.0862899, 0.16389, 0.50721, 0.16653, 0.18725, 0.31987
Cs-137/ Ba-137m	0.897759	0.661645
Eu-154	0.404619, 0.354929, 0.196985, 0.178884, 0.141536, 0.114997, 0.102929, 0.0786938, 0.0660167, 0.0482703, 0.0433013, 0.0271743, 0.0182788, 0.0140539, 0.0125961, 0.0102929, 0.0089797, 0.00841181, 0.00823435, 0.0064952, 0.00550139, 0.0050399	0.12307, 1.27445, 0.7233, 1.00476, 0.0429963, 0.87319, 0.99632, 0.042309, 0.247939, 1.2462, 0.582, 0.90405, 1.4944, 0.84359, 0.44444, 0.59181, 0.75687, 0.0486951, 1.59653, 0.0485508, 0.0499954, 1.593
Eu-156	0.102, 0.08874, 0.0876524, 0.0703168, 0.0695795, 0.0695391, 0.0662434, 0.0590223, 0.0518851, 0.0514474, 0.0478109, 0.0418873, 0.041157, 0.0387232, 0.0386635, 0.0346412, 0.0314953, 0.0238475, 0.022674, 0.0209859, 0.0172253, 0.0169071, 0.0159518, 0.0137428, 0.0136508, 0.0133512, 0.0110084, 0.00978642, 0.0089739, 0.007752, 0.00690526, 0.006189, 0.00523593	0.81177, 0.0889636, 1.23071, 1.15347, 1.64629, 0.0429963, 1.124242, 0.72347, 1.15409, 1.06514, 1.07916, 2.09768, 1.96595, 2.18671, 0.0423088, 2.02661, 1.27743, 2.18091, 0.59947, 1.93768, 1.36641, 1.87703, 0.9605, 0.86701, 0.94435, 0.0486951, 2.2699, 2.20538, 0.70986, 0.19921, 0.0485508, 0.0499954, 1.04044
I-131	0.812447, 0.0726767, 0.0605807, 0.026208, 0.0180432	0.36448, 0.636973, 0.284298, 0.080183, 0.722893
La-140	0.954, 0.459, 0.2364, 0.2074, 0.0705, 0.0559, 0.0441, 0.0343, 0.0299, 0.0268, 0.00846, 0.00539	1.59617, 0.487029, 0.81578, 0.328768, 0.92519, 0.86784, 0.75183, 2.52132, 0.43252, 0.91954, 2.3478, 0.951
Nb-95m	0.2587	0.2347
Nb-95	1	0.76583
Nd-147	0.278948, 0.130669, 0.0463337, 0.02399, 0.019874, 0.0194474, 0.0119763, 0.00870707, 0.00811433, 0.00800596	0.0911059, 0.531016, 0.0438271, 0.043713, 0.0449698, 0.319411, 0.439895, 0.398155, 0.685902, 0.275374
Pm-148m	0.936589, 0.891989, 0.328252, 0.204265, 0.189993, 0.185534, 0.123987, 0.123987, 0.06904, 0.0566413, 0.0553033	0.5501, 0.6299, 0.7256, 1.0137, 0.9153, 0.4141, 0.288, 0.5995, 0.5011, 0.4327, 0.6111
Pm-148	0.233, 0.221816, 0.125121, 0.011184	0.5501, 1.4651, 0.9149, 0.6111
Pr-144	0.00774, 0.0148	2.1875, 0.69649
Ru-103	0.863519, 0.0528314, 0.00756864	0.49708, 0.61033, 0.55704
Sb-125	0.295, 0.17641, 0.11328, 0.10325, 0.066965, 0.04838, 0.0171985, 0.015045	0.4279, 0.6006, 0.636, 0.4634, 0.17629, 0.6067, 0.6715, 0.3805
Te-129m	0.0305921, 0.00714454	0.69588, 0.72957
Te-127	0.00989999	0.4179
Te-129m	0.0736, 0.0135424, 0.00541696	0.4596, 0.48739, 0.27843
Zr-95	0.55, 0.4455	0.75674, 0.72423

MCNP Detector Model

Earlier work conducted at Georgia Tech by Randahl Palmer [7] was utilized in the Monte Carlo N-Particle Transport Code (MCNP) model of the detector. Palmer constructed the MCNP detector model of the TPM-903B. Palmer validated the detector model by determining the actual detector response to experimental point source measurements using varying attenuation thicknesses of poly(methyl methacrylate) or PMMA at different locations within the detector. Each point source measurement was then simulated in MCNP using the detector model. The MCNP detector model response was then compared with the measured detector response. Four different point sources were used—Ba-133, Co-60, Cs-137, and Na-22—emitting a variety of gamma ray energies. While the model predicted the measured experimental counts, there was some deviation. A scaling factor was developed to account for the differences between the experimental and modeled detector response. This scaling factor is defined as the ratio of the MCNP detector model response to the experimental detector response. A scaling factor was determined for each of the four point sources as shown in Table 4.10. [7] The relationship between the thickness of the PMMA and the scaling factor is shown for each point source in Figure 4.1, Figure 4.2. Figure 4.3, and Figure 4.4.

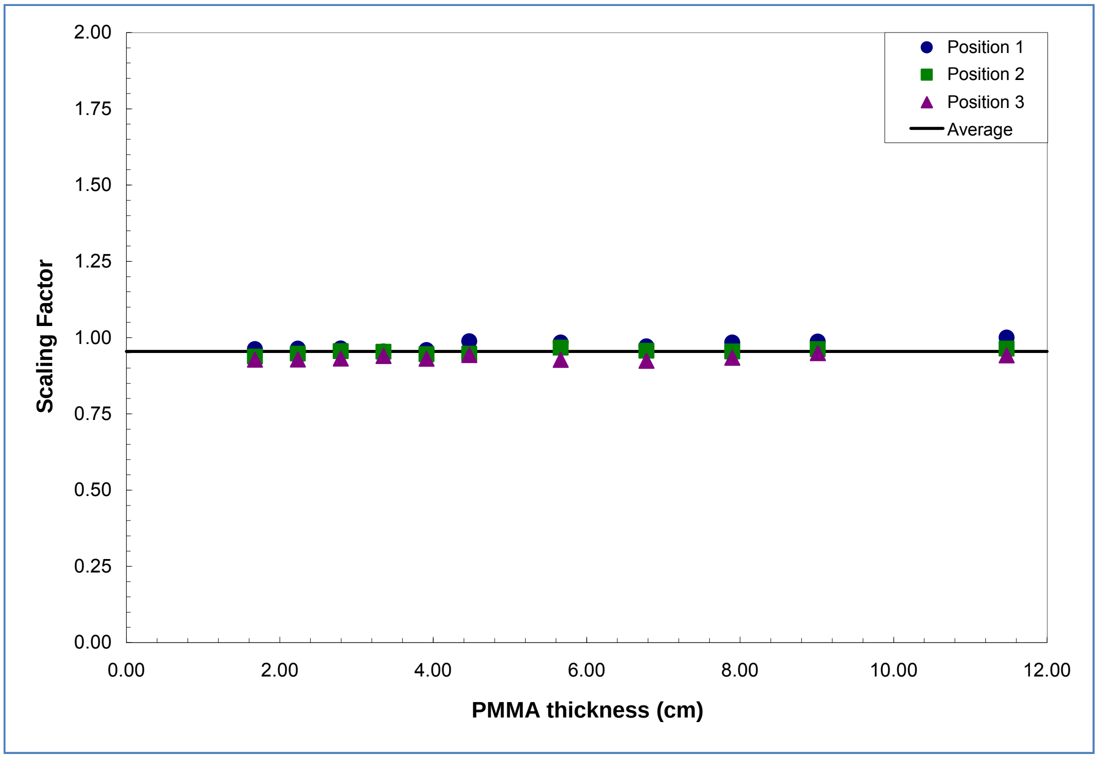

Figure 4.1 Ba-133 Scaling Factor [7]

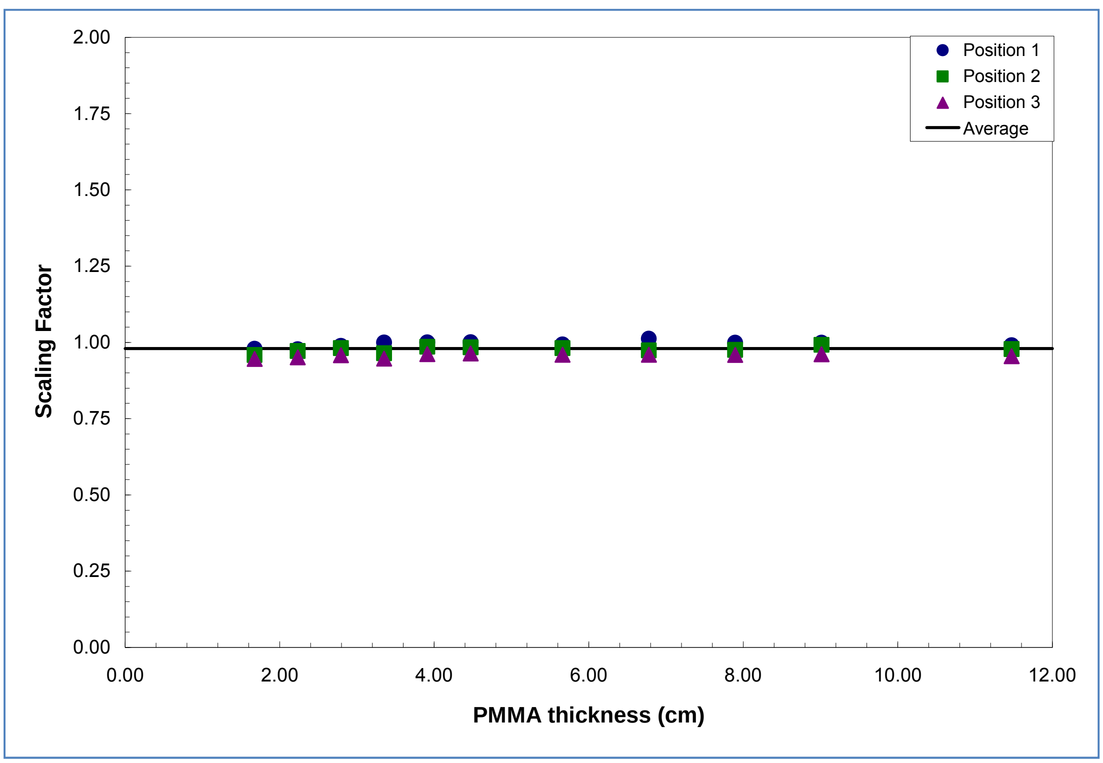

Figure 4.2 Co-60 Scaling Factor [7]

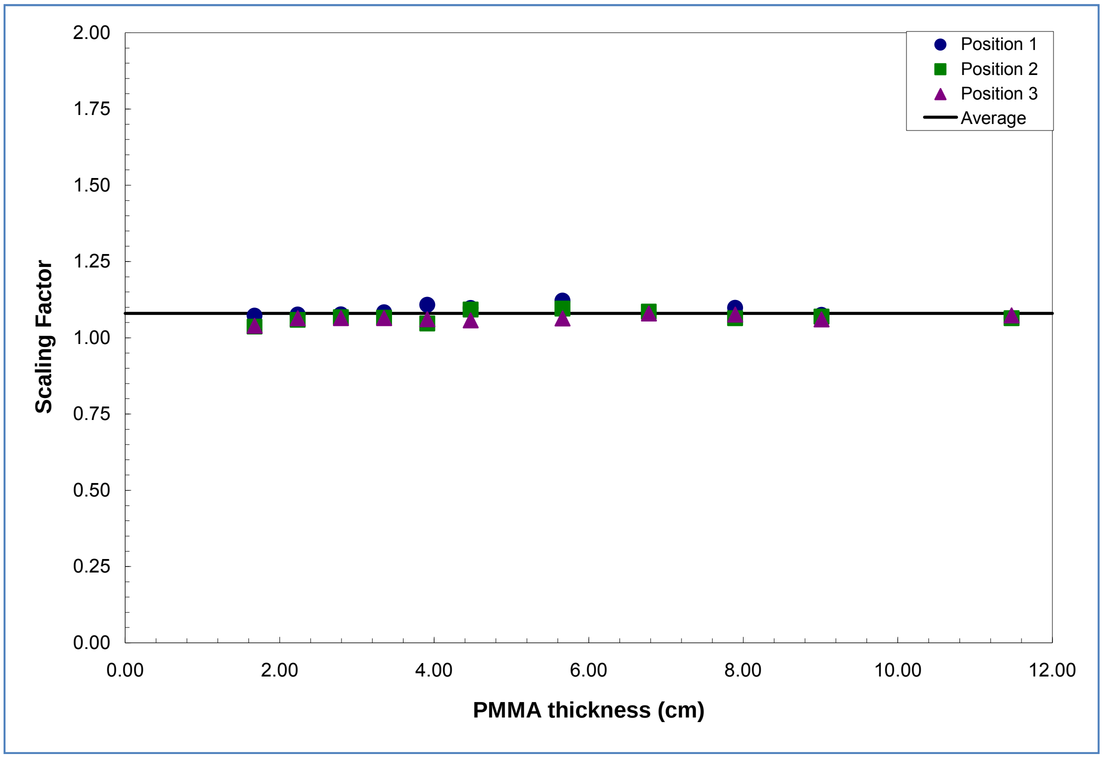

Figure 4.3 Cs-137 Scaling Factor [7]

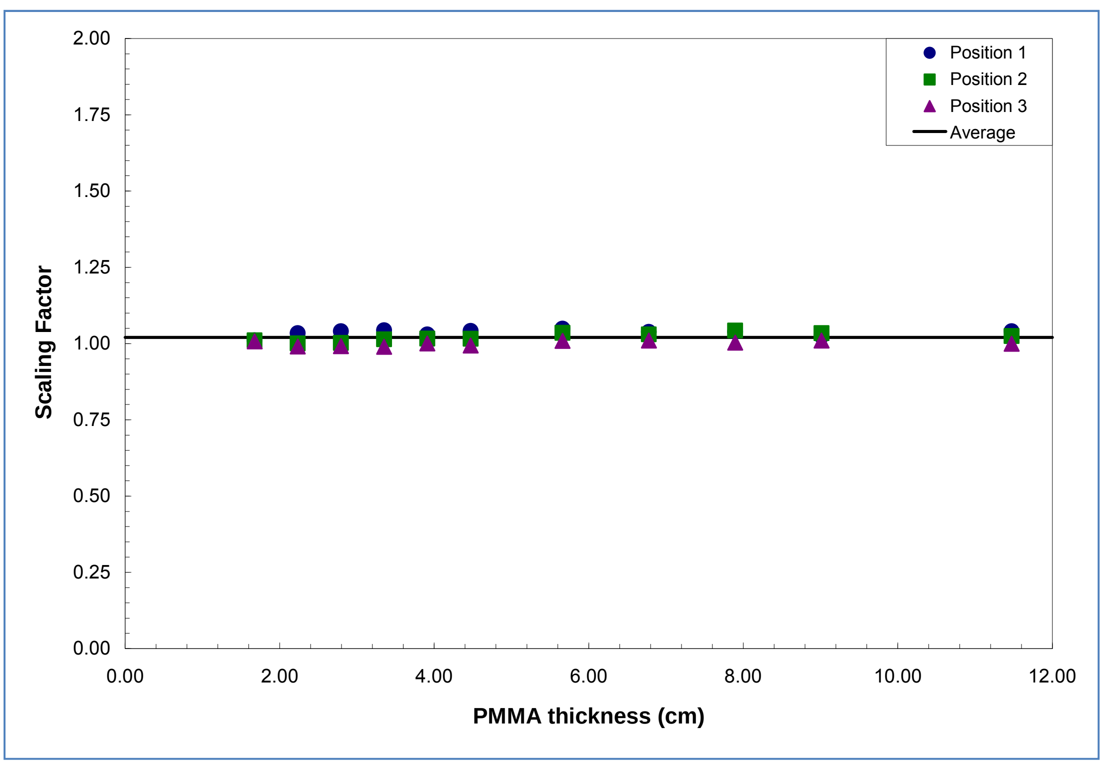

Figure 4.4 Na-22 Scaling Factor [7]

Table 4.10 Scaling factors for four point sources

Isotope	Scaling Factor
Ba-133	0.96
Co-60	0.98
Cs-137	1.08
Na-22	1.02
Average:	**1.01**

The average scaling factor value is also shown in Table 4.10. This value was used as the scaling factor for all fission product modeling.

Two MIRD phantoms were chosen for the anatomical model—the adipose male and child phantoms—to assess the detector response to internal contamination of fission products. The adipose male and child phantom Visual Editor [9] representations are shown in Figure 4.5 [9]. Previously, Georgia Tech modified the MIRD phantoms to include adipose tissue, esophageal tissue, and intestinal walls [7]. These phantoms were placed in the MCNP model of the detector oriented perpendicularly to the detector so that their anterior and posterior sides are facing the detector legs. The phantom orientation inside the detector is shown in Figure 4.6 [9] for the adipose male.

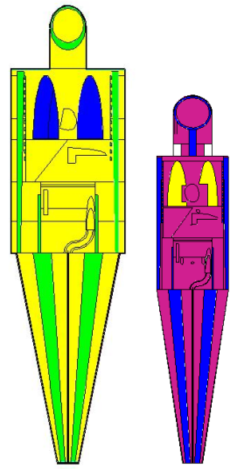

Figure 4.5 Adipose male (left) and child (right) MCNP phantom models [9]

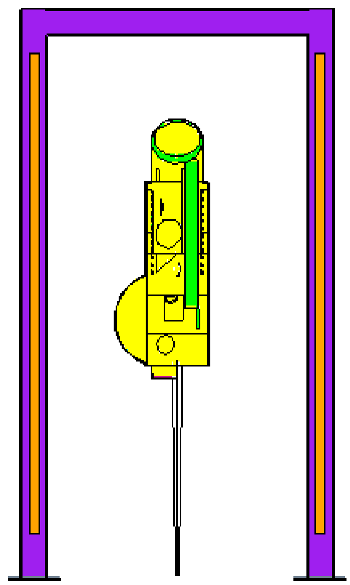

Figure 4.6 Adipose Male phantom inside TPM 903B MCNP detector model [9]

Inhaled radionuclides distribute in the body based on their chemical properties. For this reason, a radionuclide will concentrate in a specific set of organs. Because of the varying chemical properties of the fission products of concern, the organs that one fission product will migrate to are not necessarily the same as the organs that a different fission product will concentrate in. This is an important concept for the MCNP model. A unit point source with the energy and intensity distribution of the radionuclide of concern is placed in each organ of interest and the detector response is computed. In previous research, each MCNP input file was tailored to include only the organs that the radionuclide being investigated concentrated in. However, because of the large number of fission products of concern, a master input file was created to encompass all organs of interest for the entire list of fission products. The only difference between the 23 input files made for each phantom type is the energy and intensity spectrum of the unit volume source. The entire list of the organs of interest is as follows: lung, stomach, small intestines, body tissue (torso, head, legs, genitalia, breasts, abdomen), heart, colon (ascending, descending, transverse, sigmoid), bladder, liver, bone (clavicles, ribs, pelvis, spine, skull, legs, arms, scapulae), kidneys, testicles, thyroid, spleen, pancreas. The specific organ distribution of each fission product is addressed in the inclusion of biokinetic data.

A pulse-height tally was performed for each organ. The MCNP output is separated into user-specified energy bins, each including the number of particles detected by the MCNP modeled portal monitor within the specified energy range. The pulse-height spectrum for Nb-95 from a volume source located in the left lung of the adipose male phantom is displayed in Figure 4.7. The single photopeak at 0.7658 MeV corresponds to its gamma ray of energy 0.7658 MeV. The sharp drop off at 0.574 MeV corresponds to the Compton edge which is defined as the maximum energy that a photon can transfer to the detector via a single Compton scattering interaction. Energy deposited from multiple Compton scattering is seen above the Compton edge. The energy of the Compton edge can be computed using Equation 4.29, where E_γ is the photon energy and E_{CE} is the energy of the Compton edge.

$$E_{CE} = \frac{2E_\gamma^2}{0.511 MeV + 2E_\gamma} \qquad (4.29)$$

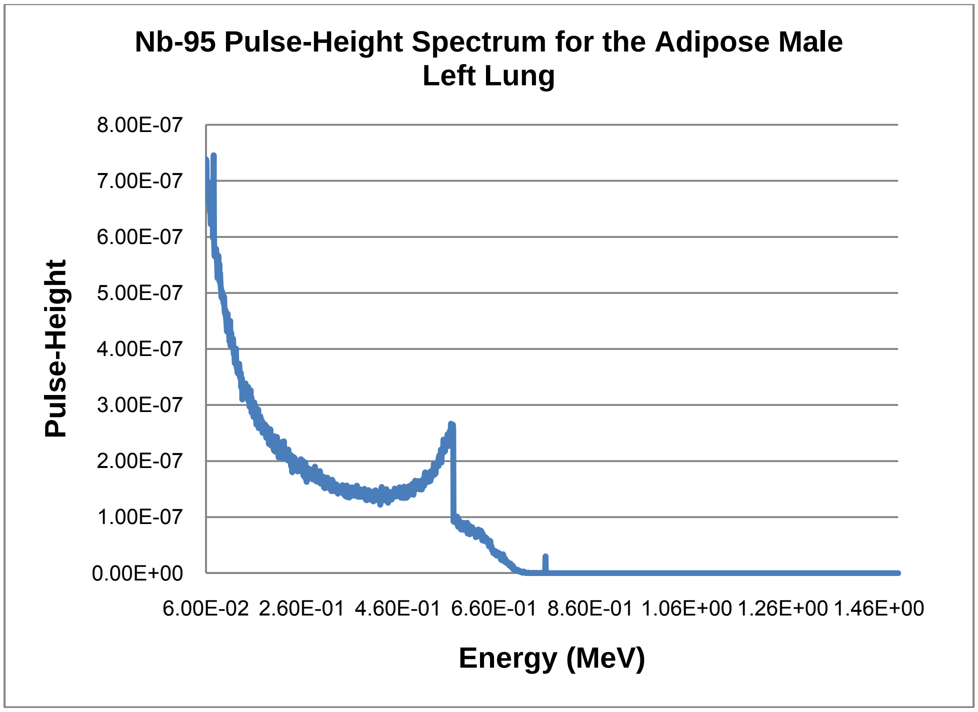

Figure 4.7 Nb-95 Pulse-height spectrum in the left lung for the adipose male

The detector response was summed over the energies above the detector cutoff of 60 keV for each organ. Each organ sum was then multiplied by the gamma emission rate for the corresponding fission product. This resulted in the count rate per becquerel of activity registered by the detector model for each source organ as described in Equation 4.30.

$$CPS/Bq = C_{O,F} * N_F \tag{4.30}$$

In Equation 4.30, $C_{O,F}$ represents the sum of the counts per source particle from all energy bins above 60 keV for organ, *O,* corresponding to fission product, *F*. N_F represents the gamma emission rate for fission product, *F*. The detector's response was determined for each fission product individually. This represents the detector response if each fission product distributed evenly throughout the source organs listed; however, biokinetic modeling is needed to determine the actual distributions of the fission products.

Biokinetic Model

The Dose and Risk Calculation software (DCAL), developed by the U.S. Environmental Protection Agency [3], was used to determine the internal distribution of each inhaled fission product. DCAL implements various user inputs to determine the fission product distribution in body organs as a function of time. The user inputs include the radionuclide of concern, the radionuclide's inhalation class, the individual's age, the type of exposure—occupational or environmental—and the radionuclide's Activity Median Aerodynamic Diameter (AMAD). [3] The list of inhalation classes used for each fission product is displayed in Table 4.11.

Table 4.11 Inhalation classes for fission products used in DCAL. [2]

Fission Products	Inhalation Class
Ba-137m, Ba-140, Cs-134, Cs-136, Cs-137, I-131,	Fast
Eu-154, Eu-156, La-140, Sb-125, Te-127m, Te-127, Te-129m, Te-129, Zr-95	Moderate
Ce-141, Ce-144, Nb-95, Nd-147, Pm-148m, Pm-148, Ru-103, Ru-106,	Slow

The DCAL input for the individual's age was chosen to be 25 years (9125 days) for both the adipose male and child analyses so that the counts computed would be conservative. Also, an environmental exposure was selected as opposed to an occupational exposure because the fission product inhalation is a concern for the public, not just radiation workers. The AMAD was assumed to be the default value of 1 micro-meter. DCAL incorporates these user inputs to determine the distribution of an intake of one bequerel of the radionuclide and its daughter products, within each body organ as a function of time post inhalation. This output is categorized by source region, i.e. lungs, thyroid, bladder, etc. DCAL accounts for the decay of the parent product to its progeny inside the body and the dose delivered by the progeny. The biokinetic data was computed for each fission product of concern in Group 1, excluding those daughter products that do not have initial concentrations of activity within the reactor core.

Combining MCNP Output with Biokinetic Data

Each organ tally generated in MCNP was combined with the corresponding DCAL calculated organ activity. The MCNP pulse height tally was multiplied by the organ activity content at each time post inhalation. This product represents the count rate registered by the detector model for each source organ in units of counts per second per bequerel of intake, (CPS/Bq), as a function of time post inhalation. Since a master input file using organs of concern for all fission products was created, the organ tallies in the MCNP calculations were eliminated if they did not have a corresponding DCAL computed organ activity.

The distribution of the blood within the body was determined using information from ICRP Publication 89 [4]. The output for the fission product in the blood for times post-inhalation is displayed in the DCAL output. DCAL does not account for the distribution of the blood within the body organs. To account for this, the percentage of the blood found in each organ was distributed to body organs according to ICRP Publication 89. Table 4.12 summarizes the percentages used for organs of interest in this research. For example, ICRP 89 states that 10% of the blood in circulation is located in the liver. Ten percent of the DCAL calculated fission product activity in the blood was added to the fission product activity in the liver. The portion of the activity in the blood after accounting for the blood volume in organs of interest was distributed evenly throughout the body tissue. [4]

Table 4.12 Distribution of blood in organs of interest according to ICRP 89 [4]

Organ	Blood Fraction
Right Lung	0.0525
Left Lung	0.0525
Stomach	0.01
Small Intestines	0.038
Ascending Colon	0.0055
Transverse Colon	0.0055
Descending Colon	0.0055
Sigmoid Colon	0.0055
Bladder	0.0002
Bone	0.02
Liver	0.1
Heart	0.1
Kidneys	0.02
Thyroid	0.0006
Sum	**0.4158**

For those fission products with gamma-emitting daughter products, a sum was performed of the MCNP simulation of the parent and its daughter(s) response(s). For those parent fission products with competing daughter products, the MCNP tallies for each organ were multiplied by the decay branching ratio [10] and then summed.

Once the MCNP data and DCAL data were combined, a sum was performed over the individual organ concentrations at each time post-inhalation to determine the total body counts for each time post-inhalation. Eventually, the total body count rate for each fission product was summed to determine the total count rate observed by the detector for an internal contamination due to a mixture of all the fission products of concern. In order to account for the relative distribution of the inhaled fission products, each fission product's total body count rate was multiplied by a weighting factor. The weighting factor is defined in Equation 4.31.

$$WF = A_F * RF_F \tag{4.31}$$

In Equation 4.31 describing the weighting factor, *WF*, *A* represents the activity of the fission product in the core, while *RF* represents the release fraction of fission product, F.

The average scaling factor, displayed in Table 4.10, was then used to convert the weighted total body counts as registered by the detector model to the weighted total body counts as expected from the portal monitor. The weighted counts per second per becquerel were determined by dividing the expected weighted counts per second per becquerel by this average scaling factor. Then, the dose coefficient for each fission product, in units of milli-sievert per becquerel (mSv/Bq), was weighted based on the released activity of the fission product. Each weighted total body count rate per becquerel was then summed for each Group 1 fission product. This summation was then divided by the weighted dose coefficient in mSv/Bq. This is then multiplied by 250 to convert to CPS per 250 mSv. This quantity of 250 mSv represents the value defined as the threshold for further testing [14]. The final result is the total body count rate per 250 mSv from Group 1 fission products. This computation is displayed in Equation 4.32.

$$\frac{CPS}{250mSv} = 250 * \left(\sum_F \left(\frac{CPS_F * WF_F}{SF_{avg}} \right) \right) * \left[\frac{1}{\sum_F WF_F * DC_F} \right] \tag{4.32}$$

CPS_F represents the weighted total body count rate in counts per second for fission product, F; SF_{avg}, represents the average scaling factor; WF_F represents the previously defined weighting factor, and DC_F is the dose coefficient in units of mSv/Bq. For the derivation of Equation 4.32 see Appendix D. Because the dose coefficient takes into account all types of radiation, all forms of radiation emitted by the fission products (and their progeny) in Group 1 have been accounted for.

The result of Equation 4.32 is equivalent to the total body count rate per 250 mSv expected to be registered by the portal monitor TPM-903B for the gamma-emitting fission products. The total body count rates for each specified time post fission product inhalation corresponding to a committed effective dose of 250 mSv for just Group 1 fission products are displayed in Table 4.13 and Table 4.14, for the adipose male and child, respectively.

Table 4.13 Total body count rate per 250 mSv for the adipose male only from Group 1 fission products

		Total Body Count
		cps per 250 mSv
Days following exposure	0.25	1.60E+06
	0.5	1.51E+06
	1	1.36E+06
	2	1.19E+06
	3	1.07E+06
	4	9.90E+05
	5	9.31E+05
	6	8.86E+05
	7	8.50E+05
	8	8.22E+05
	9	7.98E+05
	10	7.77E+05
	20	6.43E+05
	30	5.60E+05

Table 4.14 Total body count rate per 250 mSv for the child only from Group 1 fission products

		Total Body Count
		cps per 250 mSv
Days following exposure	0.25	7.96E+05
	0.5	7.47E+05
	1	6.83E+05
	2	6.06E+05
	3	5.56E+05
	4	5.20E+05
	5	4.95E+05
	6	4.75E+05
	7	4.60E+05
	8	4.47E+05
	9	4.36E+05
	10	4.27E+05
	20	3.64E+05
	30	3.23E+05

Determination of Group 2 Fission Product Contribution

Next, it was important to consider the fission product dose contributions for those fission products in Group 2. The radiation emitted by these fission products will not be registered by the detector. Because the other forms of radiation emitted by Group 2 fission products will still be contributing to the committed effective dose of 250 mSv, these contributions must be included. First, all fission products in Group 2 were analyzed to determine the kinds of radiation emitted. All members of Group 2 emit beta particles. In order to account for the beta radiation, a ratio of the dose coefficients—weighted based on released isotopic abundance—was computed. This was a ratio of the weighted dose coefficients for fission products in Group 1 divided by the sum of the weighted dose coefficients for fission products in both Group 1 and Group 2. This ratio was computed for both the adipose male and the child. The ratio is shown in Equation 4.33.

$$Ratio = \frac{\sum_F DC_F^1 * A_F^1 * RF_F^1}{\sum_F DC_F^1 * A_F^1 * RF_F^1 + \sum_F DC_F^2 * A_F^2 * RF_F^2} \quad (4.33)$$

In Equation 4.33, DC_F represents the dose coefficients, RF_F represents the corresponding release fraction, and A_F represents the core activity of the fission product, with the superscripts denoting the group of the fission product. For the adipose male, the ratio was computed to be 0.908. The ratio was computed as 0.913 for the child. These ratios were multiplied by the total body count rates per 250 mSv determined for the gamma-emitting fission products for the corresponding adipose male or child analysis. The final result is a trigger level, in counts per second, that corresponds to a committed effected dose of 250 mSv for all contributing types of radiation.

5. RESULTS

The trigger levels corresponding to a committed effective dose of 250 mSv over times post inhalation are displayed in Table 5.1 and Table 5.2 for the adipose male and child phantoms, respectively.

Table 5.1 Trigger levels for the adipose male

		Total Body Count
		cps per 250 mSv
Days following exposure	0.25	1.46E+06
	0.5	1.37E+06
	1	1.24E+06
	2	1.08E+06
	3	9.73E+05
	4	8.99E+05
	5	8.45E+05
	6	8.04E+05
	7	7.72E+05
	8	7.46E+05
	9	7.25E+05
	10	7.06E+05
	20	5.84E+05
	30	5.09E+05

Table 5.2 Trigger levels for the child

		Total Body Count
Days following exposure		cps per 250 mSv
	0.25	7.26E+05
	0.5	6.82E+05
	1	6.23E+05
	2	5.53E+05
	3	5.07E+05
	4	4.75E+05
	5	4.52E+05
	6	4.34E+05
	7	4.20E+05
	8	4.08E+05
	9	3.98E+05
	10	3.90E+05
	20	3.32E+05
	30	2.95E+05

Graphical representations of these trigger levels are displayed in Figure 5.1 and Figure 5.2 for the adipose male and child, respectively. In Figure 5.1 and Figure 5.2, the blue lines represent the lower limit of detection as calculated based on the background observed during experimental data acquisition [7]. The lower limit of detection was calculated to be 314 CPS based on the determined background count rate for the measurement location used at Georgia Tech. A composite graph of the weighted count rate for all fission products and the weighted count rates for individual fission products in Group 1 with the greatest contributors to the count rate is shown in Figure 5.1. This figure is only to show the relationships between the fission product mixture count rate and individual contributors to the count rate. The actual counts in this figure are of no real significance. The greatest Group 1 contributors to the dose are I-131, Ba-140, Cs-134, Cs-136, and Cs-137/Ba-137m. Individual trigger levels for an inhalation of purely the radionuclide listed are located in Appendix B. Detailed procedure sheets can be found in Appendix A.

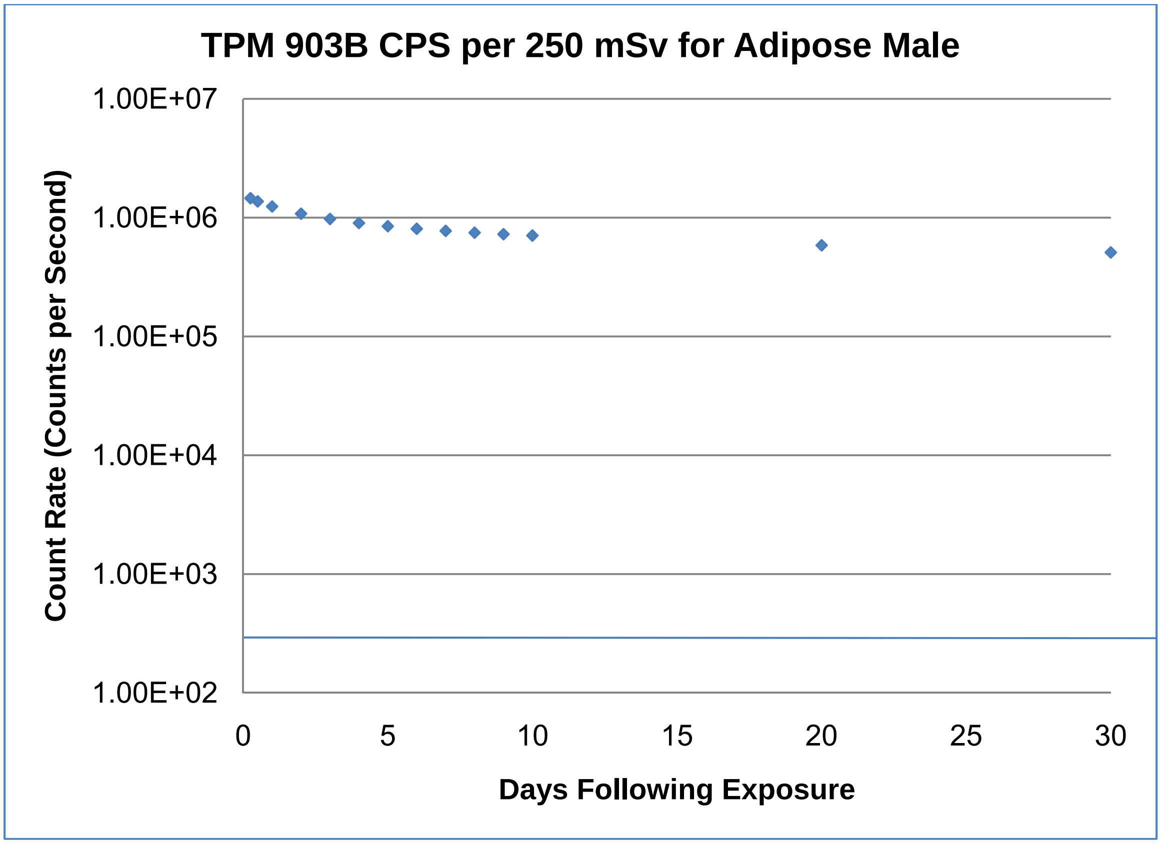

Figure 5.1 Adipose male trigger levels as a function of time post inhalation

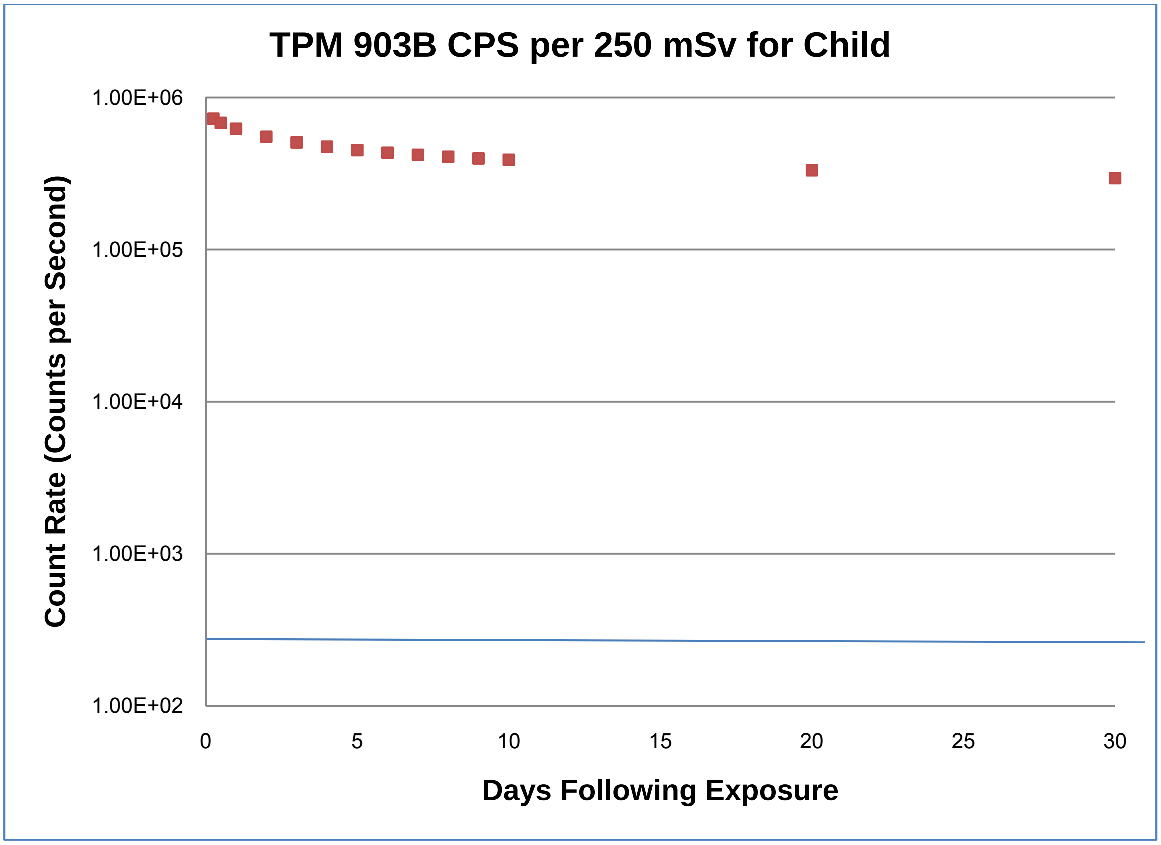

Figure 5.2 Child trigger levels as a function of time post inhalation

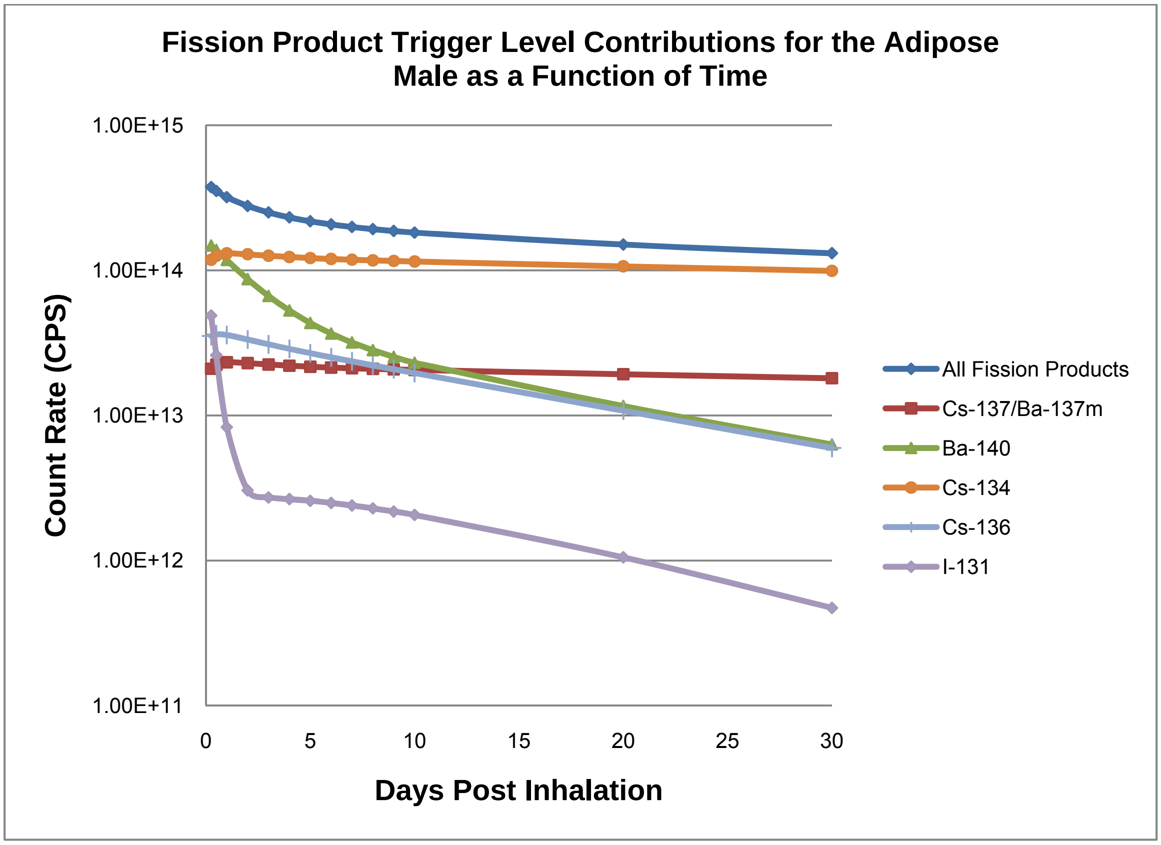

Figure 5.3 Individual fission product weighted CPS compared to mixture CPS

6. DISCUSSION

When analyzing the count rates calculated for a committed effective dose of 250 mSv from fission product inhalation, there are a few things to discuss. The count rate for the child is lower than the count rate for the adipose male when comparing data at specific times. The blue lines on Figure 5.1 and Figure 5.2 represent the lower limit of detection above background found for the experimental background level measured during MCNP model validation [7], determined previously as 314 CPS [7] for the Georgia Tech measurement location. The count rates are much greater than this lower limit of detection for times of up to 30 days post inhalation at the background level at Georgia Tech.

As displayed in Figure 5.3, the top five gamma-emitting dose contributors are I-131, Ba-140/La-140, Cs-134, Cs-136, and Cs-137/Ba-137m. These five fission products have large toxicity indices. Their large toxicity indices coupled with the relatively high energies and intensities of emitted gamma rays explains why they have the largest calculated weighted count rates.

There is some uncertainty regarding the maximum count rate magnitude that the detector can handle. No testing of the TPM 903B portal monitor under high count rate conditions was performed. According to the manufacturer of the TPM 903B, the detector may begin to have problems representing count rates accurately at count rates much higher than 30,000 CPS [17]. This is because of the detector dead time. The detector display can report count rates up to 999,999 CPS, but there is no certainty whether these count rates are accurate. The count rates for the adipose male are below 999,999 after three days post inhalation, but are never under 30,000 CPS for up to 30 days post inhalation. For the child, all count rates are below 999,999 CPS, but are never below 30,000 CPS for up to 30 days post inhalation. The count rates computed in this research may be too high to be accurately counted for the committed effective dose of 250 mSv. The inaccuracies of the higher count rates are due mostly to the dead time of the detector which leads to pulse pileup. The results of this research are scalable to a committed effective dose different from 250 mSv. For a count rate of 30,000 CPS based on these results, a committed effective dose of 6 mSv would be represented for the adipose male, and 12 mSv for the child. A count rate of 999,999 CPS would be equivalent to 200 mSv committed effective dose for the adipose male and 401 mSv for the child. There are uncertainties stemming from the detectors ability to represent the rates actually counted associated with the count rates above a committed effective dose of 6 mSv for the adipose male and 12 mSv for the child.

7. CONCLUSION AND FUTURE WORK

The TPM 903B portal monitor was determined to be a limited tool for triaging members of the public exposed to an ex-vessel release of fission products for a committed effective dose of 250 mSv. The count rates for these trigger levels are far above the lower limit of detection observed in Georgia Tech's lab for post inhalation times of up to 30 days but are too high to be accurately represented by the detector.

While this research was performed for the two phantom types that resulted in the most conservative results in previous work [7], this analysis could be performed for other phantom types to include the reference male, reference female, adipose female, and post-menopausal adipose female. The methodology could be applied to the remaining phantom types, or a relational factor between the investigated phantom types and the remaining phantom types could be determined. The relational factor could be determined using similar research endeavors to compare the count rates for different phantom types. Additionally, this methodology could be applied to voxel phantoms, which in some cases may provide more accurate representations of human populations.

Another counting method, whether using a different, less sensitive portal monitor, or a different geometrical set up between the individual being analyzed and the actual detector, should be assessed. The two legs of the detector can be separated to create more distance between the individual being counted and the detector. This will decrease the efficiency of the detector and could create a decrease in count rate to within 30,000 CPS. An MCNP calculation with an increase of 10 feet of spacing between the detector legs resulted in a 12% decrease in the count rate for purely inhaled

Cs-137 at the 250 mSv threshold. The count rates were still in the range of 200,000 CPS.

Only one nuclear reactor accident scenario was investigated in this research; future work could include applying this methodology to many different accident scenarios involving various reactor types. Additionally, quantification of the uncertainty associated with the results of this research could be beneficial.

APPENDIX A:

DETAILED PROCEDURE SHEETS

(Modified from Reference 7)

TPM-903B (Adipose Male with Inhaled Fission Products)
Basic Operation [7]

- “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.” [7]

Trigger Levels if Inhaled

Time (days)	Fission Products (cps)
0.25	1.46 E+06
0.5	1.37 E+06
1	1.24 E+06
2	1.08 E+06
3	9.73 E+05
4	8.99 E+05
5	8.45 E+05
6	8.04 E+05
7	7.72 E+05
10	7.06E+05
20	5.84E+05
30	5.09E+05

TPM-903B (Child with Inhaled Fission Products)
Basic Operation [7]

- "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." [7]

Trigger Levels if Inhaled

Time (days)	Fission Products (cps)
0.25	7.26E+05
0.5	6.82E+05
1	6.23E+05
2	5.53E+05
3	5.07E+05
4	4.75E+05
5	4.52E+05
6	4.34E+05
7	4.20E+05
10	3.90E+05
20	3.32E+05
30	2.95E+05

APPENDIX B:

SAMPLE MCNP INPUT FILES

Adipose Male MCNP Input File using Ba-140

```
Adi Male with Ba-140
C Cell Card
1     1 -.001293    -1 (603:-609:602) (-602:601:35) (600:-35) 604 605
                    (609:-612:610) (609:-612:611) (606:4:-609)
                    (-607:609:-43:44:4:-608) 507 508 510 511 512 #600
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
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
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     45 -37 43 -44 -4 46 39 40 72 73 #700$ 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 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    3 -0.9869     -107 7 -4 #700                      $ breast
```

```
42    3 -0.9869     -108 7 -4 #700                      $ breast
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     -103 712 -37                        $ leg bone
51    4 -1.4862     -104 712 -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
Interior
67    3 -0.9869     -143 7 -4 #700                      $ Abdoman-
Adipose
600   0             -600 34 35: -35 -601 602 33: &
                    -6 37 606 605 604 7 -603 507 508 510 511 512 : &
                     108 -605 7 : &
                    107 -604 7: 143 -606 7: &
                    -611 -607 38 39 40 : -602 6 33 -603: &
                    -610 611 -607 38 39: &
                    -38 612 -610 : -38 612 -611 : &
$ Feet
                    -37 609 -603 4 39 40: -37 609 -4 -603 40 -43: &
                    -37 609 -4 -603 39 44: -37 609 -603 43 -44 -46: &
                    -609 607 4 -611 39 40 : -609 607 4 -610 39 611: &
                    -609 45 -43 -611 40: -609 45 44 -610 39: &
                    -609 45 43 -44 608 -46: -45 607 -4 608 39 &
                    40 43 -44: -4 -45 607 -43 -611 40: &
                    -4 -45 607 44 -610 39
700   5 -1.04       -34 102 35: -35 6 701 -33: -6 702 -7 701: &
                    -6 37 -7 703 706 704 705: -143 706 7 -87: &
                    -108 705 7 -87: -37 38 -39 710: -37 38 -40 711: &
                    -107 704 7 -87: -37 45 46 &
                    -708 -44 43: -44 43 39 40 -707 45 708 -4: &
                    -712 38 -39 : 38 -712 -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 +++++++++++++++++++++
68    0             1

c Surface Card
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
702   PZ  69.8
602   PZ  70.2
7     SQ  1 3.3359 0 0 0 0 -488.41 0 0 0
703   SQ 141.6102597 479.61 0 0 0 0 -67917.69667 0 0 0
603   SQ 151.2902685 497.29 0 0 0 0 -75235.1376 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 96.04 46.24 0 0 0 0 -4440.8896 0 0 0
601  SQ 104.04 51.84 0 0 0 0 -5393.4336 0 0 0
34    SQ  7225 3540.25 4900 0 0 0 -354025 0 0 85.5
700  SQ 6616.1956 3185.4736 4440.8896 0 0 0 -305932.8845 0 0 85.5
600  SQ 7874.7876 3923.7696 5393.4336 0 0 0 -408228.9892 0 0 85.5
35    PZ  85.5
36    PZ  94
37    PZ  0
609   PZ -0.2
38    PZ  -80
612   PZ -80.2
712   PZ -79.8
39    GQ  5 5 0 0 0 -1 -100 0 0 0
710 601 GQ  5 5 0 0 0 -1 -98 0 0 0
610 600 GQ  5 5 0 0 0 -1 -102 0 0 0
40    GQ  5 5 0 0 0 1 100 0 0 0
711 600 GQ  5 5 0 0 0 1 98 0 0 0
611 601 GQ 5 5 0 0 0 1 102 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
707   pz  -4.6
607  PZ -5.0
46    P   0 10 1 -100
708 702 P   0 10 1 -100
608 602 P   0 10 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  -22.1
69    PX  22.1
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  0.5624 0.62316 1.60473 0 0 0 -56.24 -7.5 -5 50
704    SQ 2829.804157 3142.274588 8306.470934 0 0 0 -271774.3912 -7.5 -5
50
604    SQ 3524.072262 3896.755141 9789.091211 0 0 0 -366644.4781 -7.5 -5
50
108    SQ  0.5624 0.62316 1.60473 0 0 0 -56.24 7.5 -5 50
705    SQ 2829.804157 3142.274588 8306.470934 0 0 0 -271774.3912 7.5 -5
50
605    SQ 3524.072262 3896.755141 9789.091211 0 0 0 -366644.4781 7.5 -5
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
C      Colon Wall
138   SQ 1 1 0 0 0 0 -3.209 -8.5 -2.36 0
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
142   TY 3 0 0 3 0.91 0.91
C      Abdomen Adipose
143   SQ 1 1.06575 1 0 0 0 -308 0 -7.1 17.55
706   SQ 84959.40437 90613.05755 84959.40437 0 0 0 -25574482.32 0 -7.1
17.55
606   SQ 93206.81855 99262.78565 93206.81855 0 0 0 -29365737.6 0 -7.1
17.55
c +++++++++++++++++++
c   BC408 Volume
c +++++++++++++++++++
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
c +++++++++++++++++
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
c ++++++++++++++++++++++++++++++++
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
c +++++++++++++++++++++++
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
c +++++++++++++++++++++
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
```

```
c +++++++++++++++++++++
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 Card
tr600 -0.2
tr601 0.2
tr602 0 -0.2009
tr702 0 0.2009
tr900 0 0 -64 0 1 0 1 0 0 0 0 1
c VOL   0 9.90E3 5.38E4 2.70E4 1.40E4 5.75E4 6.06E4 5.50E4 3.43E2
c      3.43E2 3.42E2 3.42E2 3.39E2 3.39E2 3.38E2 3.39E2 3.37E2
c       3.36E2 3.34E2 3.35E2 1.09E4 5.01E4 5.00E4 9.88E3 8.08E2
c      8.25E3 1.09E4 3.49E3 2.39E3 5.47E2 4.20E2 7.22E2 5.23E2
c      1.11E2 1.12E2 1.72E2 3.63E3 5.17E3 6.31E3 1.07E3 1.08E3
c      8.50E2 8.55E2 1.49E3 1.05E3 3.59E2 1.45E2 4.78E3 8.25E3
c      8.23E3 5.81E1 5.71E1 2.81E3 2.81E3 5.81E2 5.90E2 1.56E2
c      1.56E2 1.10E1 1.11E1 2.32E2 5.78E2 7.58E2 6.15E2 2.16E2
c      4.10E4 1.91E4 1.89E4 1.6059E4 1.6059E4 1.6059E4 23.9241 9.2379
c      53.9171 10.2532 28.1078 23.9241 9.2379 53.9171 10.2532 28.1078
c      23.9241 9.2379 53.9171 10.2532 28.1078 0
IMP:P 1 72R 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 0.537274 0.162609 0.30485 0.423722 0.437575
SP1 0.2439  0.0621   0.043   0.0315   0.0193
C Left Lung, Right Lung, Stomach, Small Int, Body (3, 4,
C 5, 6, 7, 8, 21, 22, 23, 25, 41, 42, 67), Heart,
C Ascending Colon, Sigmoid Colon, Transvers Colon,
C Descending Colon, Bladder, Liver, Left Clavicle,
C Right Clavicle, Ribs (9, 10, 11, 12, 13, 14, 15, 16, 17,
C 18, 19, 20), Pelvis, Spine, Skull, Left Leg, Right Leg,
C Left Arm, Right Arm, Left Scapulae, Right Scapulae,
C Left Kidney, Right Kidney, Left Testicle, Right Testicle,
C Thyroid, Spleen, Pancreas
SI2 L 2 24 29 40 3 4 5 6 7 8 21 22 23 25 41 42 67 28
      30 31 32 33 45 27 58 59 9 10 11 12 13 14 15 16
      17 18 19 20 38 39 49 50 51 54 55 56 57 43 44 35
      36 37 46 47
SP2 D 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 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 28 29 30 31 32 33 34 35 36 37 38 39 40 41
      42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58
      59 60
DS4 L 8.5 0 43.4   -8.5 0 43.4   8 -4 35   0 -3.8 11.3
      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  -7.5 -5 50   7.5 -5 50   0 -7.1 17.55
      -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 26.9   2.4 -5.45 67.9
     -2.4 -5.45 67.9   0 0 43.4   0 0 35   0 0 37.8   0 0 40.6
      0 0 46.2   0 0 49   0 0 51.8   0 0 54.6   0 0 57.4
      0 0 60.2   0 0 63   0 0 65.8   0 0 -0.1   0 5.5 21.9   0 0 85.5
```

```
      10.55 0 -80.1   -10.55 0 -80.1   18.4 0 -0.1   -18.4 0 -0.1
      13.5 6.5 50.8   -13.5 6.5 50.8   6 6 32.5   -6 6 32.5
      1.3 -8 -2.3   -1.3 -8 -2.3   0 -6 69.9   11 3 37   -0.1 0 37
DS5 S 80 81 0 82 83 84 85 86 87 88 89 90 91 92 0 0 0 0
      93 94 95 96 0 97 98 99 100 101 102 103 104 105 106
      107 108 109 110 111 112 113 0 114 115 116 117 118
      119 0 0 0 0 120 0 121
DS6 L 0 0 1   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   0 0 0
      0 0 0   0 0 0   0 0 0   0 0 1   0 0 1
      1 0 0   0 0 1   0 0 0   0 0 1   1 0 0
      -1 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   0 0 1   0 0 1   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 0   0 0 0   0 0 0
      0 0 0   0 0 1   0 0 0   1 0 0
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 21.2
SP11 -21 1
SI12 0 21.3
SP12 -21 1
SI13 0 21.3
SP13 -21 1
SI14 0 21.3
SP14 -21 1
SI15 0 21.3
SP15 -21 1
SI16 0 21.3
SP16 -21 1
SI17 0 10.1
SP17 -21 1
SI18 0 11
SP18 -21 1
SI19 0 11
SP19 -21 1
SI20 0 8.1
SP20 -21 1
SI21 0 10.1
SP21 -21 2
SI22 0 10.1
SP22 -21 2
SI23 0 17.6
SP23 -21 2
SI24 0 8.2
SP24 -21 2
SI25 0 2.6
SP25 -21 1
SI26 0 7.1
```

```
SP26 -21 1
SI27 0 3.85
SP27 -21 1
SI28 0 4
SP28 -21 1
SI29 0 5.2
SP29 -21 2
SI30 0 16.5
SP30 -21 1
SI31 0 4.3
SP31 -21 1
SI32 0 4.3
SP32 -21 1
SI33 0 17.1
SP33 -21 1
SI34 0 17.1
SP34 -21 1
SI35 0 17.1
SP35 -21 1
SI36 0 17.1
SP36 -21 1
SI37 0 17.1
SP37 -21 1
SI38 0 17.1
SP38 -21 1
SI39 0 17.1
SP39 -21 1
SI40 0 17.1
SP40 -21 1
SI41 0 17.1
SP41 -21 1
SI42 0 17.1
SP42 -21 1
SI43 0 17.1
SP43 -21 1
SI44 0 17.1
SP44 -21 1
SI45 0 12
SP45 -21 1
SI46 0 2.6
SP46 -21 1
SI47 0 9.9
SP47 -21 2
SI48 0 9.6
SP48 -21 1
SI49 0 9.6
SP49 -21 1
SI50 0 2.5
SP50 -21 1
SI51 0 2.5
SP51 -21 1
SI52 0 4.3
SP52 -21 1
SI53 0 4.3
SP53 -21 1
SI54 0 5.6
SP54 -21 2
```

SI55 0 5.6
SP55 -21 2
SI56 0 1.6
SP56 -21 2
SI57 0 1.6
SP57 -21 2
SI58 0 2.2
SP58 -21 1
SI59 0 6.1
SP59 -21 2
SI60 0 3.1
SP60 -21 1
SI80 0 24.6
SP80 -21 0
SI81 0 24.6
SP81 -21 0
SI82 0 10.2
SP82 -21 0
SI83 0 27.2
SP83 -21 0
SI84 0 16.6
SP84 -21 0
SI85 0 8.1
SP85 -21 0
SI86 0 16.2
SP86 -21 0
SI87 0 15.2
SP87 -21 0
SI88 0 12.2
SP88 -21 0
SI89 0 24.2
SP89 -21 0
SI90 0 80.2
SP90 -21 0
SI91 0 80.2
SP91 -21 0
SI92 0 5
SP92 -21 0
SI93 0 9.75
SP93 -21 0
SI94 0 8.92
SP94 -21 0
SI95 0 21.2
SP95 -21 0
SI96 0 16
SP96 -21 0
SI97 0 16.2
SP97 -21 0
SI98 0 13.8
SP98 -21 0
SI99 0 13.8
SP99 -21 0
SI100 0 1.6
SP100 -21 0
SI101 0 1.6
SP101 -21 0
SI102 0 1.6

```
SP102 -21 0
SI103 0 1.6
SP103 -21 0
SI104 0 1.6
SP104 -21 0
SI105 0 1.6
SP105 -21 0
SI106 0 1.6
SP106 -21 0
SI107 0 1.6
SP107 -21 0
SI108 0 1.6
SP108 -21 0
SI109 0 1.6
SP109 -21 0
SI110 0 1.6
SP110 -21 0
SI111 0 1.6
SP111 -21 0
SI112 0 22.1
SP112 -21 0
SI113 0 56.7
SP113 -21 0
SI114 0 80.2
SP114 -21 0
SI115 0 80.2
SP115 -21 0
SI116 0 69.2
SP116 -21 0
SI117 0 69.2
SP117 -21 0
SI118 0 16.6
SP118 -21 0
SI119 0 16.6
SP119 -21 0
SI120 0 5.2
SP120 -21 0
SI121 0 15.1
SP121 -21 0
C
C Tally Cards
F8:P 501
E8 0 1e-8 0.005 2000i 1.5
FT8 SCX 2
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 Detectors 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
NPS   4E9
RAND GEN=2 SEED=1561615651
PHYS:P 4J 1
PRINT
MODE P
```

Child MCNP Input File using Ce-141

```
TPM
C Child with Ce-141
c +++++++++++++++++++++++++++++++++++++++++
c
c    File Prepared by Body Builder
c    CopyRight 1996-2004, White Rock Science
c
c    This input file is for the use of
c    BodyBuilder License holder only.
c    Distribution is Prohibited.
c
c +++++++++++++++++++++++++++++++++++++++++
c
c    Co-60 Internal Source
c
c ++++++++++++++++++++++++++++++++++++++++++++++
c           CELLS
c ++++++++++++++++++++++++++++++++++++++++++++++
c SkeletonVolume = 3321.900000, skel_vol = 3307.142857
c
c         LEG BONES
50      2 -1.40    -4 36 -51
                 vol=  625.00
c
51      2 -1.40    -4 36 -52
                 vol=  625.00
c
c         ARM BONES
70     2 -1.40     4 -73 (-71 : -72)
                 vol=   404.00
c
c         PELVIS
90     2 -1.40     91 -92 93 4 -101 (95 : -94)
                 vol=   258.00
c
c         SPINE
100    2 -1.40   -100 -103 101
101    2 -1.40   -100 -8   103
102    2 -1.40   -105 -102 8
c               Total Spine vol=   411.00
c
c         SKULL & FACE
110    2 -1.40   (111 -110):(121 -120 122 -1 -123 110)
                 vol=   595.00
c
c         RIBS
130    2 -1.40    132 -131 ((134 -133):(136 -135):(138 -137):(74 -139):
                 (76 -75):(78 -77):(80 -79):(82 -81):(84 -83):
                 (86 -85):(88 -87):(98 -89))
                 vol=   295.00
c
c         CLAVICLES
140    2 -1.40    -140 ((141 -143):(-142 144))
                 vol=    23.20
```

```
c
c         SCAPULAE
150    2 -1.40     131 -156 154 -155 ((150 -152):(-151 153))
                 vol=    85.70
c
c         ADRENALS
160     1 -1.04     162 (-160:-161)
                  vol=     6.94
c
c         BRAIN
180     1 -1.04    -111
                 vol=  1310.00
c
c         GALL BLADDER
200   1 -1.04       (-202 -200):(202 -201 -203)
                 vol=    44.00
c
c         OESOPHAGUS
212   1 -1.04       (213 -212 322 -8 100) :
                    (-216 217 -218 210 350 100)
                 vol=   18.70
c           Air in Upper Oesophagus
213   4 -0.001293   -213 322 -8
c
c         STOMACH
210   1 -1.04       -210
                 vol=   209.80
c
c         SMALL INTESTINE
220   1 -1.04       -91 221 -222 223 -7
C                exclude         Ascending Colon
                        (232:230:-223)
c                exclude         Transverse Colon
                        (241 : -242 : -221 : -232 : 243)
c                exclude         Transverse Colon Wall
                        (241 : -242 : -221 : -232 : 240)
c                exclude         Descending Colon
                        (232:250:-223)
                  vol=   447.00
c
c         ASCENDING COLON INTERIOR
230   1 -1.04       -233 231 -232
                  vol=61.776
c
c         ASCENDING COLON Wall
231   1 -1.04       233 -230 231 -232
                  vol=17.824
c
c         TRANSVERSE COLON INTERIOR
240   1 -1.04       -243 -241 242
            vol=80.712
c
c         TRANSVERSE COLON WALL
241   1 -1.04       243 -240 -241 242
            vol=23.288
c
c         DESCENDING COLON INTERIOR
```

```
250   1 -1.04       -252 251 -232 -91
             vol=61.275
c
c        DESCENDING COLON WALL
251   1 -1.04       -250 252 251 -232 -91
             vol=20.425
c
c        SIGMOID COLON
280   1 -1.04       (-283 282 -251):(-284 -282 4)
             vol=33.8
c
c        SIGMOID COLON WALL
281   1 -1.04       (-280 283 282 -251):(-281 284 -282 4)
             vol=11.2
c
c        HEART
290     1 -1.04     (290((-291 -292):(291 -293))):
                    (-290((-291 -295):(291 -294)))
                 vol=   355.00
c
c        KIDNEYS
310     1 -1.04     (-310 312 -162):(-311 -313 -162)
                  vol=   166.00
c
c        LIVER
320     1 -1.04     -320 -321 7 -322 -132
                   vol=   853.00
c
c        LUNGS
330     3 -0.296   332 ((-331 (-335:336:334:-333)):
                        (-330 ( 339:338:337)))
                 vol=  1530.00
c moritz st c 330 s
c
c        OVARIES
340    1 -1.04       -340:-341
             vol=    3.01
c
c        PANCREAS
350   1 -1.04       -350 351 (352:-312)
                 vol=    28.90
c
c        SPLEEN
360   1 -1.04       -360
                 vol=   74.40
c
c        TESTICLES
370   1 -1.04       -370:-371
             vol=    1.82
c
c        THYMUS
380     1 -1.04  -380
                vol=    30.20
c
c        THYROID
390     1 -1.04    -390 391 -392 -393 8
                 vol=     7.62
```

```
c
c         URINARY BLADDER
410   1 -1.04       -410
             vol=  120.90
c
c             UTERUS
420   1 -1.04       -420 421
             vol=    4.00
c
c         PENIS & SCROTUM
40     1 -1.04       -1 -4 47 -45 49 -48 37 38 31 32
c                exclude         Testicles
                  370 371
             vol=   34.38
c
c         SKIN
c
c              Head & Neck Skin
22    1 -1.04       ((-21 22 9):(-20 23 -9 12))
28    1 -1.04       28 -27 8 -12
             vol=  127.00
c            (Above Volume for Head + Neck Skin Combined
c
c           Trunk Skin
17    1 -1.04       (-8 18 20 -10)
                   : (4 -18 -10 11)
             vol=  385.00
c
c         Penis & Scrotum Skin
41     1 -1.04       -1 -4  41 -42 43 -44 31 32 #40
c                exclude         Testicles
                  370 371
             vol=    4.05
c        Legs Skin
34    1 -1.04      (-4 36 34 35 (-31 : -32)) : &
                   (33 -36 (-31 : -32))
             vol=  363.00
c
c            HEAD
c
20    1 -1.04       ((-22 9):(-23 -9 12))
c                exclude         Skull & Brain
                        110
c                exclude         Face Bones
                        (-121:120:-122:1:123:-110)
c                exclude         Spine
                        (105:-8:102)
c                exclude         Thyroid
                        (390:-391:392:393:-8)
c
c            NECK
c
27    1 -1.04       -28 8 -12
c                exclude         Spine
                         105
c                exclude         Thyroid
                        (390:-391:392:393:-8)
```

```
c
c         OUTER TRUNK---ARMS & SCAPULAE
c
10    1 -1.04       4 131 -18 -11
c                exclude         Scapulae
                       (-131:156:-150:152:-154:155)
                       (-131:156:151:-153:-154:155)
c                exclude         Arm Bones
                       (-4:71:73) (-4:72:73)
c                exclude           Uterus
                       (420:-421)
c
c         UPPER TRUNK---ABOVE RIBS
c
11    1 -1.04   ((-18 -131 133) : (-8 18 -20 -10))
c                exclude         Spine
                      (105:102:-8)(100:8:-133)
c                exclude         Clavicles
                      (140:-141:143) (140:142:-144)
c                exclude         Upper Lungs
                       (-133:330) (-133:331)
c                exclude          Thymus
                       380
c                exclude          Esophagus
                      #212 #213
c
c
c         UPPER RIB CAGE
c
12    1 -1.04       -131 132 79 -133
c                exclude         Ribs 1-9
                 (131:-132:133:-134) (131:-132:135:-136) (131:-
132:137:-138)
                 (131:-132:139:-74) (131:-132:75:-76) (131:-132:77:-
78)
c
c
c         LOWER RIB CAGE
c
13    1 -1.04       -131 132 -79 98
c                exclude         Ribs 10-12
                 (131:-132:85:-86) (131:-132:87:-88) (131:-132:89:-98)
                 (131:-132:79:-80) (131:-132:81:-82) (131:-132:83:-84)
c
c
c         HIGH CHEST ORGANS
c
14    1 -1.04       -132 -133 332
c                exclude          Spine
                       (100:133:-332)
c                exclude          Heart
                       #290
c                exclude          Lungs
                       (330:133:-332:(-339 -338 -337))
                       (331:133:-332:(335 -336 -334 333))
c                exclude          Thymus
                       380
```

```
c                exclude          Esophagus
                      #212 #213
c
c         CHEST---LIVER LEVEL
c
15    1 -1.04       ((-132 -332 98):(-131 -98 7))
c                exclude          Spine
                       (100:332:-7)
c                exclude          Adrenals
                      (160:-162) (161:-162)
c                exclude          Gall Bladder
                       (202:200) (-202:201:203)
c                exclude          Kidneys
                       (310:-312) (311:313)
c                exclude          Liver
                       #320
c                      (320:321:322:-7)
c                exclude         Pancreas
                      (350:-351:(-352 312))
c                exclude          Spleen
                       360
c                exclude          Esophagus
                      #212 #213
c                exclude         Stomach
                      210
c
c
c         LOWER TRUNK
c
16    1 -1.04       -131 4 -7 371 370
c                exclude           Spine
                       (100:-101:7)
c                exclude           Pelvis
                       #90
c                exclude           Small Intestine
                       (91:-221:222:-223:7)
c                exclude           Ascending Colon
                       (232:230:-231)
c                exclude           Descending Colon
                       (232:250:-251)
c                exclude           Sigmoid Colon
                       (280:-282:251) (281:282:-4)
c                exclude           Urinary Bladder
                       410
c                exclude          Uterus
                       (420:-421)
c                exclude           Ovaries
                       340 341
c
c        LEGS
c
30    1 -1.04       -4 36 51 52 #34 #41 (-34 : -35)
             vol=  7317.00
c
c         SURROUNDING AIR
600    4 -0.001293   -600
c            exclude         HEAD & NECK
```

```
                       (21:-9)  (20:9:-8)
c             exclude         TRUNK
                        (-4:10:8)
c             exclude         LEGS
                        (4:-33:(31 32))
c             exclude         GENITALIA
                    (1:4:-41:42:-43:44:-31:-32)
c             exclude    detector
                    (507 508 510 511 512)
c             air            OUTSIDE of NECK
601    4 -0.001293   -20 27 8 -12
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 +++++++++++++++++++++
700   0               600

c ++++++++++++++++++++++++++++++++++++++++++++++
c           SURFACES
c ++++++++++++++++++++++++++++++++++++++++++++++
c Planes used in several places
c
1     py 0
4     pz 0
332   pz    31.5700
7     pz    19.5900
8     pz    50.8000
9     pz    67.1800
12    pz    55.5000
c
c         BODY SURFACE
c
c             HEAD
21    sq  4039.2380  2537.7112  5117.2562 0 0 0 -229028.4313 0 0
67.180
22    sq  3837.3069  2397.4439  4877.9050 0 0 0 -211838.1446 0 0
67.180
20    sq    90.2500    56.7009 0 0 0 0 -5117.256225 0 0 0
23    sq    88.3600    55.2049 0 0 0 0 -4877.904964 0 0 0
c
```

```
c
c              NECK
27    cz     4.5000
28    cz     4.4000
c
c
c              TORSO
10    sq    72.2500   196.0000 0 0 0 0 -14161.000000 0 0 0
c              Torso Skin
11    sq    70.5600   193.2100 0 0 0 0 -13632.897600 0 0 0
18    pz    50.7000
c
c              LEGS
31    gq 1 1 0 0 0  -0.1544   -14.0000 0 0 0
32    gq 1 1 0 0 0   0.1544    14.0000 0 0 0
33    pz  -66.100
c                 Leg Skin
34  7  gq 1 1 0 0 0  -0.1544   -13.7000 0 0 0
35  8  gq 1 1 0 0 0   0.1544    13.7000 0 0 0
36    pz  -66.000
c                 Genitalia Skin
37  7  gq 1 1 0 0 0  -0.1544   -14.1000 0 0 0
38  8  gq 1 1 0 0 0   0.1544    14.1000 0 0 0
c
c          PENIS & SCROTUM
41    pz    -1.7800
42    p  0 -12.95 -1  90.00
43    p   -12.95 0 1 -90.00
44    p    -12.95 0 -1  90.00
c
c              Penis & Scrotum Skin
47    pz    -1.6800
45    p  0 -13.04 -1  90.00
49    p   -13.04 0 1 -90.00
48    p    -13.04 0 -1  90.00
c
c     SKELETON
c
c
c          LEG BONES
51    gq   1 1  0.005459 0 0  -0.154679   -13.900000
            0   0.963851      42.3854
52    gq   1 1  0.005459 0 0   0.154679    13.900000
            0   0.963851      42.3854
53    pz   -65.9000
c
c          ARM BONES ( left/right) )
71     gq   1.062812     0.194065 0 0 0     0.020590
             -28.217664 0    -0.283315   187.044744
72    gq   1.062812   0.194065 0 0 0    -0.020590
              28.217664 0    -0.283315     187.044744
73    pz     50.0700
c
c          PELVIS
91    sq    90.0601    61.6225 0 0 0 0 -5549.7285
       0    -3.1900 0
92    sq   101.6064    69.5556 0 0 0 0 -7067.2941 0    -2.5200 0
```

```
93    py    -2.5200
94    py     4.2000
95    pz    10.1600
c
c         SPINE
100      sq      4.4100     1.9321 0 0 0 0    -8.5206 0     4.6200 0
105      sq      4.4100     1.9321 0 0 0 0    -8.5206 0     0.9000 0
101      pz    15.9700
102      pz    60.8400
103      pz    25.4700
c
c     SKELETON
c
c
c             SKULL (head)
c
c
c             CRANIUM
110    sq  3365.2761  2072.1796  4316.0958 0 0 0
     -173488.0607 0 0    67.1800
111    sq   2311.8403  1362.4736  3047.5699 0 0 0
          -97976.0213 0 0    67.1800
c
c         FACIAL
120      sq     79.2100    48.0249 0 0 0 0 -3804.0523 0 0 0
121      sq     66.5856    38.3161 0 0 0 0 -2551.3005 0 0 0
c
122      pz    59.1100
123      pz    69.2300
c
c         RIBS
131      sq     67.7329   139.7124 0 0 0 0 -9463.1260 0 0 0
132      sq     61.4656   130.6449 0 0 0 0 -8030.1672 0 0 0
133      pz    48.8900
134     pz    47.8700
135     pz     46.8500
136     pz     45.8300
137     pz     44.8100
138     pz     43.7900
139     pz     42.7700
74      pz     41.7500
75      pz     40.7300
76      pz     39.7100
77      pz     38.6900
78      pz     37.6700
79      pz     36.6500
80      pz     35.6300
81      pz     34.6100
82      pz     33.5900
83      pz     32.5700
84      pz     31.5500
85      pz    30.5300
86      pz    29.5100
87      pz    28.4900
88      pz    27.4700
89      pz    26.4500
98      pz    25.4300
```

```
c
c         CLAVICLES
140      tz    0     4.9300    49.5300
           12.4000   0.598100   0.598100
141      p   6.258100 1 0      4.930
142      p   6.258100 -1 0     -4.930
143      p   0.657080 1 0      4.930
144      p   0.657080 -1 0     -4.930
c
c         SCAPULAE
156      sq    67.7329   174.2400 0 0 0 0 -11801.7805
           0 0 0
150   p      0.3000 1 0 0
151   p      0.3000 -1 0 0
152   p      0.9700 1 0 0
153   p      0.9700 -1 0 0
154   pz    36.9400
155   pz    48.8400
c
c         ADRENALS
160   1 sq     2.0042    18.0379     0.2082 0 0 0    -2.7436 0 0 0
161   2 sq     2.0042    18.0379     0.2082 0 0 0    -2.7436 0 0 0
162    pz    27.5800
c
c         GALL BLADDER
200  3 so     1.8740
201  3 gq 1 1 -0.05175625 0 0 0 0 0   0.852670  -3.511876
202  3 pz 0
203  3 pz     7.0700
c
c         OESOPAHGUS
212    sq     0.1296     0.6241 0  0 0 0    -0.0809 0     2.0400 0
213    sq     0.0121     0.2916 0  0 0 0    -0.0035 0     2.0400 0
216 6  cx     0.5200
217 6  px     0.0000
218 6  px     5.7500
c
c         STOMACH
210    sq   253.4273   332.8216    74.025 0 0 0 -2498.6918
            5.5600    -3.5100    25.4000
c extent     2.4200     8.7000    -6.2500    -0.7700    19.5900
31.2100
c
c         SMALL INTESTINE
221    py    -4.0800
222    py     1.8500
223    pz    12.3400
c
c         ASCENDING COLON
230    sq     4.4100     3.0276 0 0 0 0   -13.3517    -5.9100    -
1.9800 0
231    pz    10.4900
232    pz    17.4200
c
c         ASCENDING COLON WALL
233    sq     0.450431     0.292184 0 0 0 0   -1    -5.9100    -1.9800
0
```

```
c
c         TRANSVERSE COLON
240    sq  0   1.166400     4.4100 0 0 0    -5.1438 0    -1.9800
18.5100
241    px     7.3000
242    px    -7.3000
c
c         TRANSVERSE COLON WALL
243    sq  0   0.292186   1.451598 0 0 0    -1 0    -1.9800    18.5100
c
c         DESCENDING COLON
251    pz     6.3300
250    gq   3.204100   1.716100     0.069190 0     0.649921    -
0.313245
            -35.748001      -4.113998       0.968404    96.676774
c
c         DESCENDING COLON WALL
252  9  gq   3.14963   1.7028   0.06919   0     0.638872   -0.30792
            -35.1403      -4.04406       0.968404    96.6768
c
c         SIGMOID COLON
282    px     2.0900
280    ty     2.0900 0     6.3300     4.1500     1.5000     0.9600
281    ty     2.090 0 0      2.180     1.5000     0.9600
c
c         SIGMOID COLON WALL
283    ty     2.0900 0     6.3300     4.1500    1.3    0.76
284    ty     2.090 0 0      2.180     1.3    0.76
C
c         HEART
c
290  4 px 0
291  4 pz 0
c
c         Left Ventricle
292   4 sq   461.4591  1360.1639   695.9888 0 0 0 -20900.8226 0 0 0
c        Right Ventricle
293   4 sq    90.7371   267.4500   695.9888 0 0 0 -4109.7444 0 0 0
c
c        Left Atrium
294   4 sq    90.7371   105.6558   274.9495 0 0 0 -1623.5491 0 0 0
c
c        Right Atrium
295   4 sq   461.4591   537.3309   274.9495 0 0 0 -8256.8422 0 0 0
c
c
c         KIDNEYS
310    sq    34.4017   213.2593    28.9466 0 0 0  -460.8320
              4.1700     5.0400    23.5900
311    sq    34.4017   213.2593    28.9466 0 0 0  -460.8320
             -4.1700     5.0400    23.5900
312    px     1.7400
313    px    -1.7400
c
c         LIVER
320    sq    46.6489   130.6449 0 0 0 0 -6094.4409 0 0 0
321     p       926.0       686.0      -652.1    -20353.5
```

```
322    pz    31.2100
c
c
c         LUNGS
330    sq      12.0442       4.4282       0.5792 0 0 0
               -175.7536     5.9100 0    31.5700
331   sq      12.0442       4.4282       0.5792 0 0 0
              -175.7536    -5.9100 0    31.5700
333    px    -4.1000
334    py     1.3000
335    pz    33.4000
336    pz    39.6000
337    px     5.9000
338    py     0.7500
339    pz    40.0000
c
c         OVARIES
340    sq     0.2959     0.8057     0.0697 0 0 0    -0.1289
              4.1700 0    10.8900
341    sq     0.2959     0.8057     0.0697 0 0 0    -0.1289
             -4.1700 0    10.8900
c
c
c         PANCREAS
350 sq     3.9856   479.4042    86.1704 0 0 0  -405.7677
          -0.3800 0    26.8500
351    px    -0.3800
352    pz    26.8500
c
c         SPLEEN
360    sq    53.4069   111.7355    16.6660 0 0 0  -315.3622
              7.6500     2.5200    26.8500
c extent     5.2200    10.0800     0.8400     4.2000    22.5000
31.2000
c
c         TESTICLES
370    sq     0.2134440     0.155867     0.066822 0 0 0    -0.0471498
              0.4700    -6.1500    -0.8400
371    sq     0.2134440     0.155867     0.066822 0 0 0    -0.0471498
             -0.4700    -6.1500    -0.8400
c
c         THYMUS
380    sq    15.2100    52.0562     3.4225 0 0 0
            -52.0562 0    -6.1300    43.0000
c extent    -1.8500     1.8500    -7.1300    -5.1300    39.1000
46.9000
c
c             THYROID
390    c/z 0    -2.7500     1.6000
391    c/z 0    -2.7500     0.7300
392    py    -2.7500
393    pz    54.4300
c
c         URINARY BLADDER
410    sq    63.9232    90.1417   120.4375 0 0 0  -833.0538 0
              3.7800     5.8100
```

```
c extent    -3.6100     3.6100     0.7400     6.8200     3.1800
8.4400
c
c              UTERUS
420    sq     1.5299216     0.2690497     3.89944009 0 0 0    -
1.26692809
          0   -1.680   10.160
421    py    -2.7800
c
c      Void
600    so 200
c
c ++++++++++++++++
c   BC408 Volume
c +++++++++++++++++++
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
c +++++++++++++++++
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
c ++++++++++++++++++++++++++++++++
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
c +++++++++++++++++++++++
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
c +++++++++++++++++++++
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
c ++++++++++++++++++++++
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 ++++++++++++++++++++++++++++++++++++++++
c     STATISTICS
c  Weight =    32.69 kg ( =    72.07 pounds)
c  Height =   139.97 cm ( =    55.11 inches)

c ++++++++++++++++++++++++++++++++++++++++++++++
c
c         TRANSFORMATIONS
c ++++++++++++++++++++++++++++++++++++++++++++++
c
c         ADREANALS
tr1        2.430      4.200    27.5800
        0.541708   0.840566 0
       -0.840566   0.541708 0
      0       0       1
```

```
tr2       -2.430      4.200    27.5800
         0.541708  -0.840566 0
         0.840566   0.541708 0
      0       0       1
c
c         GALL BLADDER
tr3       -1.690     -2.690     21.770
        -0.040010   0.985289   -0.166150
         0.972189   0.000000   -0.234200
         0.230700   0.170900    0.957899
c
c         HEART
tr4       0.800      -1.700     36.600
       0.634505  -0.537000  -0.555900
      -0.424330   0.359122  -0.831250
       0.646018   0.763322     0.0000
c
c         ESOPHAGUS
tr6       0.000       2.040     30.620
       0.678998  -0.677776  -0.282102
       0.706470   0.707743   0.000000
       0.199729  -0.199370   0.959354
c
c         SKIN ON LEFT LEG & GENITALIA
tr7   0.2
c
c         SKIN ON RIGHT LEG & GENITALIA
tr8    -0.2
c
c         DESCENDING COLON WALL
tr9   0 -0.1
c
tr900 0 0 -50 0 1 0 1 0 0 0 0 1
c
IMP:P 1 60R 0
c ++++++++++++++++++++++++++++++++++++++++++++++
c      SOURCES
c      Internal Organs
c ++++++++++++++++++++++++++++++++++++++++++++++
SDEF  PAR=2  ERG=D1  CEL=D2  RAD=fcel=D3  &
      POS=fcel=D4  EXT=fcel=D5  AXS=fcel=D6
c
SI1 L 0.14544 0.0407484 0.0406532  0.0417924
SP1   0.48    0.0174874 0.00900864 0.00702144
c
c Left Lung, Right Lung, Stomach, Small Int., Heart,
c Asc. Colon, Tr. Colon, De. Colon, Si Colon, Bladder,
c Body Tissue (40, 20, 27, 10, 11, 12, 13, 14, 15, 16,
c 30), Liver, Left Kidney, Right Kidney, Bones (50, 51,
c 70(x2), 90, 100, 101, 102, 110, 130, 140, 150(x2)),
c Testicles, Ovaries, Thyroid
c
c
SI2 L 330 330 210 220 290 231 240 250 280 410 40 20
      27 10 11 12 13 14 15 16 30 320 310 310 50 51
      70 70 90 100 101 102 110 130 140 150 150 340
      340 370 370 390
```

```
SP2 D 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
c
DS3 S 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
      23 24 25 26 27 28 29 30 31 32 33 34 35 36 37
      38 39 40 41 42 43 44 45 46 47 48
c
DS4 L 5.91 0 14.1   -5.91 0 14.1   5.56 -3.51 25.4
      0 -3.19 12.3   0 0 32   -5.91 -1.98 10.48
      -7.4 -1.98 18.51   6.2 -1.1 6.3   2.85 0 -0.1
      0 3.78 5.81   -7 -3.45 0.84   0 0 55.4
      0 0 50.7   0 0 -0.1   0 0 48.7   0 0 36.55
      0 0 25.33   0 0 31.47   0 0 19.49   0 0 -0.1
      0 0 -66.1   0 0 19.49   4.17 5.04 23.59
      -4.17 5.04 23.59   5 0 -66.2   -5 0 -66.2
      -12.9 0 -0.1   12.9 0 -0.1   0 -2.52 -0.1
      0 4.62 15.87   0 4.62 25.37   0 0.9 49.8
      0 0 59.01   0 0 25.33   -11.43 -4.67 49.565
      -9.4 5.15 36.83   9.4 5.15 36.83   4.17 0 10.89
      -4.17 0 10.89   0.47 -6.15 -0.84   -0.47 -6.15 -0.84
      0 -2.75 50.7
c
DS5 S 50 51 0 52 53 54 55 56 57 0 58 59 60 61 62 63
      64 65 66 67 68 69 0 0 70 71 72 73 74 75 76 77
      78 79 80 81 82 0 0 0 0 83
c
DS6 L 0 0 1   0 0 1   0 0 0   0 0 1   0 0 1   0 0 1
      1 0 0   0 0 1   0 0 1   0 0 0   1 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   0 0 0   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   1 0 0   0 0 1
      0 0 1   0 0 0   0 0 0   0 0 0   0 0 0   0 0 1
c
SI7 0 6.31
SP7 -21 1
SI8 0 6.31
SP8 -21 1
SI9 0 5.9
SP9 -21 2
SI10 0 9.5
SP10 -21 1
SI11 0 6.75
SP11 -21 1
SI12 0 2.2
SP12 -21 1
SI13 0 2.2
SP13 -21 1
SI14 0 2.9
SP14 -21 1
SI15 0 4.5
SP15 -21 1
SI16 0 3.7
SP16 -21 2
SI17 0 4.5
SP17 -21 1
SI18 0 9.5
```

SP18 -21 1
SI19 0 4.5
SP19 -21 1
SI20 0 14
SP20 -21 1
SI21 0 14.1
SP21 -21 1
SI22 0 11.9
SP22 -21 1
SI23 0 11.83
SP23 -21 1
SI24 0 11.9
SP24 -21 1
SI25 0 11.9
SP25 -21 1
SI26 0 11.9
SP26 -21 1
SI27 0 14.5
SP27 -21 1
SI28 0 11.43
SP28 -21 1
SI29 0 4.1
SP29 -21 2
SI30 0 4.1
SP30 -21 2
SI31 0 5
SP31 -21 1
SI32 0 5
SP32 -21 1
SI33 0 1.5
SP33 -21 1
SI34 0 1.5
SP34 -21 1
SI35 0 10.18
SP35 -21 1
SI36 0 2.2
SP36 -21 1
SI37 0 2.2
SP37 -21 1
SI38 0 2.2
SP38 -21 1
SI39 0 9.15
SP39 -21 1
SI40 0 11.9
SP40 -21 1
SI41 0 3.33
SP41 -21 1
SI42 0 3
SP42 -21 1
SI43 0 3
SP43 -21 1
SI44 0 1.4
SP44 -21 2
SI45 0 1.4
SP45 -21 2
SI46 0 0.9
SP46 -21 2

```
SI47 0 0.9
SP47 -21 2
SI48 0 1.7
SP48 -21 1
c
SI50 0 35
SP50 -21 0
SI51 0 35
SP51 -21 0
SI52 0 7.4
SP52 -21 0
SI53 0 10
SP53 -21 0
SI54 0 7.13
SP54 -21 0
SI55 0 14.8
SP55 -21 0
SI56 0 11.2
SP56 -21 0
SI57 0 6.5
SP57 -21 0
SI58 0 14
SP58 -21 0
SI59 0 22.5
SP59 -21 0
SI60 0 4.8
SP60 -21 0
SI61 0 50.9
SP61 -21 0
SI62 0 2.2
SP62 -21 0
SI63 0 12.35
SP63 -21 0
SI64 0 10.5
SP64 -21 0
SI65 0 17.52
SP65 -21 0
SI66 0 12.18
SP66 -21 0
SI67 0 19.79
SP67 -21 0
SI68 0 66.2
SP68 -21 0
SI69 0 11.82
SP69 -21 0
SI70 0 66.3
SP70 -21 0
SI71 0 66.3
SP71 -21 0
SI72 0 50.27
SP72 -21 0
SI73 0 50.27
SP73 -21 0
SI74 0 16.17
SP74 -21 0
SI75 0 9.7
SP75 -21 0
```

```
SI76 0 25.53
SP76 -21 0
SI77 0 10.5
SP77 -21 0
SI78 0 17.42
SP78 -21 0
SI79 0 23.66
SP79 -21 0
SI80 0 22.86
SP80 -21 0
SI81 0 12.95
SP81 -21 0
SI82 0 12.95
SP82 -21 0
SI83 0 3.93
SP83 -21 0
c
c ++++++++++++++
c Tally
c
c ++++++++++++++
F8:P 501
E8 0 1e-8 0.005 2000i 1.5
FT8 SCX 2
c ++++++++++++++
c
c ++++++++++++++++++++++++++++++++++++++++++++++
c      MATERIALS
c      Compositions from ORNL Report TM-8381
c ++++++++++++++++++++++++++++++++++++++++++++++
c      Adult Tissues (Density = 1.04 g/cc)
m1       1000  -0.10454
         6000  -0.22663
         7000  -0.02490
         8000  -0.63525
        11000  -0.00112
        12000  -0.00013
        14000  -0.00030
        15000  -0.00134
        16000  -0.00204
        17000  -0.00133
        19000  -0.00208
        20000  -0.00024
        26000  -0.00005
        30000  -0.00003
        37000  -0.00001
        40000  -0.00001
c
c       Skeleton (Density = 1.4 g/cc)
m2       1000  -0.07337
         6000  -0.25475
         7000  -0.03057
         8000  -0.47893
         9000  -0.00025
        11000  -0.00326
        12000  -0.00112
        14000  -0.00002
```

```
        15000  -0.05095
        16000  -0.00173
        17000  -0.00143
        19000  -0.00153
        20000  -0.10190
        26000  -0.00008
        30000  -0.00005
        37000  -0.00002
        38000  -0.00003
        82000  -0.00001
c
c       Lung (Density = 0.296 g/cc)
m3       1000  -0.10134
         6000  -0.10238
         7000  -0.02866
         8000  -0.75752
        11000  -0.00184
        12000  -0.00007
        14000  -0.00006
        15000  -0.00080
        16000  -0.00225
        17000  -0.00266
        19000  -0.00194
        20000  -0.00009
        26000  -0.00037
        30000  -0.00001
        37000  -0.00001
c
c      Air (Density = 0.001020 /cc)
m4       6000  -0.00012
         7000  -0.75527
         8000  -0.23178
        18000  -0.01283
c
c Detectors 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
NPS   4E9
RAND GEN=2 SEED=1561615651
PHYS:P 4J 1
PRINT
MODE P
```

APPENDIX C:

COUNT RATES CORRESPONDING TO 250 mSv FOR INDIVIDUAL FISSION PRODUCTS

Table C.1 Cs-137/Ba-137m count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	**F**
Days following exposure	0.25	1.62E+06
	0.5	1.73E+06
	1	1.79E+06
	2	1.77E+06
	3	1.73E+06
	4	1.70E+06
	5	1.67E+06
	6	1.65E+06
	7	1.63E+06
	8	1.61E+06
	9	1.60E+06
	10	1.59E+06
	20	1.48E+06
	30	1.39E+06

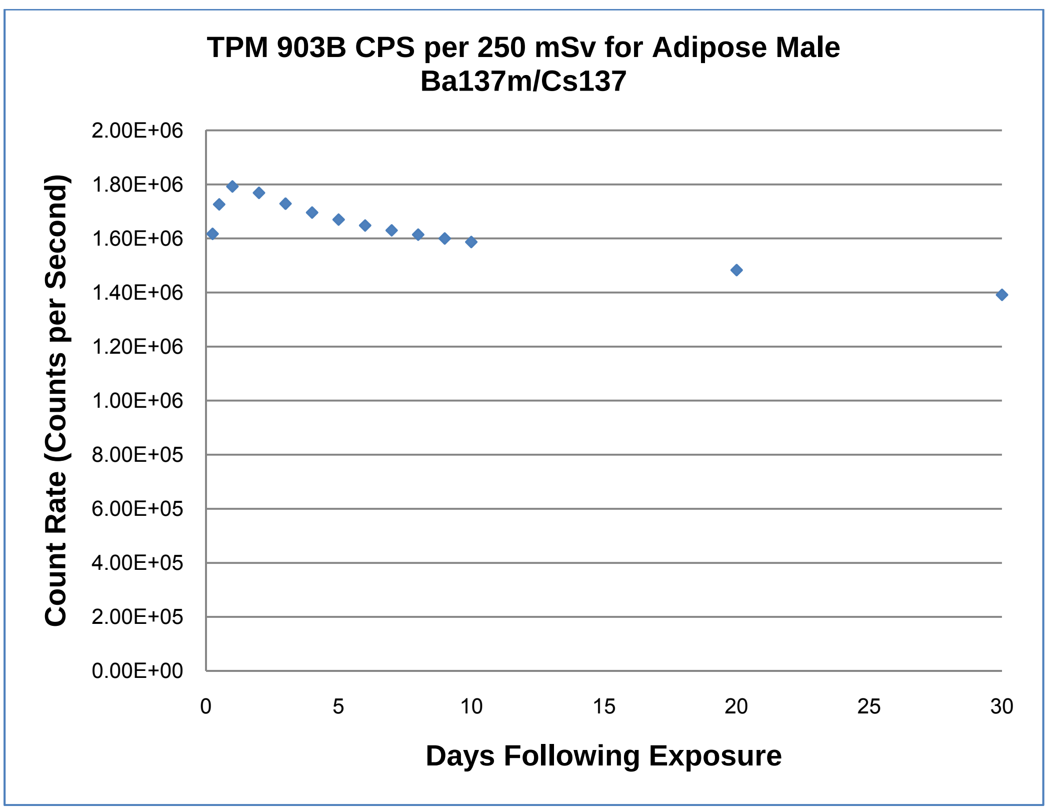

Figure C.1 Cs-137/Ba-137m count rate per 250 mSv for adipose male

Table C.2 Ba-140/La-140 count rate per 250 mSv for adipose male

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	F
	0.25	1.37E+07
	0.5	1.28E+07
	1	1.09E+07
	2	8.04E+06
	3	6.15E+06
	4	4.88E+06
	5	4.01E+06
	6	3.39E+06
	7	2.94E+06
	8	2.60E+06
	9	2.34E+06
	10	2.13E+06
	20	1.07E+06
	30	5.83E+05

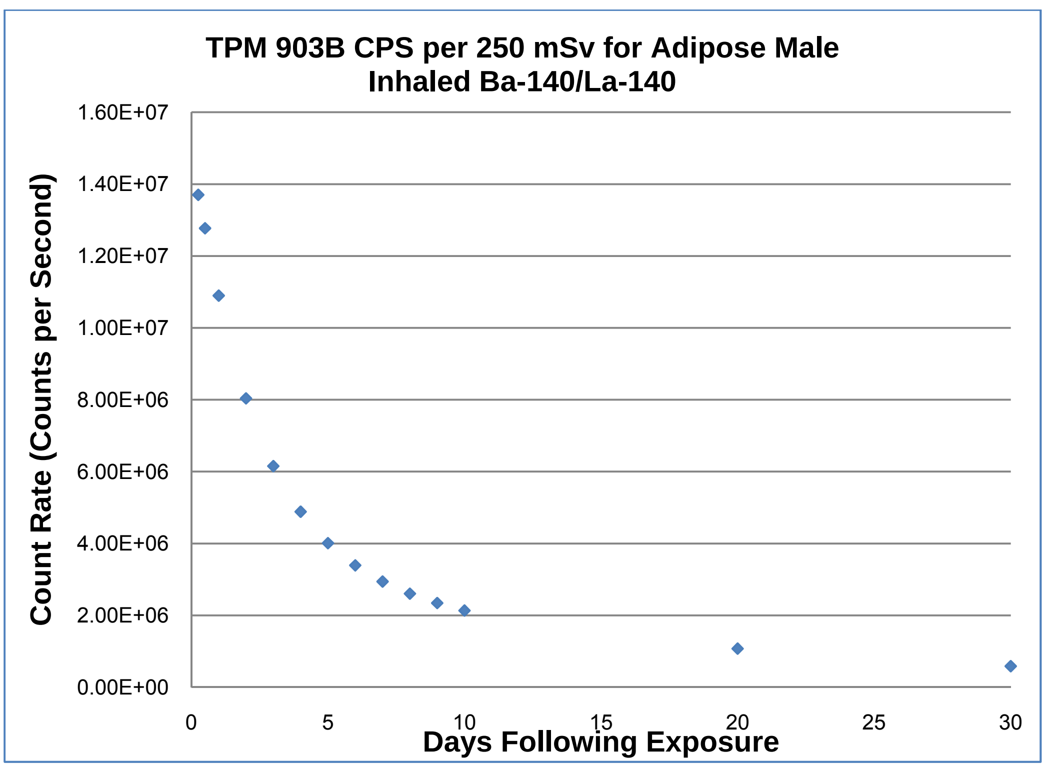

Figure C.2 Ba-140/La-140 count rate per 250 mSv for adipose male

Table C.3 Ce-141 count rate per 250 mSv for adipose male

		Total Body Count
		cps per mSv
	Class →	S
Days following exposure	0.25	8.87E+03
	0.5	8.71E+03
	1	7.89E+03
	2	6.12E+03
	3	5.10E+03
	4	4.60E+03
	5	4.34E+03
	6	4.16E+03
	7	4.03E+03
	8	3.90E+03
	9	3.79E+03
	10	3.68E+03
	20	2.79E+03
	30	2.13E+03

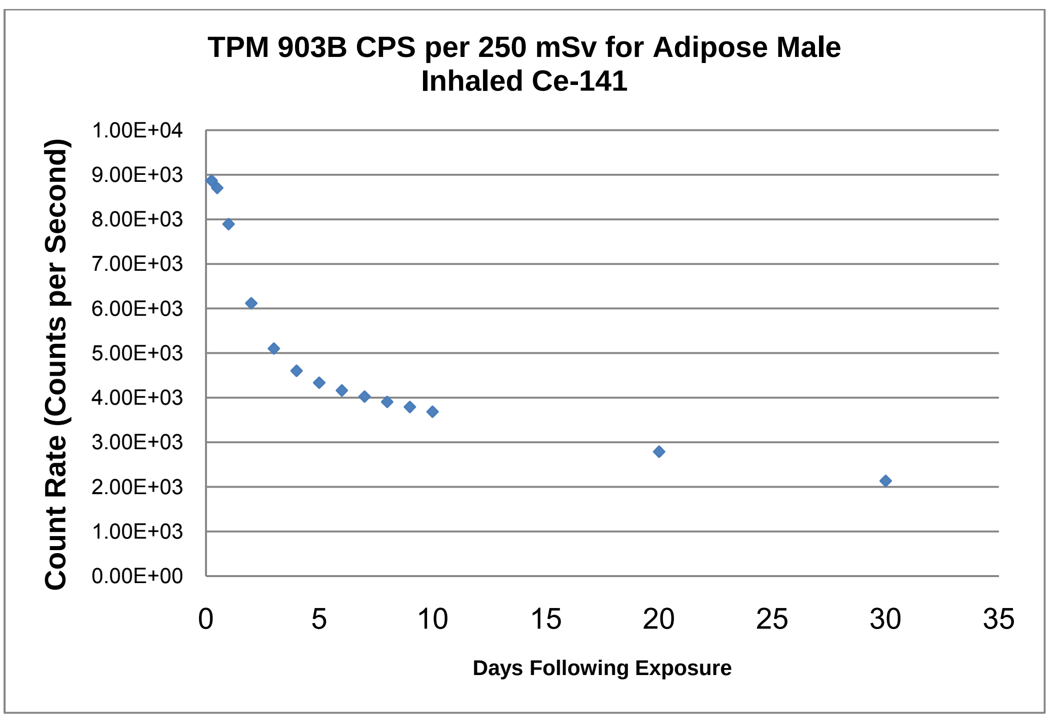

Figure C.3 Ce-141 count rate per 250 mSv for adipose male

Table C.4 Ce-144/Pr-144 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	S
Days following exposure	0.25	4.18E+02
	0.5	4.10E+02
	1	3.51E+02
	2	2.48E+02
	3	1.97E+02
	4	1.74E+02
	5	1.65E+02
	6	1.60E+02
	7	1.58E+02
	8	1.55E+02
	9	1.54E+02
	10	1.52E+02
	20	1.38E+02
	30	1.27E+02

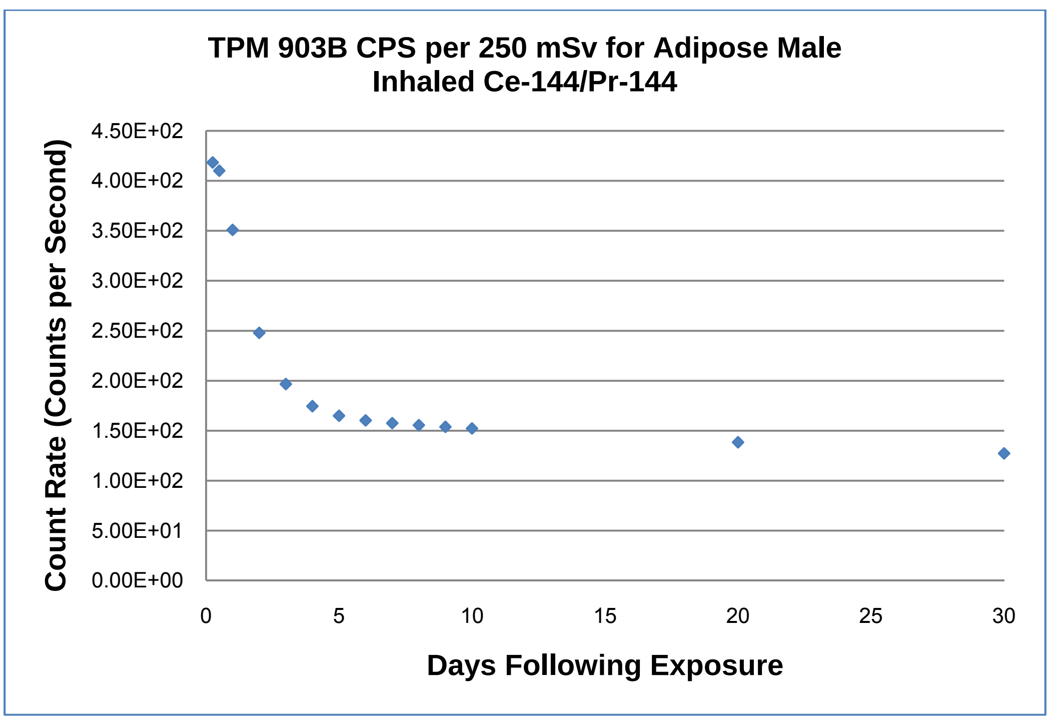

Figure C.4 Ce-144/Pr-144 count rate per 250 mSv for adipose male

Table C.5 Cs-134 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	F
Days following exposure	0.25	2.79E+06
	0.5	2.97E+06
	1	3.09E+06
	2	3.04E+06
	3	2.97E+06
	4	2.91E+06
	5	2.87E+06
	6	2.83E+06
	7	2.79E+06
	8	2.76E+06
	9	2.74E+06
	10	2.71E+06
	20	2.51E+06
	30	2.34E+06

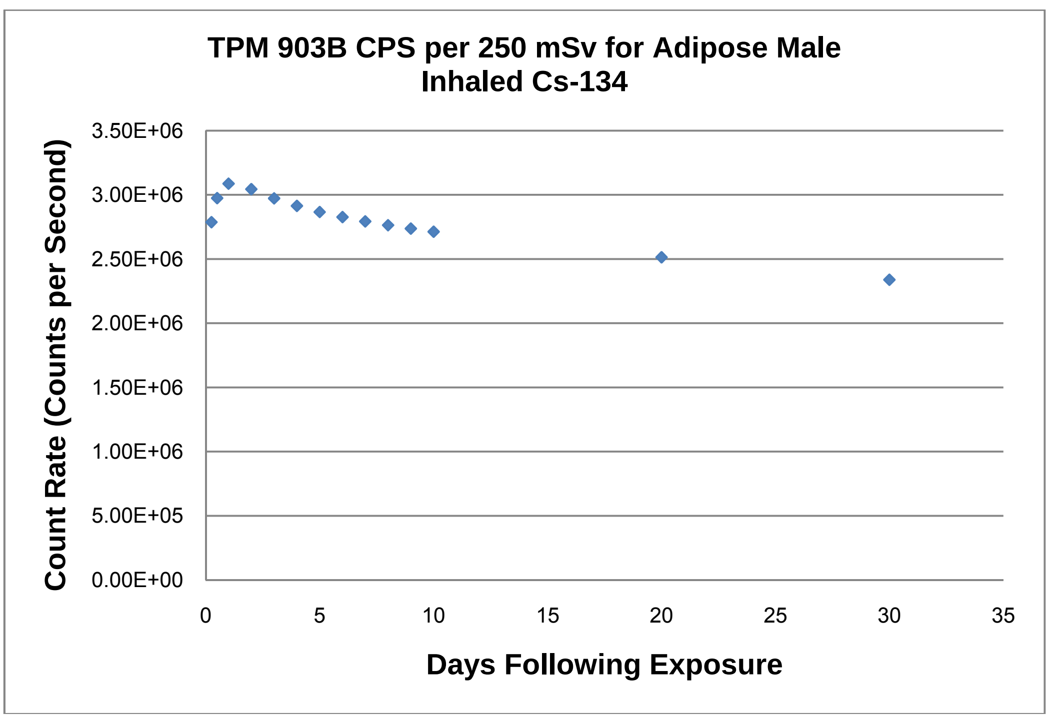

Figure C.5 Cs-134 count rate per 250 mSv for adipose male

Table C.6 Cs-136 count rate per 250 mSv for adipose male

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	F
	0.25	1.84E+07
	0.5	1.89E+07
	1	1.87E+07
	2	1.74E+07
	3	1.62E+07
	4	1.50E+07
	5	1.40E+07
	6	1.31E+07
	7	1.23E+07
	8	1.16E+07
	9	1.09E+07
	10	1.02E+07
	20	5.65E+06
	30	3.12E+06

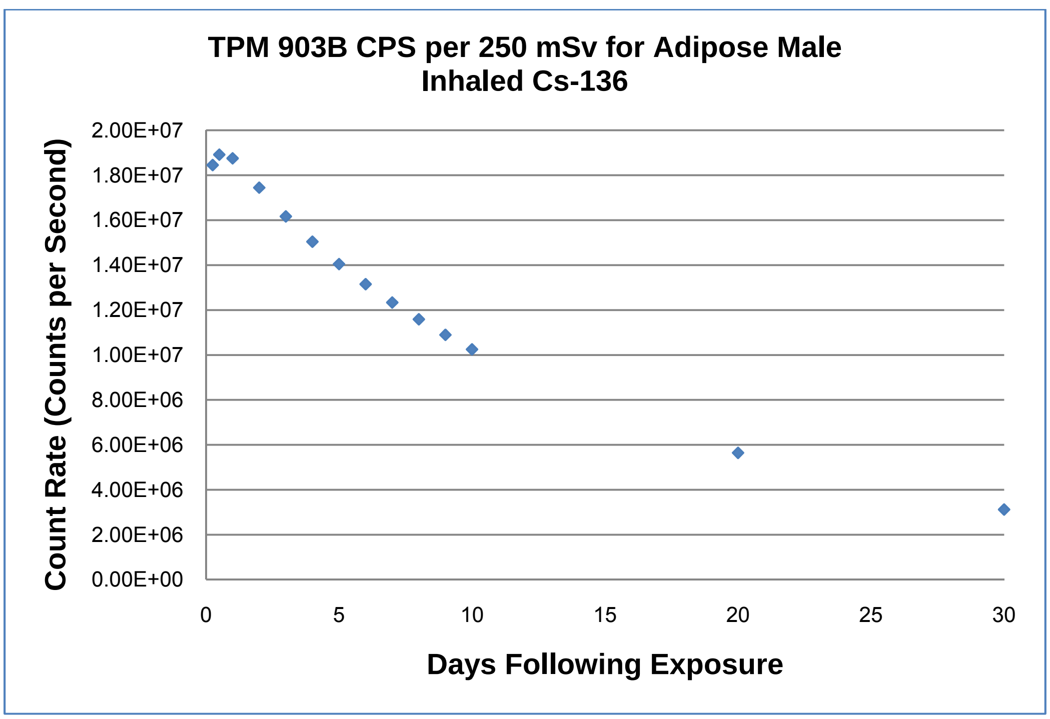

Figure C.6 Cs-136 count rate per 250 mSv for adipose male

Table C.7 Eu-154 count rate per 250 mSv for adipose male

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	M
	0.25	2.00E+04
	0.5	2.21E+04
	1	2.25E+04
	2	2.01E+04
	3	1.87E+04
	4	1.81E+04
	5	1.80E+04
	6	1.81E+04
	7	1.82E+04
	8	1.83E+04
	9	1.85E+04
	10	1.87E+04
	20	2.01E+04
	30	2.15E+04

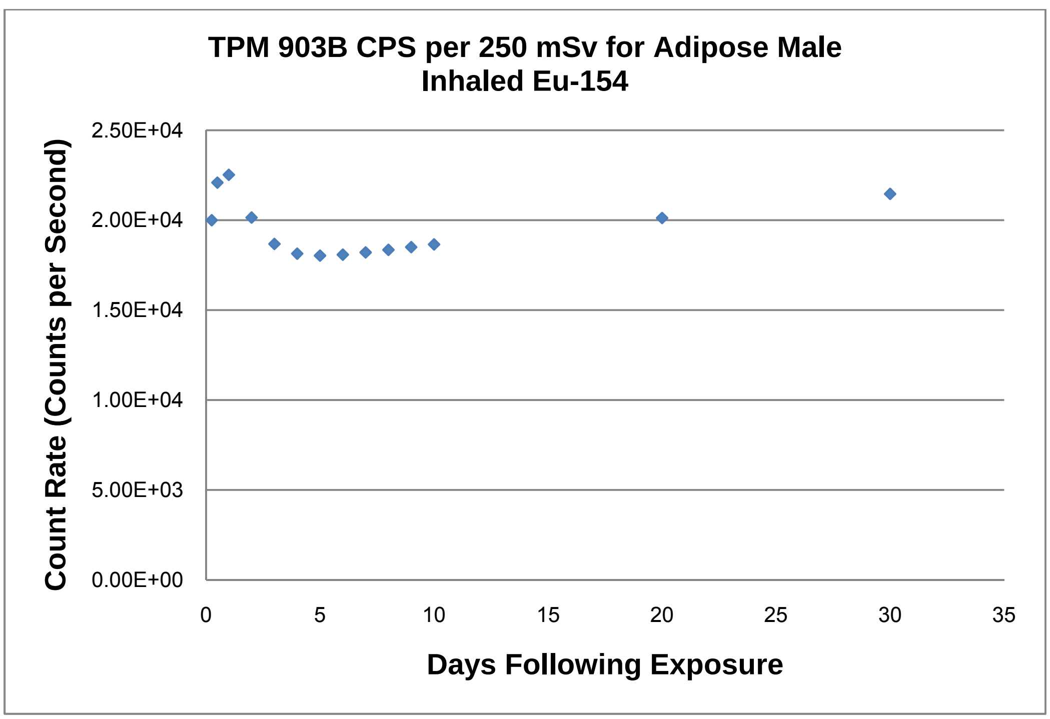

Figure C.7 Eu-154 count rate per 250 mSv for adipose male

Table C.8 Eu-156 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	S
Days following exposure	0.25	8.52E+05
	0.5	8.13E+05
	1	6.73E+05
	2	4.30E+05
	3	2.96E+05
	4	2.23E+05
	5	1.75E+05
	6	1.41E+05
	7	1.14E+05
	8	9.30E+04
	9	7.58E+04
	10	6.19E+04
	20	8.31E+03
	30	1.14E+03

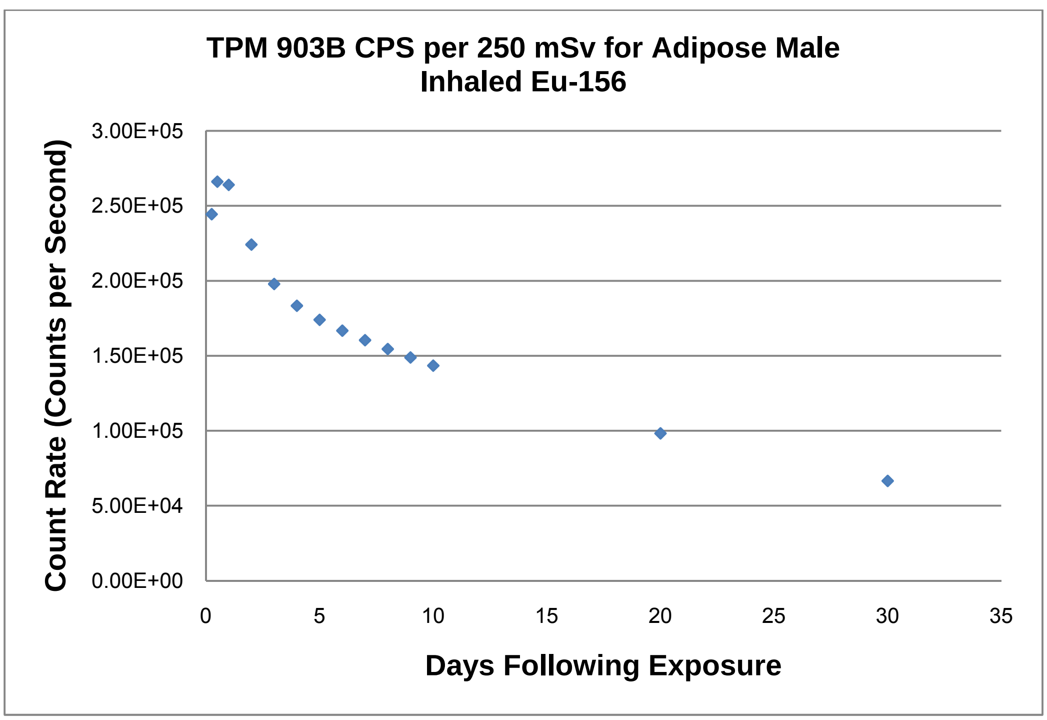

Figure C.8 Eu-156 count rate per 250 mSv for adipose male

Table C.9 I-131 count rate per 250 mSv for adipose male

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	F
	0.25	4.10E+05
	0.5	2.18E+05
	1	6.97E+04
	2	2.56E+04
	3	2.28E+04
	4	2.23E+04
	5	2.17E+04
	6	2.09E+04
	7	2.01E+04
	8	1.92E+04
	9	1.83E+04
	10	1.73E+04
	20	8.84E+03
	30	3.96E+03

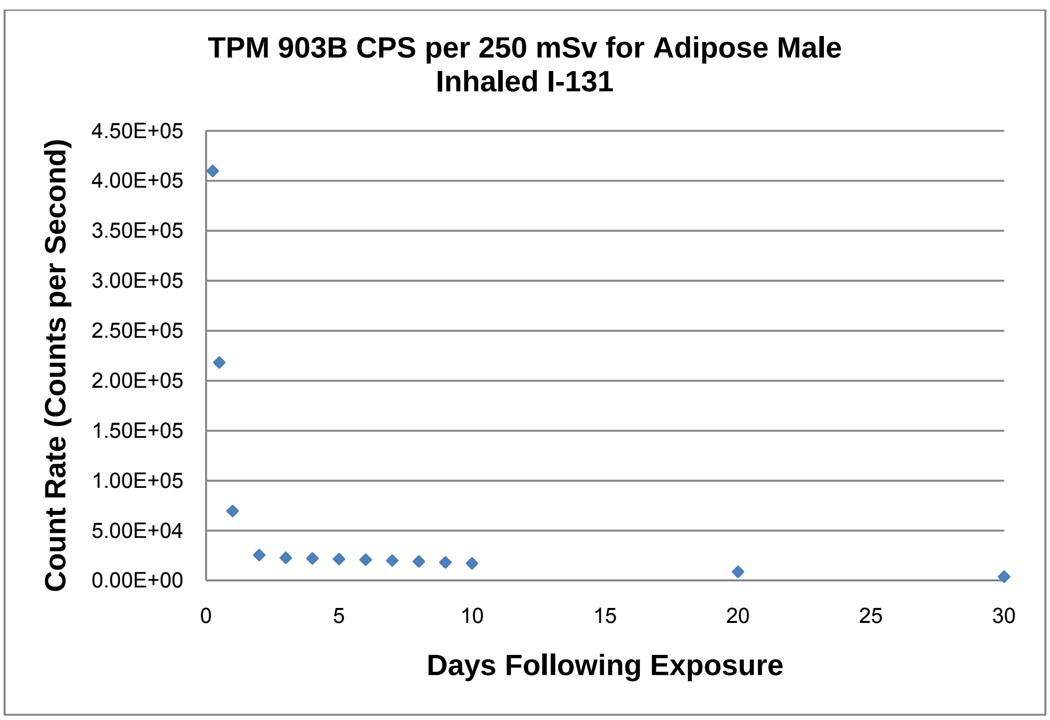

Figure C.9 I-131 count rate per 250 mSv for adipose male

Table C.10 La-140 count rate per 250 mSv for adipose male

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	M
	0.25	1.72E+06
	0.5	1.52E+06
	1	1.14E+06
	2	6.44E+05
	3	3.90E+05
	4	2.49E+05
	5	1.63E+05
	6	1.08E+05
	7	7.20E+04
	8	4.79E+04
	9	3.19E+04
	10	2.13E+04
	20	3.66E+02
	30	6.24E+00

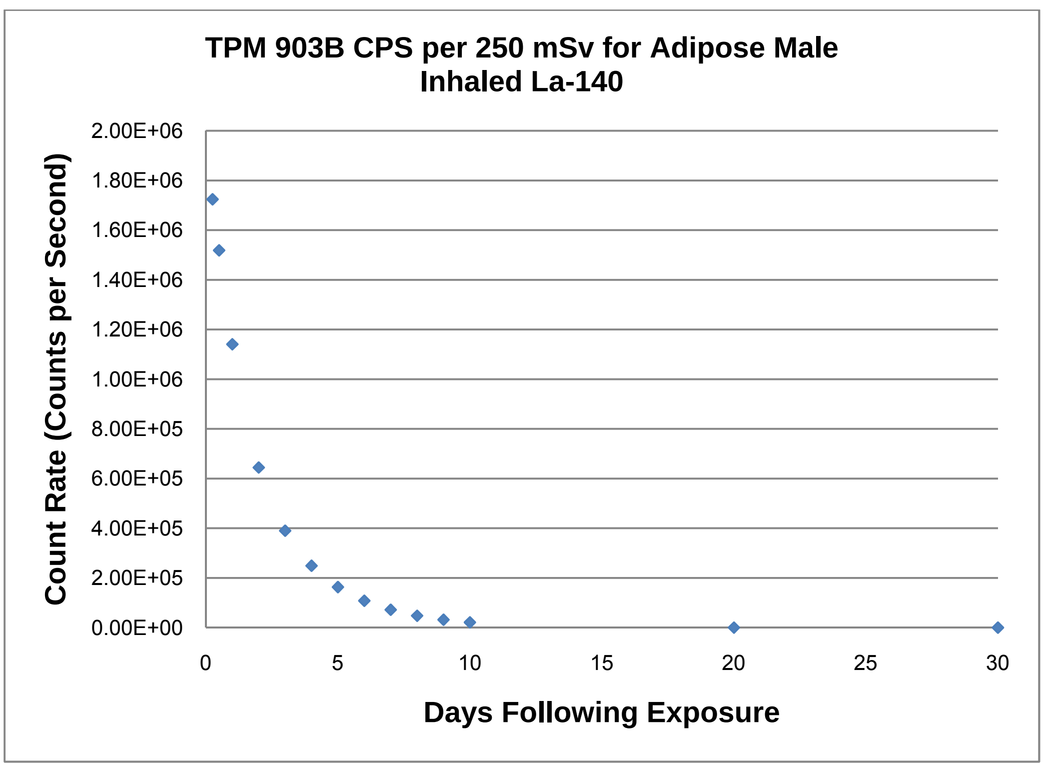

Figure C.10 La-140 count rate per 250 mSv for adipose male

Table C.11 Nb-95m/Nb-95 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	S
Days following exposure	0.25	8.52E+05
	0.5	8.13E+05
	1	6.73E+05
	2	4.30E+05
	3	2.96E+05
	4	2.23E+05
	5	1.75E+05
	6	1.41E+05
	7	1.14E+05
	8	9.30E+04
	9	7.58E+04
	10	6.19E+04
	20	8.31E+03
	30	1.14E+03

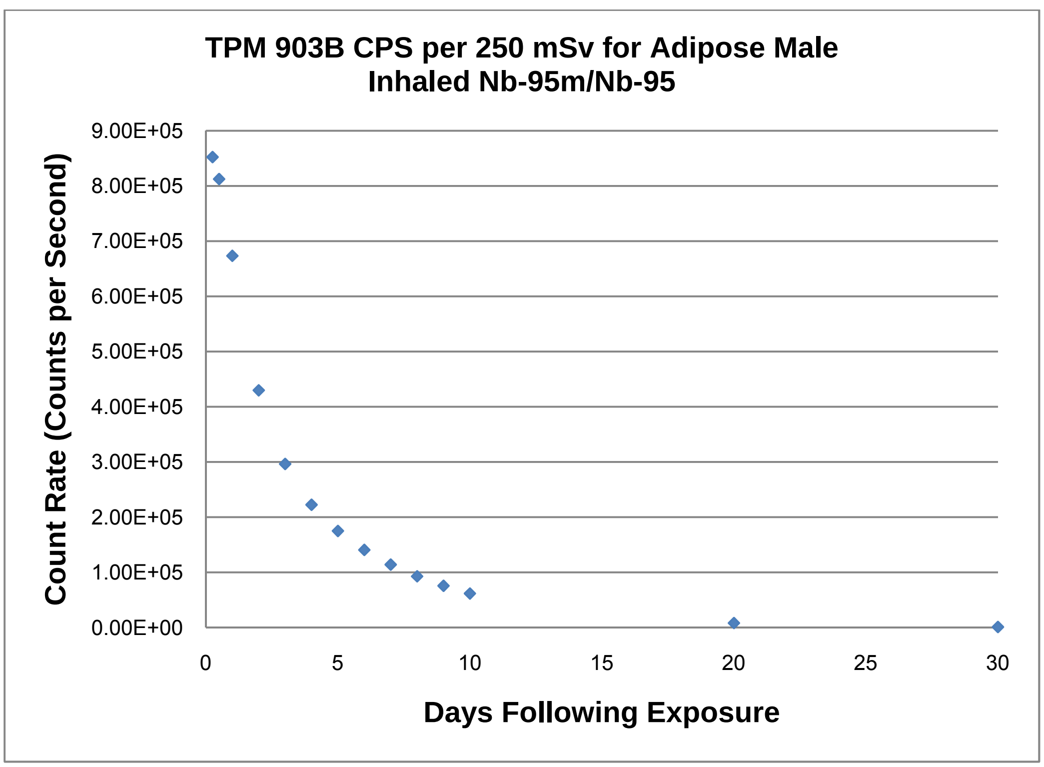

Figure C.11 Nb-95m/Nb-95 count rate per 250 mSv for adipose male

Table C.12 Nb-95 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	S
Days following exposure	0.25	3.89E+05
	0.5	3.86E+05
	1	3.48E+05
	2	2.62E+05
	3	2.14E+05
	4	1.91E+05
	5	1.78E+05
	6	1.70E+05
	7	1.64E+05
	8	1.59E+05
	9	1.54E+05
	10	1.49E+05
	20	1.12E+05
	30	8.65E+04

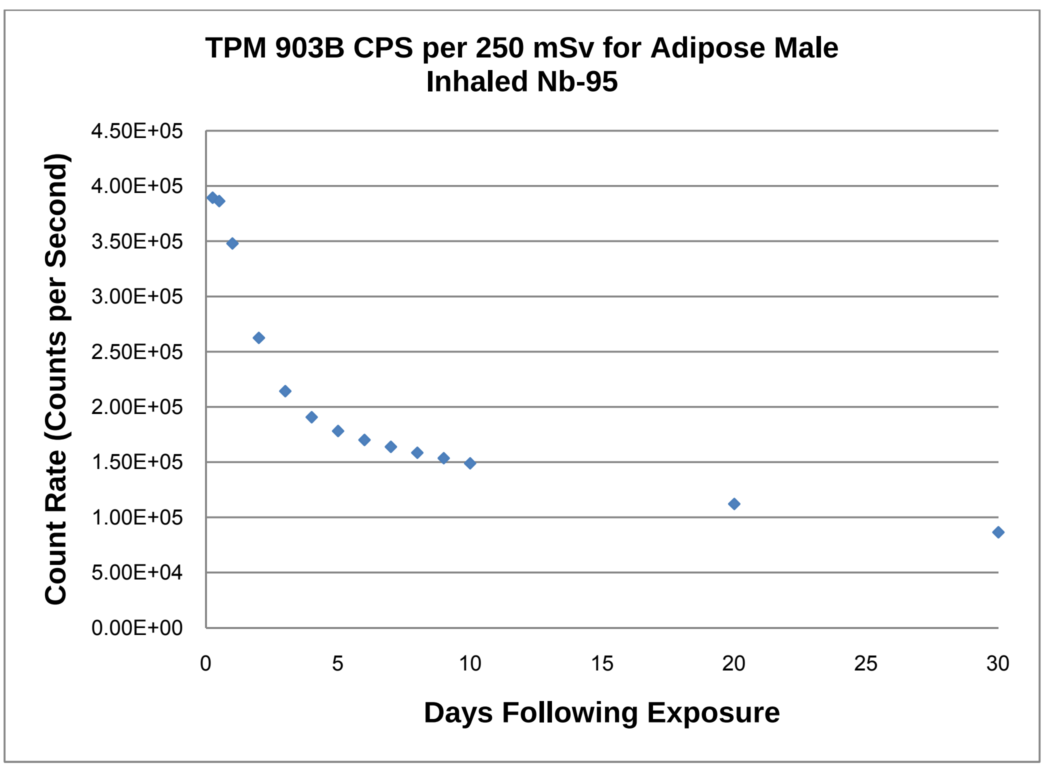

Figure C.12 Nb-95 count rate per 250 mSv for adipose male

Table C.13 Nd-147 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	S
Days following exposure	0.25	4.65E+04
	0.5	4.49E+04
	1	3.90E+04
	2	2.77E+04
	3	2.15E+04
	4	1.83E+04
	5	1.64E+04
	6	1.51E+04
	7	1.40E+04
	8	1.30E+04
	9	1.21E+04
	10	1.13E+04
	20	5.61E+03
	30	2.82E+03

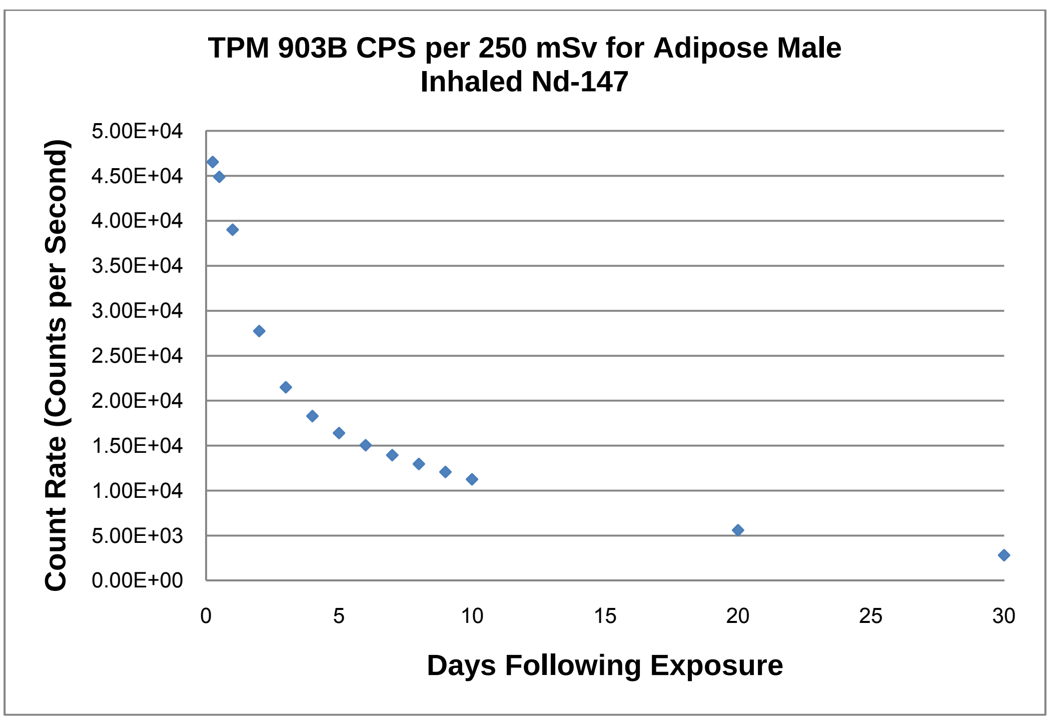

Figure C.13 Nd-147 count rate per 250 mSv for adipose male

Table C.14 Pm-148m/Pm-148 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	S
Days following exposure	0.25	4.14E+05
	0.5	4.02E+05
	1	3.56E+05
	2	2.62E+05
	3	2.11E+05
	4	1.87E+05
	5	1.75E+05
	6	1.68E+05
	7	1.63E+05
	8	1.59E+05
	9	1.55E+05
	10	1.51E+05
	20	1.20E+05
	30	9.60E+04

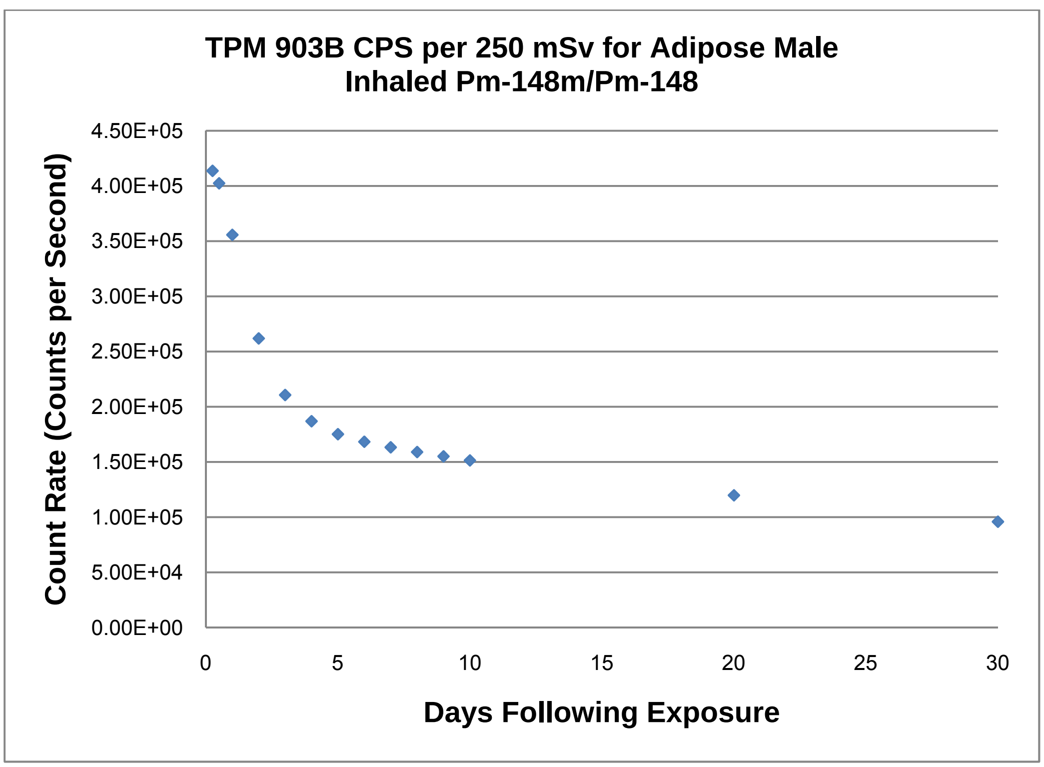

Figure C.14 Pm-148m/Pm-148 count rate per 250 mSv for adipose male

Table C.15 Pm-148 count rate per 250 mSv for adipose male

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	S
	0.25	1.71E+05
	0.5	1.62E+05
	1	1.34E+05
	2	8.76E+04
	3	6.26E+04
	4	4.94E+04
	5	4.13E+04
	6	3.55E+04
	7	3.07E+04
	8	2.67E+04
	9	2.33E+04
	10	2.03E+04
	20	5.24E+03
	30	1.36E+03

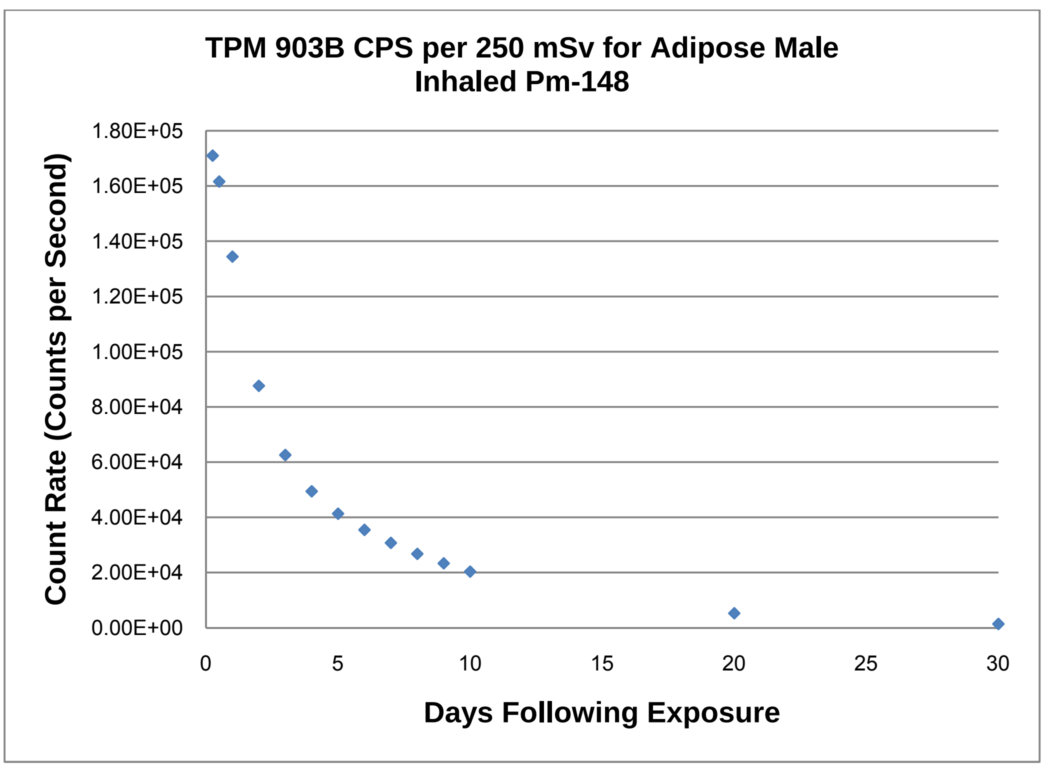

Figure C.15 Pm-148 count rate per 250 mSv for adipose male

Table C.16 Ru-103 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	S
Days following exposure	0.25	1.91E+05
	0.5	1.89E+05
	1	1.70E+05
	2	1.29E+05
	3	1.07E+05
	4	9.55E+04
	5	8.97E+04
	6	8.60E+04
	7	8.32E+04
	8	8.07E+04
	9	7.84E+04
	10	7.62E+04
	20	5.85E+04
	30	4.57E+04

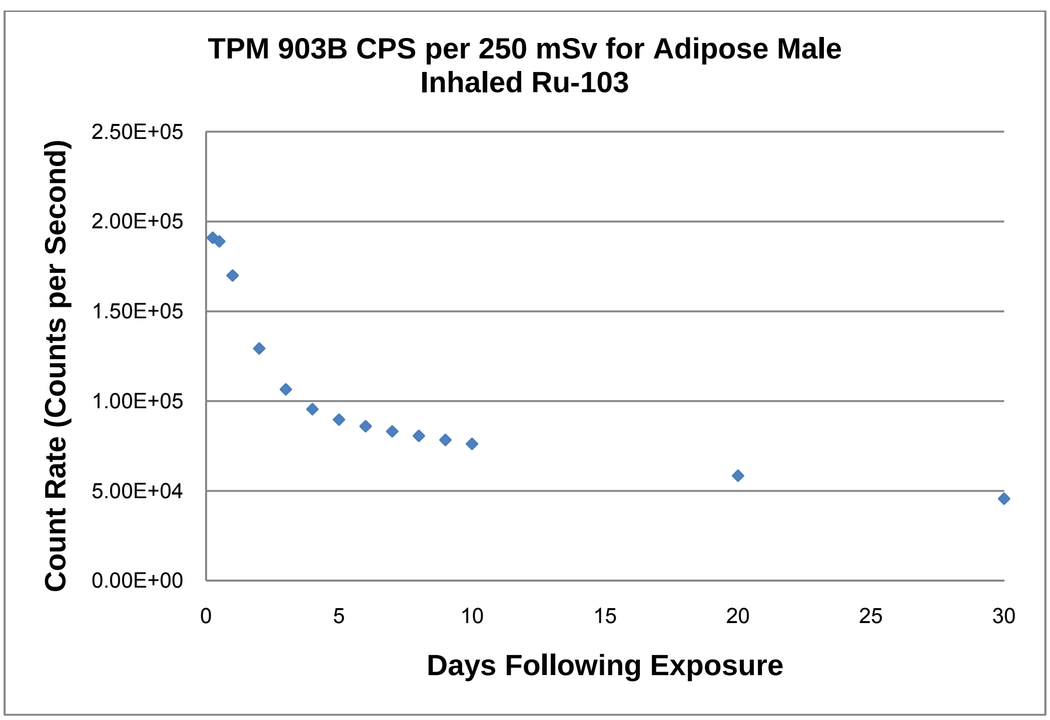

Figure C.16 Ru-103 count rate per 250 mSv for adipose male

Table C.17 Ru-106/Rh-106 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
Days following exposure	Class →	S
	0.25	3.19E+03
	0.5	3.16E+03
	1	2.86E+03
	2	2.20E+03
	3	1.84E+03
	4	1.67E+03
	5	1.59E+03
	6	1.55E+03
	7	1.53E+03
	8	1.50E+03
	9	1.48E+03
	10	1.47E+03
	20	1.32E+03
	30	1.20E+03

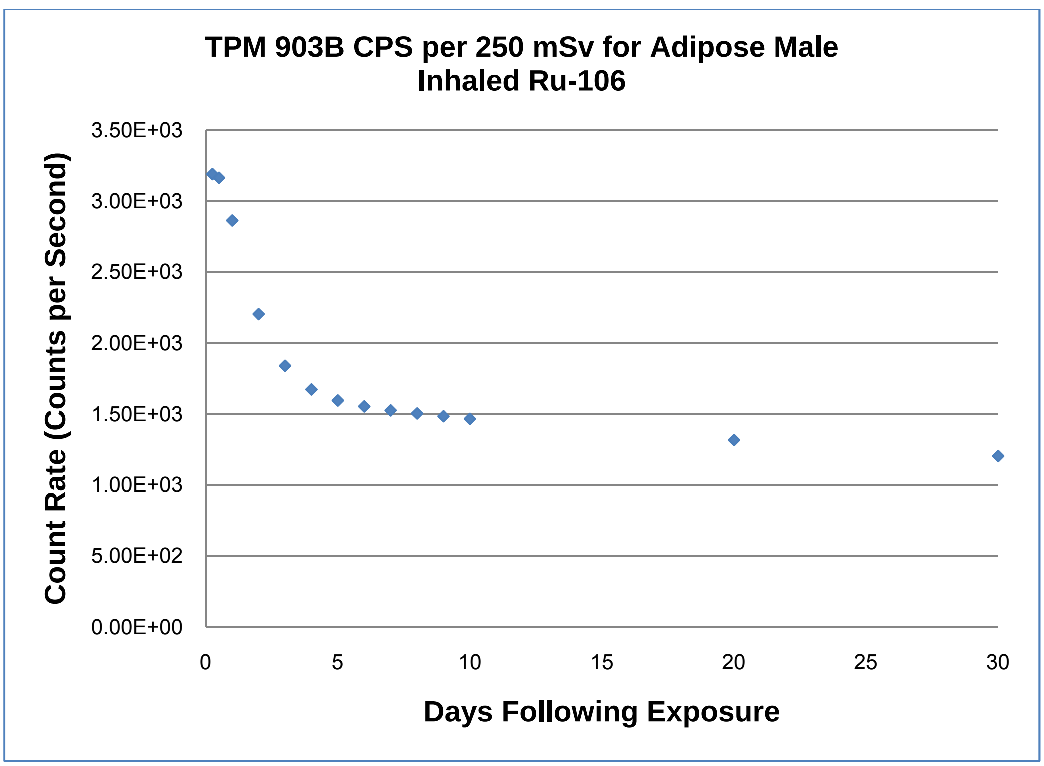

Figure C.17 Ru-106/Rh-106 count rate per 250 mSv for adipose male

Table C.18 Sb-125 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	M
Days following exposure	0.25	1.85E+05
	0.5	1.92E+05
	1	1.87E+05
	2	1.61E+05
	3	1.42E+05
	4	1.29E+05
	5	1.20E+05
	6	1.13E+05
	7	1.08E+05
	8	1.03E+05
	9	9.85E+04
	10	9.47E+04
	20	7.38E+04
	30	6.60E+04

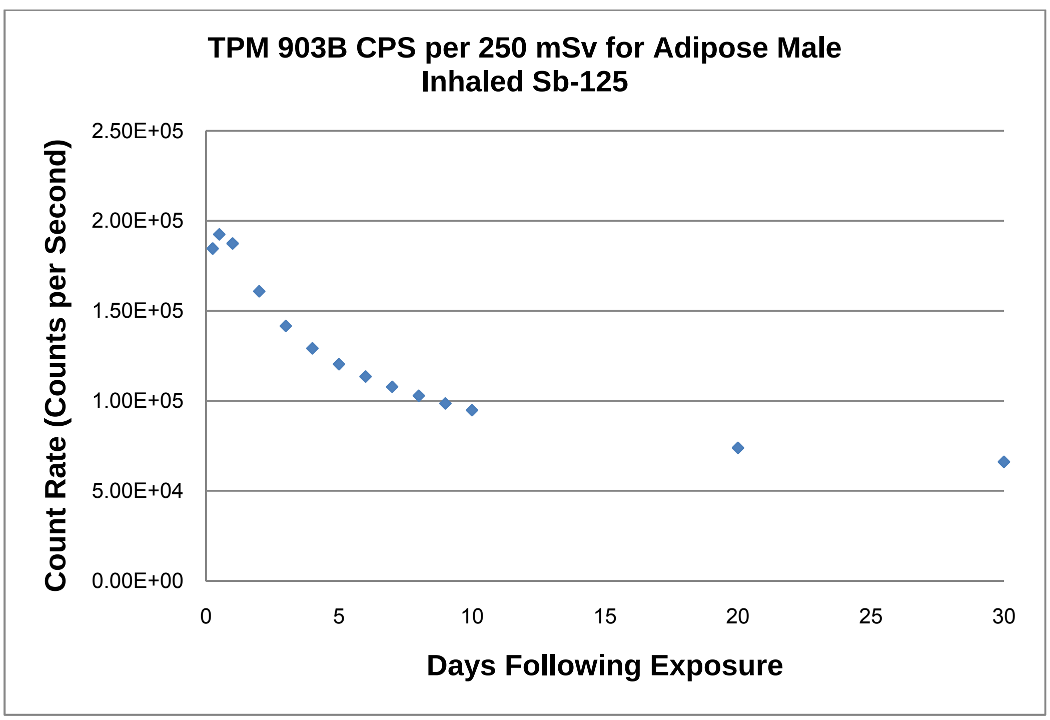

Figure C.18 Sb-125 count rate per 250 mSv for adipose male

Table C.19 Te-127m/Te-127 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	M
Days following exposure	0.25	1.58E+03
	0.5	1.64E+03
	1	1.58E+03
	2	1.41E+03
	3	1.32E+03
	4	1.28E+03
	5	1.26E+03
	6	1.24E+03
	7	1.23E+03
	8	1.22E+03
	9	1.21E+03
	10	1.20E+03
	20	1.13E+03
	30	1.06E+03

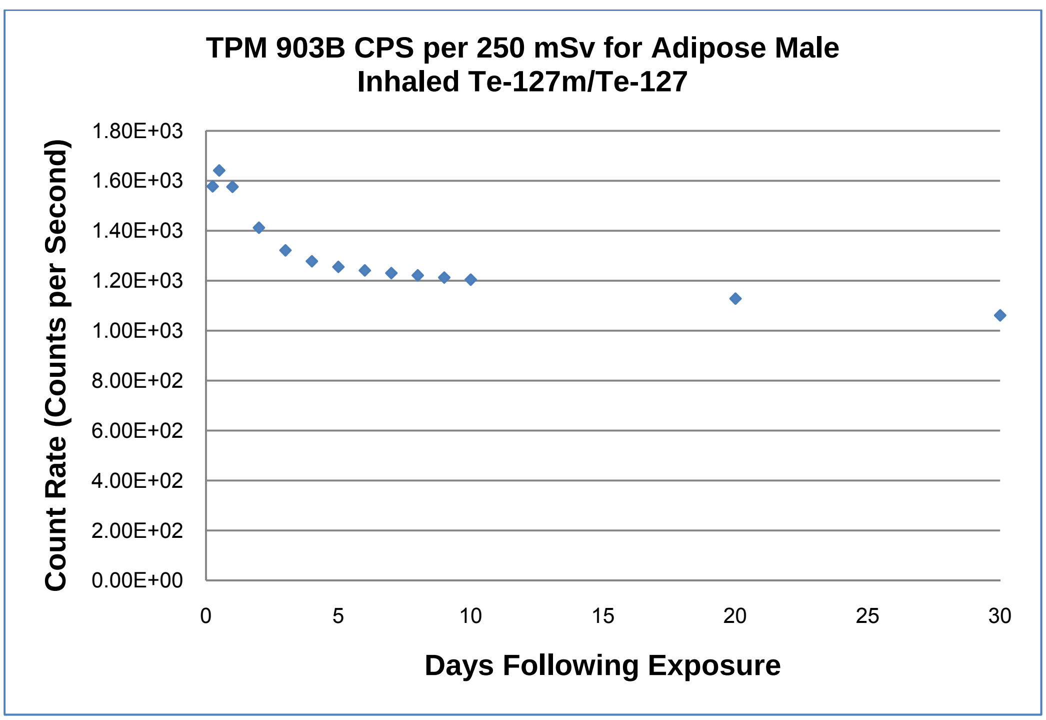

Figure C.19 Te-127m/Te-127 count rate per 250 mSv for adipose male

Table C.20 Te-127 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	M
Days following exposure	0.25	5.66E+04
	0.5	3.85E+04
	1	1.52E+04
	2	2.32E+03
	3	3.69E+02
	4	6.05E+01
	5	1.01E+01
	6	1.70E+00
	7	2.86E-01
	8	4.82E-02
	9	8.12E-03
	10	1.37E-03
	20	2.56E-11
	30	5.06E-20

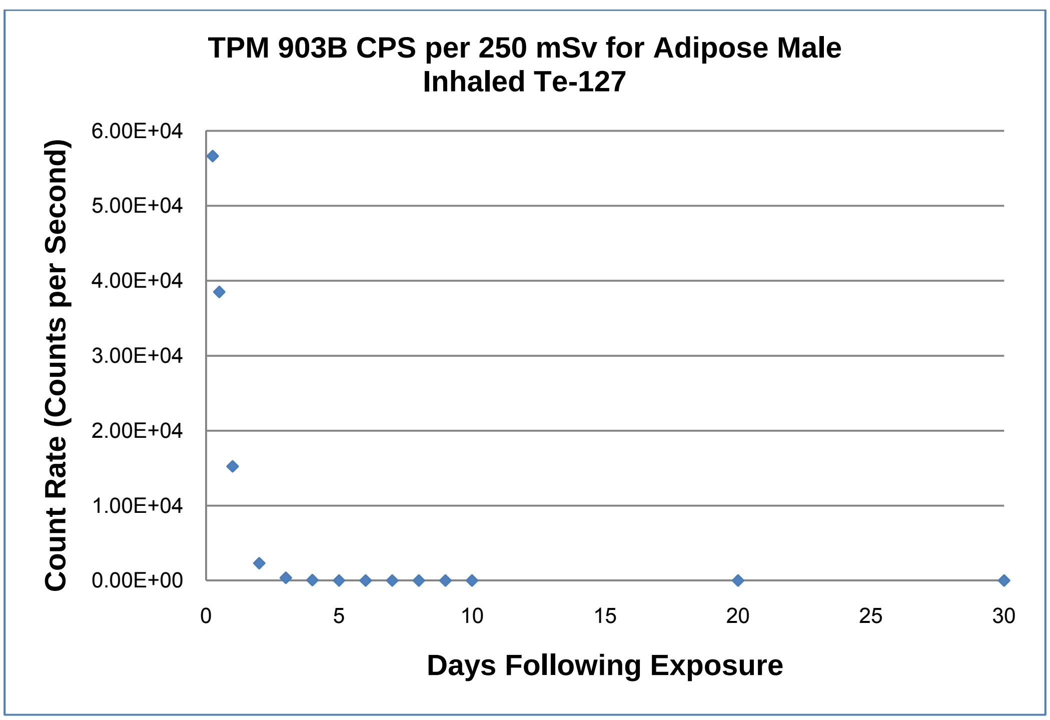

Figure C.20 Te-127 count rate per 250 mSv for adipose male

Table C.21 Te-129m/Te-129 count rate per 250 mSv for adipose male

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	M
	0.25	2.48E+04
	0.5	2.57E+04
	1	2.45E+04
	2	2.15E+04
	3	1.98E+04
	4	1.89E+04
	5	1.83E+04
	6	1.78E+04
	7	1.74E+04
	8	1.71E+04
	9	1.67E+04
	10	1.63E+04
	20	1.33E+04
	30	1.08E+04

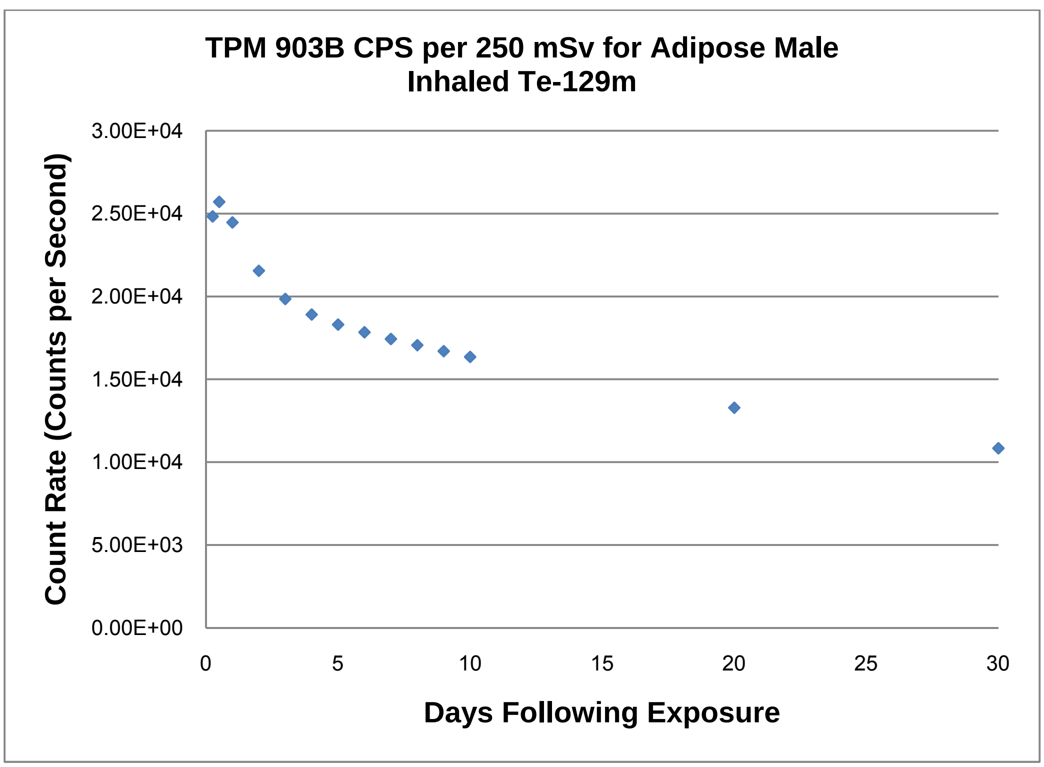

Figure C.21 Te-129m/Te-129 count rate per 250 mSv for adipose male

Table C.22 Te-129 count rate per 250 mSv for adipose male

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	M
	0.25	7.32E+04
	0.5	2.44E+03
	1	1.81E+00
	2	9.62E-07
	3	5.35E-13
	4	0.00E+00
	5	0.00E+00
	6	0.00E+00
	7	0.00E+00
	8	0.00E+00
	9	0.00E+00
	10	0.00E+00
	20	0.00E+00
	30	0.00E+00

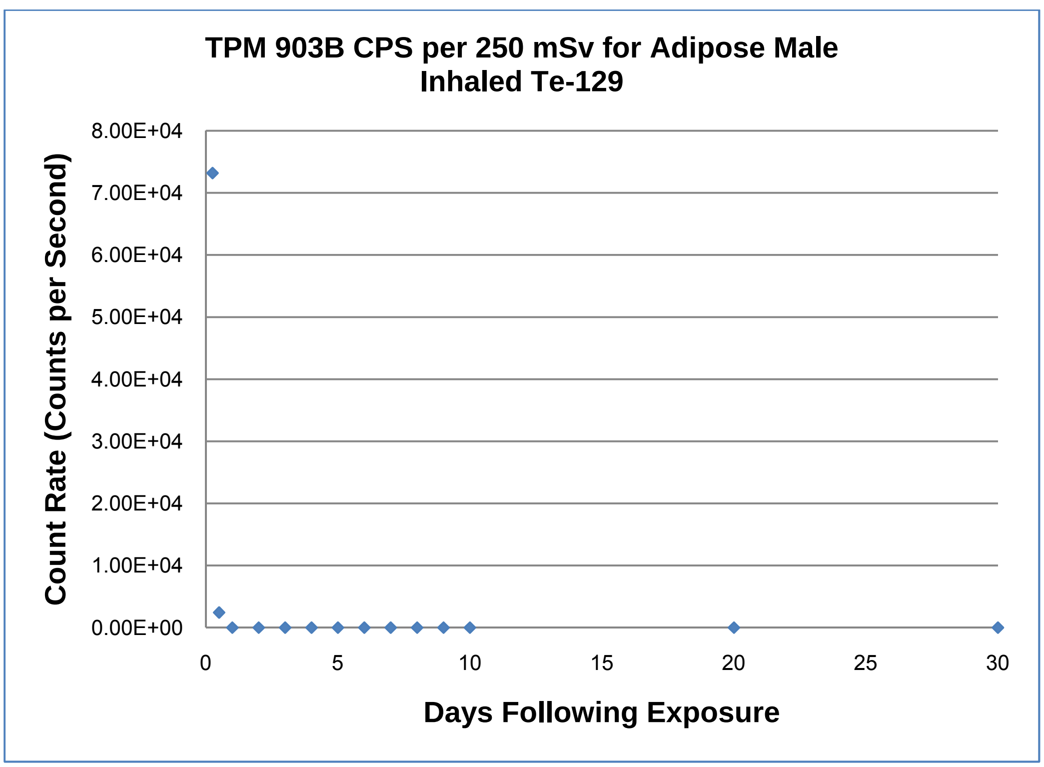

Figure C.22 Te-129 count rate per 250 mSv for adipose male

Table C.23 Zr-95/Nb-95m/Nb-95 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	**M**
Days following exposure	0.25	5.54E+05
	0.5	5.86E+05
	1	5.93E+05
	2	5.41E+05
	3	5.02E+05
	4	4.81E+05
	5	4.68E+05
	6	4.58E+05
	7	4.51E+05
	8	4.44E+05
	9	4.38E+05
	10	4.33E+05
	20	3.95E+05
	30	3.69E+05

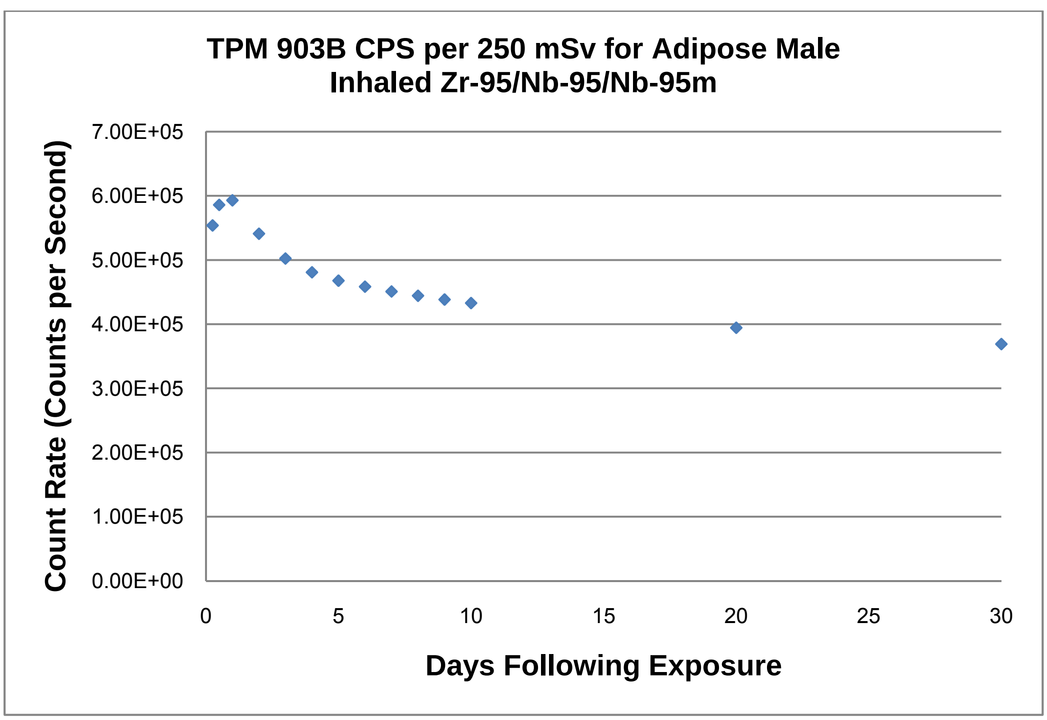

Figure C.23 Zr-95/Nb-95/Nb-95m count rate per 250 mSv for adipose male

Table C.24 Cs-137/Ba-137m count rate per 250 mSv for child

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	F
	0.25	4.50E+06
	0.5	4.79E+06
	1	4.97E+06
	2	4.90E+06
	3	4.79E+06
	4	4.70E+06
	5	4.63E+06
	6	4.57E+06
	7	4.52E+06
	8	4.47E+06
	9	4.43E+06
	10	4.40E+06
	20	4.11E+06
	30	3.86E+06

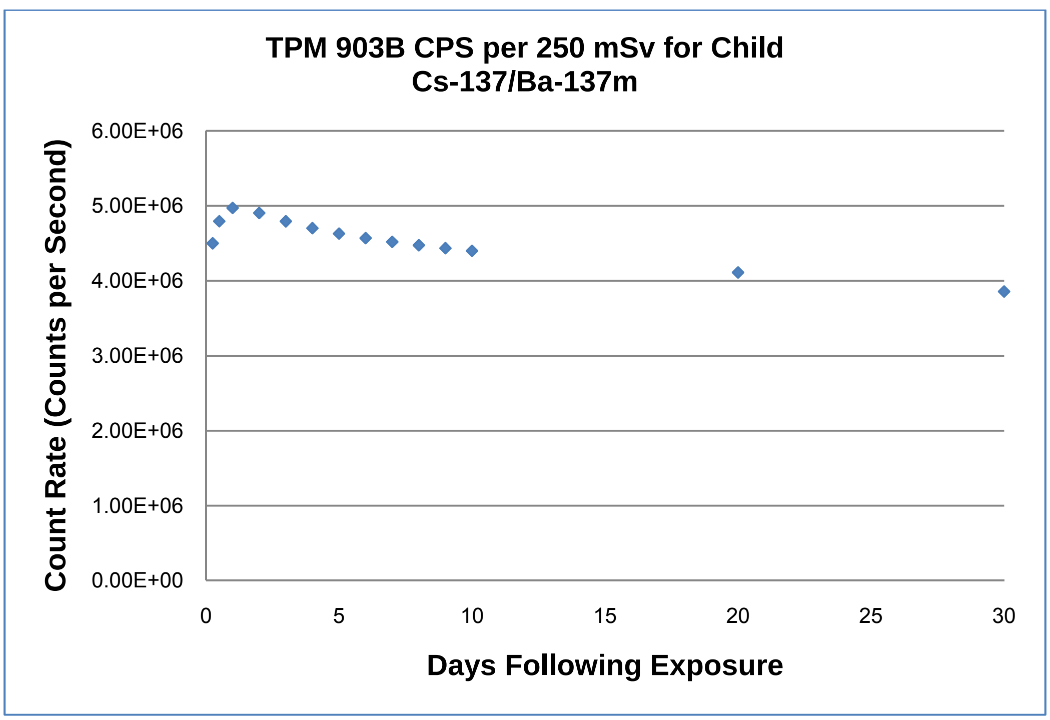

Figure C.24 Cs-137/Ba-137m count rate per 250 mSv for child

Table C.25 Ba-140/La-140 count rate per 250 mSv for child

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	F
	0.25	4.28E+06
	0.5	3.88E+06
	1	3.25E+06
	2	2.35E+06
	3	1.76E+06
	4	1.37E+06
	5	1.11E+06
	6	9.29E+05
	7	7.97E+05
	8	7.00E+05
	9	6.26E+05
	10	5.68E+05
	20	2.82E+05
	30	1.54E+05

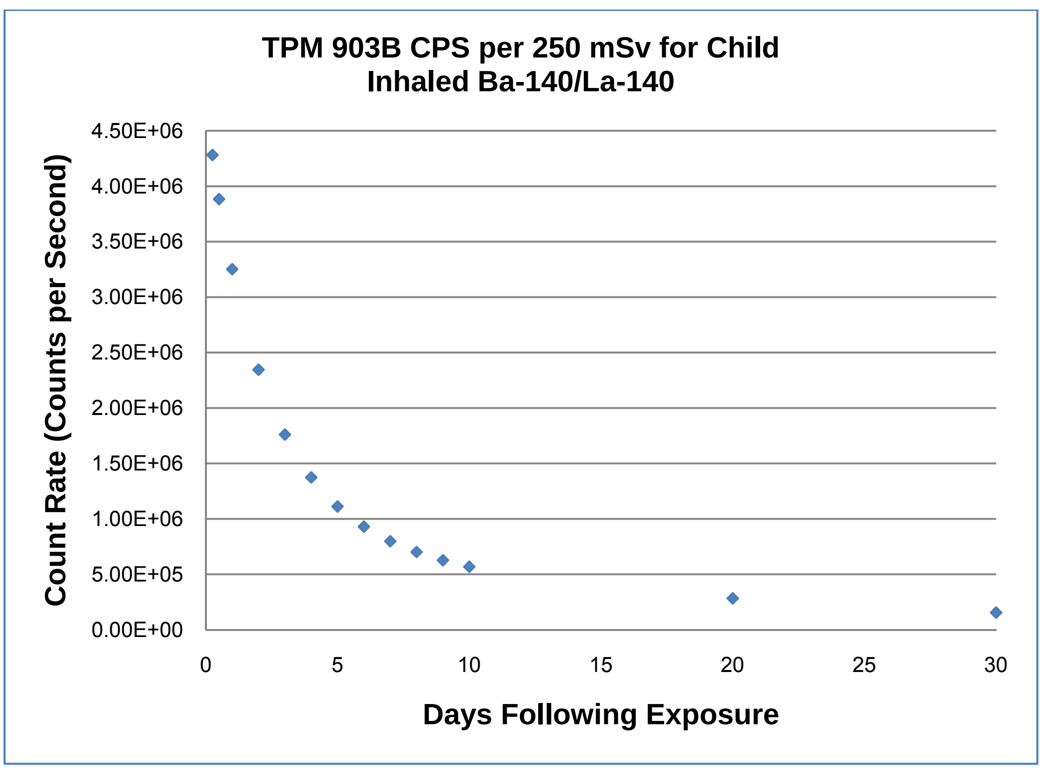

Figure C.25 Ba-140/La-140 count rate per 250 mSv for child

Table C.26 Ce-141 count rate per 250 mSv for child

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	S
	0.25	1.07E+04
	0.5	1.03E+04
	1	9.00E+03
	2	6.65E+03
	3	5.39E+03
	4	4.80E+03
	5	4.49E+03
	6	4.30E+03
	7	4.16E+03
	8	4.03E+03
	9	3.91E+03
	10	3.80E+03
	20	2.86E+03
	30	2.17E+03

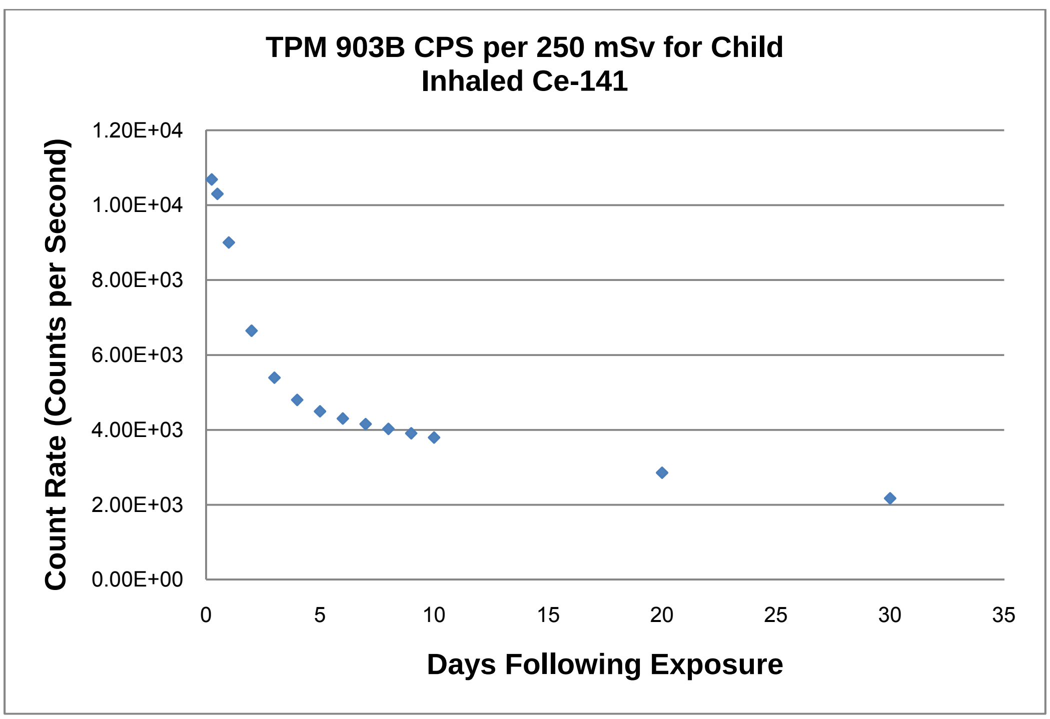

Figure C.26 Ce-141 count rate per 250 mSv for child

Table C.27 Ce-144/Pr-144 count rate per 250 mSv for child

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	S
	0.25	3.58E+02
	0.5	3.46E+02
	1	3.02E+02
	2	2.22E+02
	3	1.79E+02
	4	1.60E+02
	5	1.52E+02
	6	1.48E+02
	7	1.46E+02
	8	1.44E+02
	9	1.42E+02
	10	1.41E+02
	20	1.28E+02
	30	1.17E+02

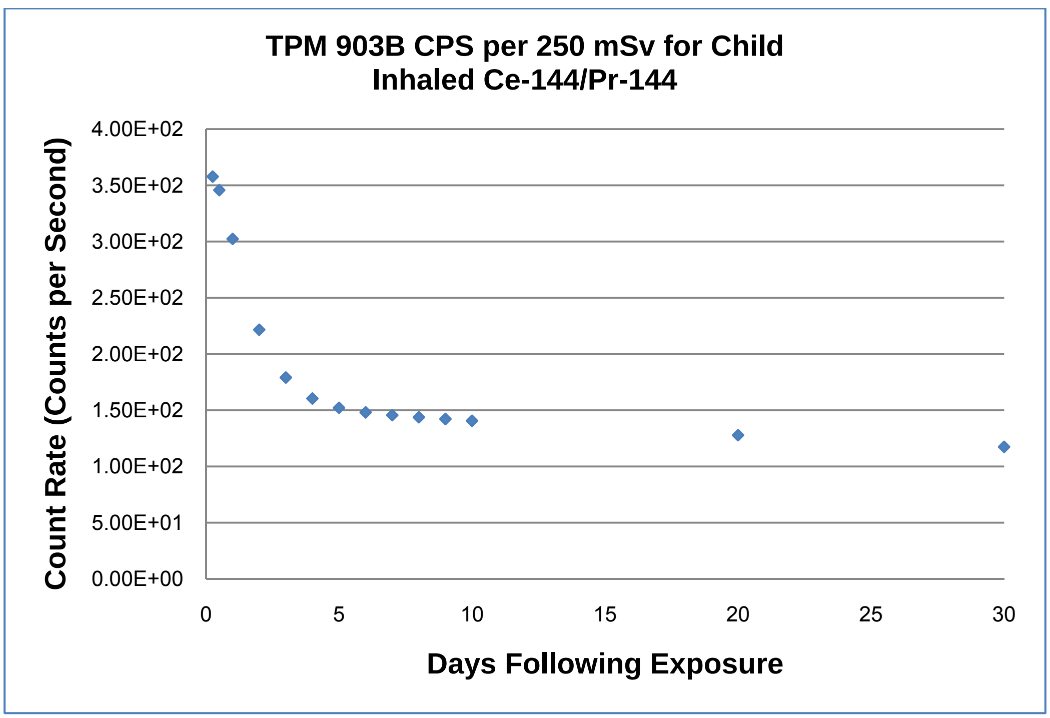

Figure C.27 Ce-144/Pr-144 count rate per 250 mSv for child

Table C.28 Cs-134 count rate per 250 mSv for child

		Total Body Count
		cps per 250 mSv
	Class →	F
Days following exposure	0.25	3.26E+06
	0.5	3.48E+06
	1	3.60E+06
	2	3.55E+06
	3	3.47E+06
	4	3.40E+06
	5	3.34E+06
	6	3.30E+06
	7	3.26E+06
	8	3.22E+06
	9	3.19E+06
	10	3.17E+06
	20	2.93E+06
	30	2.73E+06

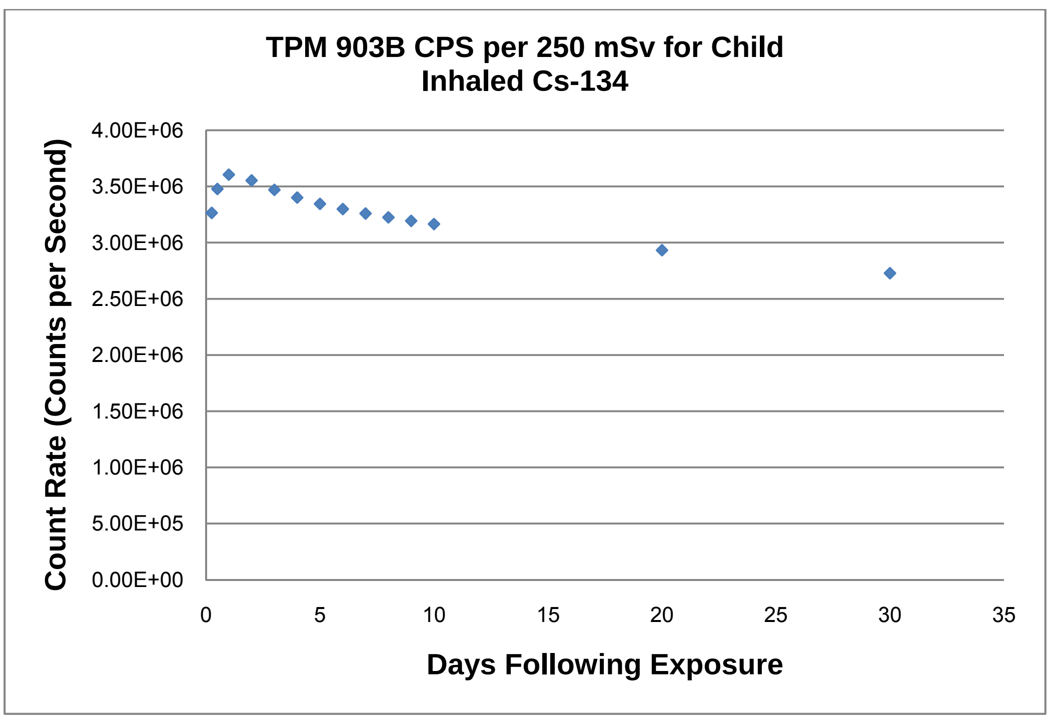

Figure C.28 Cs-134 count rate per 250 mSv for child

Table C.29 Cs-136 count rate per 250 mSv for child

		Total Body Count
		cps per 250 mSv
	Class →	F
Days following exposure	0.25	1.04E+07
	0.5	1.06E+07
	1	1.05E+07
	2	9.77E+06
	3	9.05E+06
	4	8.42E+06
	5	7.87E+06
	6	7.37E+06
	7	6.91E+06
	8	6.49E+06
	9	6.10E+06
	10	5.74E+06
	20	3.16E+06
	30	1.75E+06

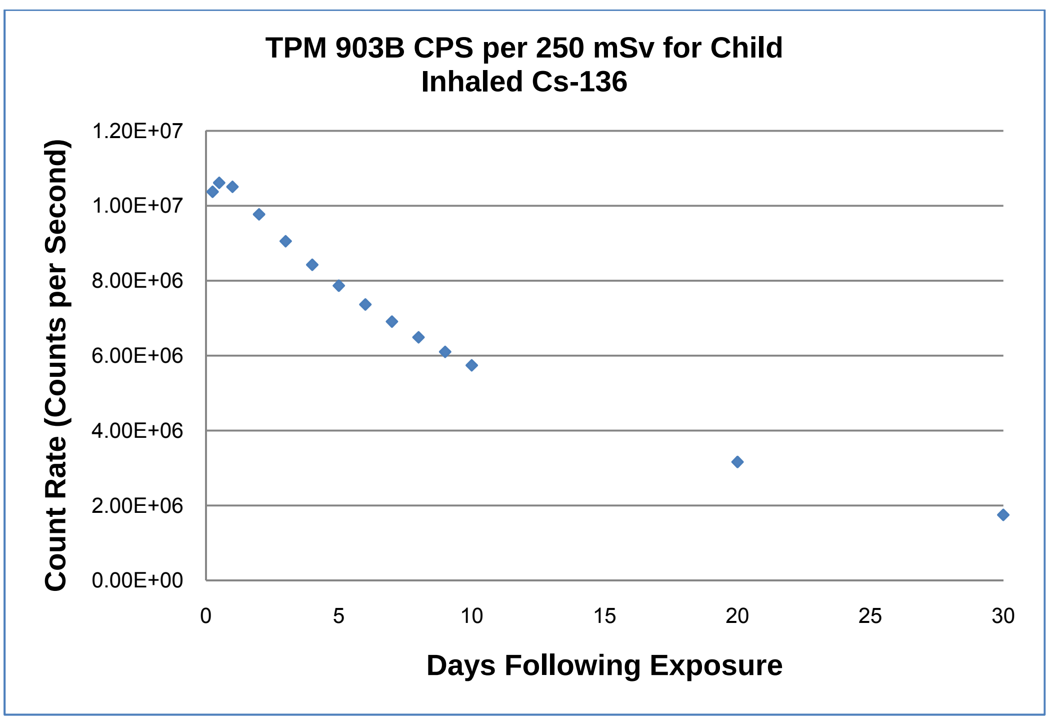

Figure C.29 Cs-136 count rate per 250 mSv for child

Table C.30 Eu-154 count rate per 250 mSv for child

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	M
	0.25	1.71E+04
	0.5	1.79E+04
	1	1.72E+04
	2	1.43E+04
	3	1.27E+04
	4	1.21E+04
	5	1.19E+04
	6	1.18E+04
	7	1.18E+04
	8	1.19E+04
	9	1.19E+04
	10	1.20E+04
	20	1.24E+04
	30	1.29E+04

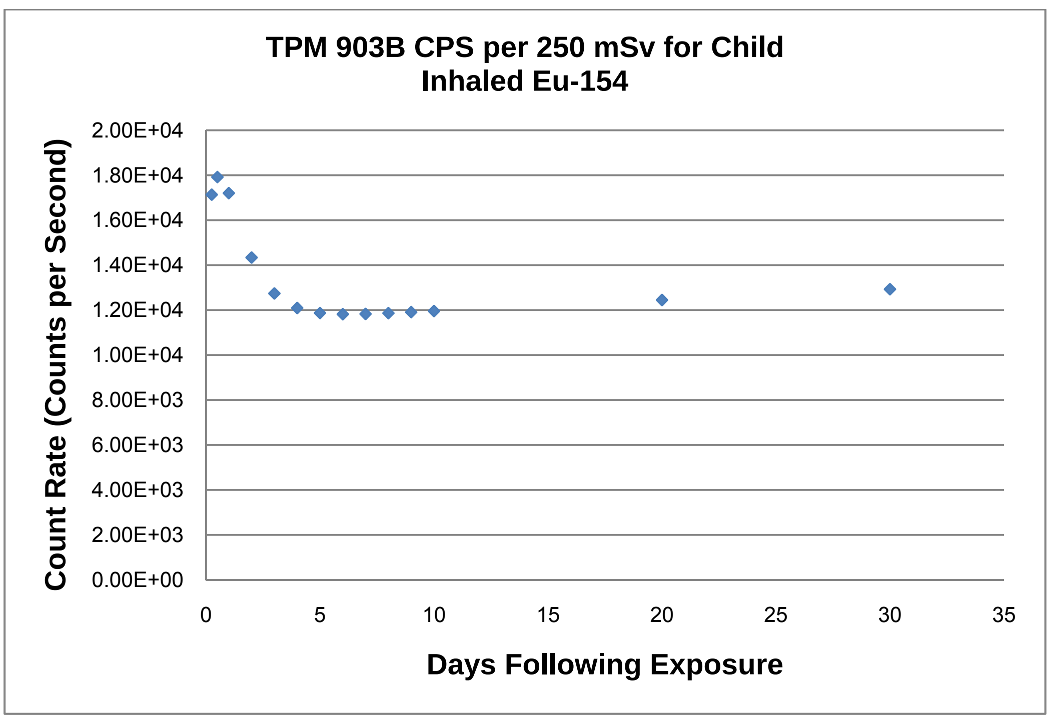

Figure C.30 Eu-154 count rate per 250 mSv for child

Table C.31 Eu-156 count rate per 250 mSv for child

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	M
	0.25	1.58E+05
	0.5	1.63E+05
	1	1.53E+05
	2	1.21E+05
	3	1.03E+05
	4	9.31E+04
	5	8.73E+04
	6	8.31E+04
	7	7.94E+04
	8	7.62E+04
	9	7.30E+04
	10	7.01E+04
	20	4.64E+04
	30	3.06E+04

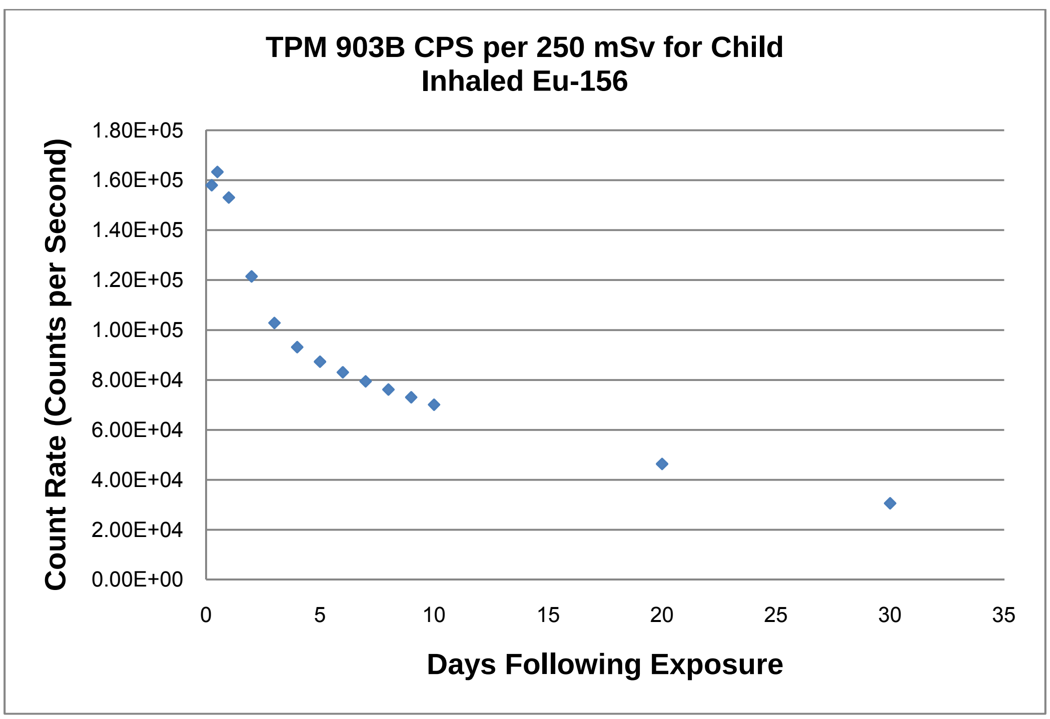

Figure C.31 Eu-156 count rate per 250 mSv for child

Table C.32 I-131 count rate per 250 mSv for child

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	F
	0.25	1.59E+05
	0.5	8.55E+04
	1	2.84E+04
	2	1.13E+04
	3	1.01E+04
	4	9.74E+03
	5	9.39E+03
	6	9.01E+03
	7	8.60E+03
	8	8.18E+03
	9	7.74E+03
	10	7.31E+03
	20	3.64E+03
	30	1.62E+03

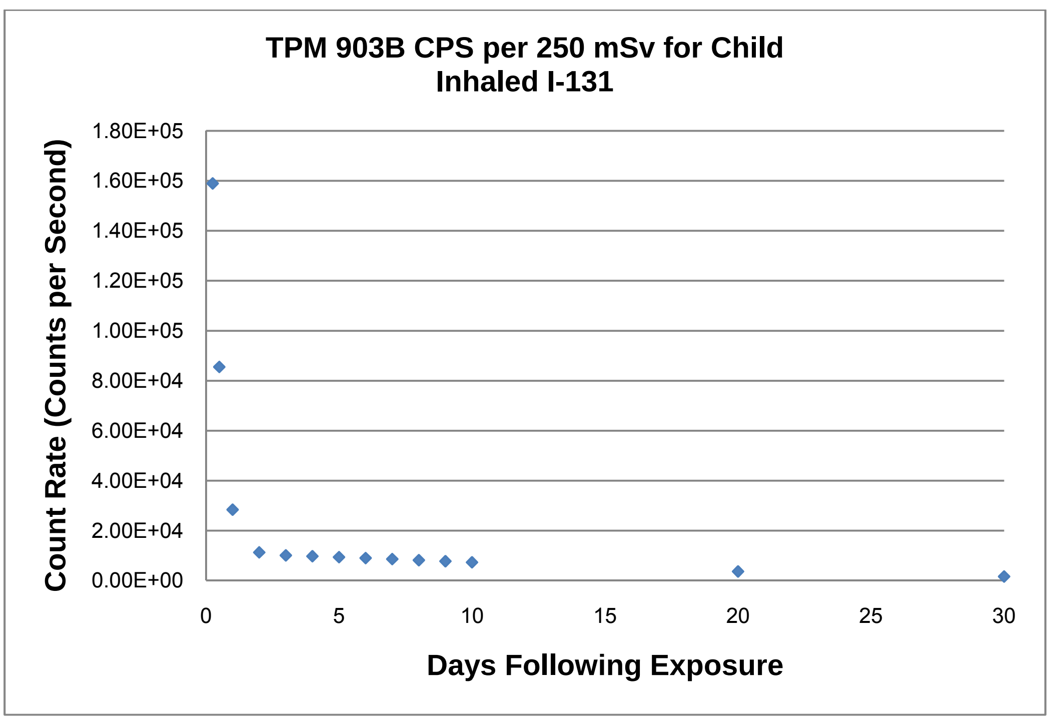

Figure C.32 I-131 count rate per 250 mSv for child

Table C.33 La-140 count rate per 250 mSv for child

		Total Body Count
		cps per 250 mSv
	Class →	M
Days following exposure	0.25	1.01E+06
	0.5	8.71E+05
	1	6.33E+05
	2	3.40E+05
	3	1.99E+05
	4	1.25E+05
	5	8.13E+04
	6	5.35E+04
	7	3.55E+04
	8	2.35E+04
	9	1.56E+04
	10	1.04E+04
	20	1.74E+02
	30	2.91E+00

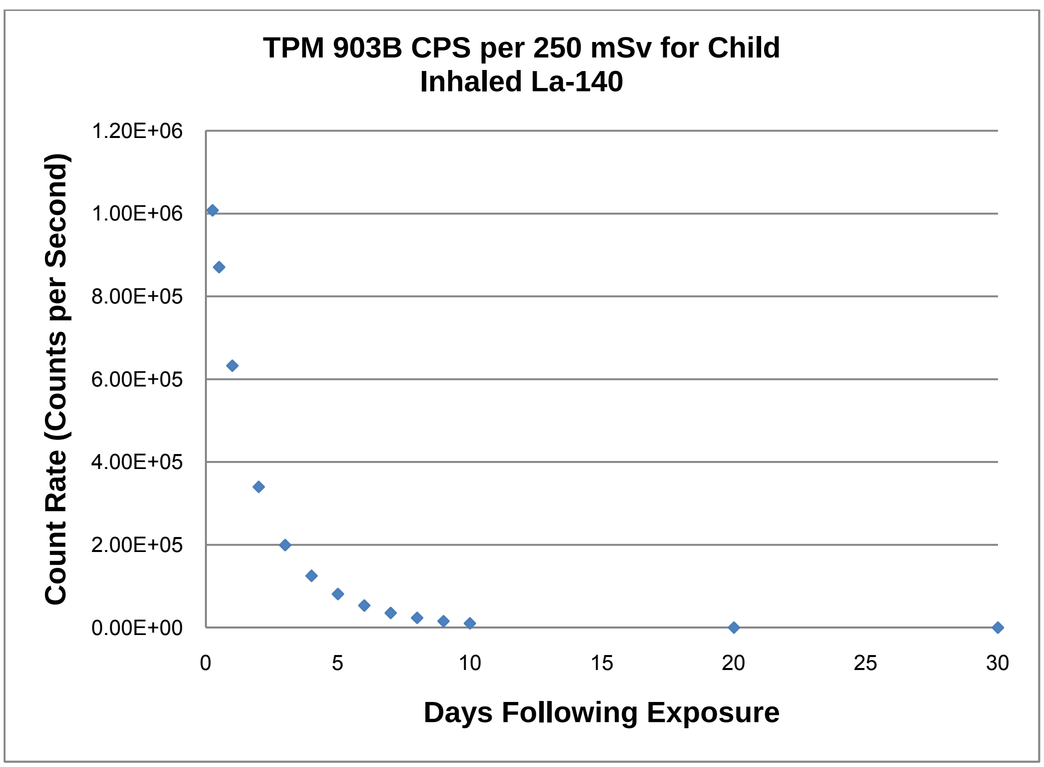

Figure C.33 La-140 count rate per 250 mSv for child

Table C.34 Nb-95m/Nb-95 count rate per 250 mSv for adipose male

		Total Body Count
		cps per 250 mSv
	Class →	S
Days following exposure	0.25	7.36E+05
	0.5	6.89E+05
	1	5.55E+05
	2	3.43E+05
	3	2.32E+05
	4	1.72E+05
	5	1.35E+05
	6	1.09E+05
	7	8.82E+04
	8	7.18E+04
	9	5.86E+04
	10	4.79E+04
	20	6.45E+03
	30	8.85E+02

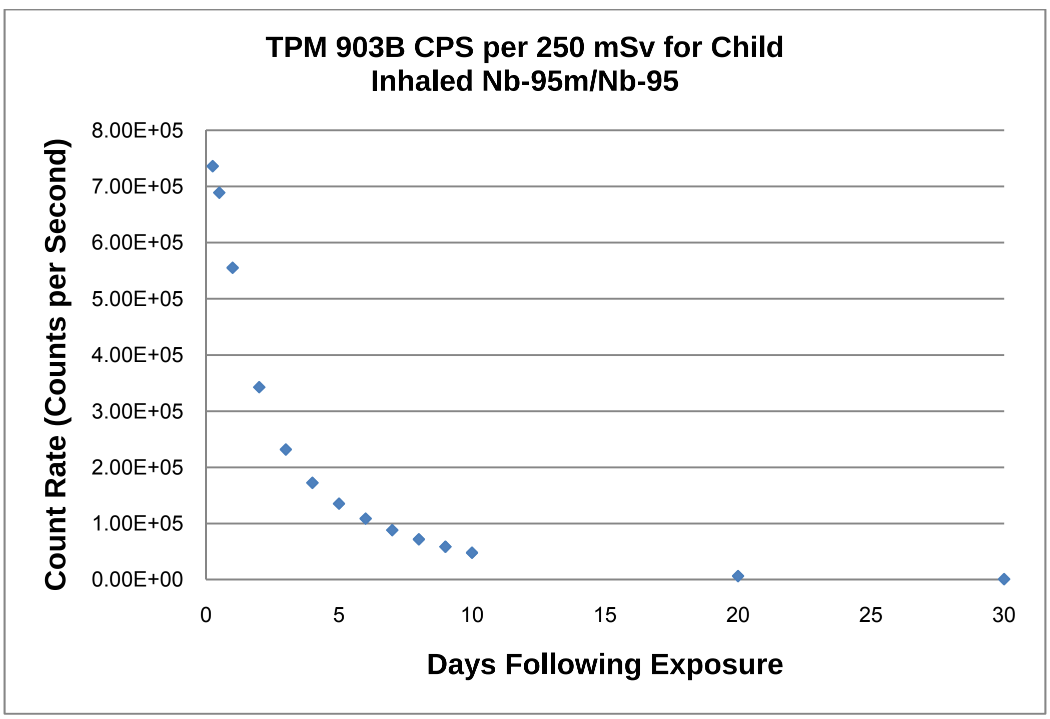

Figure C.34 Nb-95m/Nb-95 count rate per 250 mSv for adipose male

Table C.35 Nb-95 count rate per 250 mSv for child

		Total Body Count
		cps per 250 mSv
	Class →	S
Days following exposure	0.25	3.43E+05
	0.5	3.35E+05
	1	2.94E+05
	2	2.15E+05
	3	1.72E+05
	4	1.52E+05
	5	1.41E+05
	6	1.35E+05
	7	1.30E+05
	8	1.26E+05
	9	1.22E+05
	10	1.18E+05
	20	8.93E+04
	30	6.87E+04

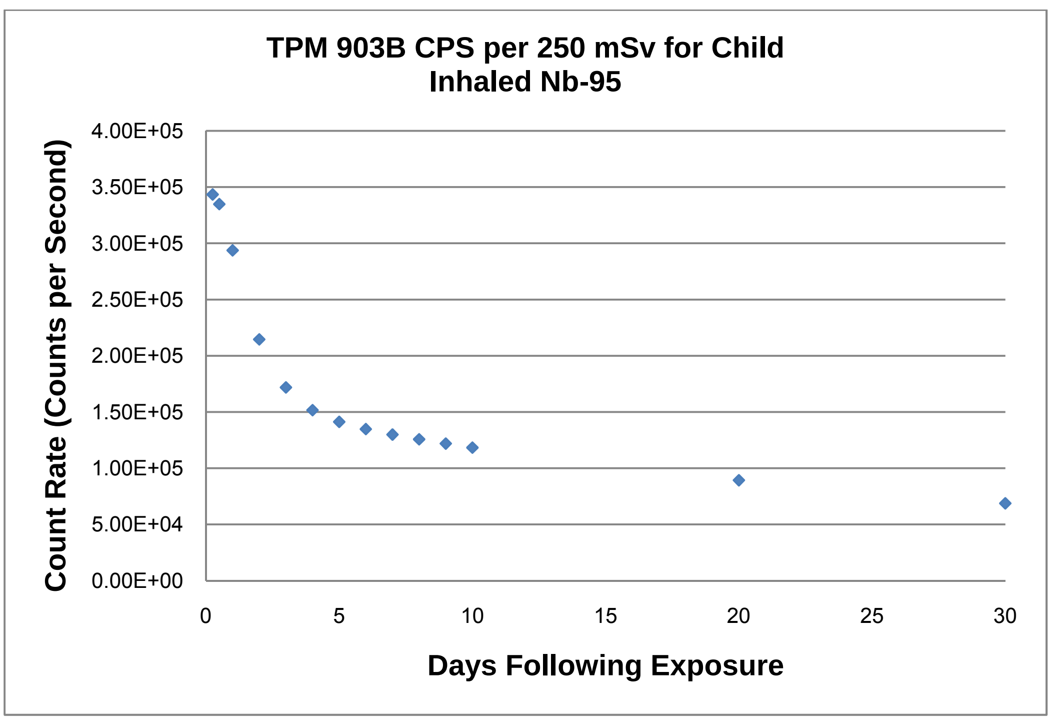

Figure C.35 Nb-95 count rate per 250 mSv for child

Table C.36 Nd-147 count rate per 250 mSv for child

		Total Body Count
		cps per 250 mSv
	Class →	S
Days following exposure	0.25	4.35E+04
	0.5	4.15E+04
	1	3.52E+04
	2	2.43E+04
	3	1.85E+04
	4	1.56E+04
	5	1.39E+04
	6	1.27E+04
	7	1.18E+04
	8	1.09E+04
	9	1.02E+04
	10	9.47E+03
	20	4.69E+03
	30	2.35E+03

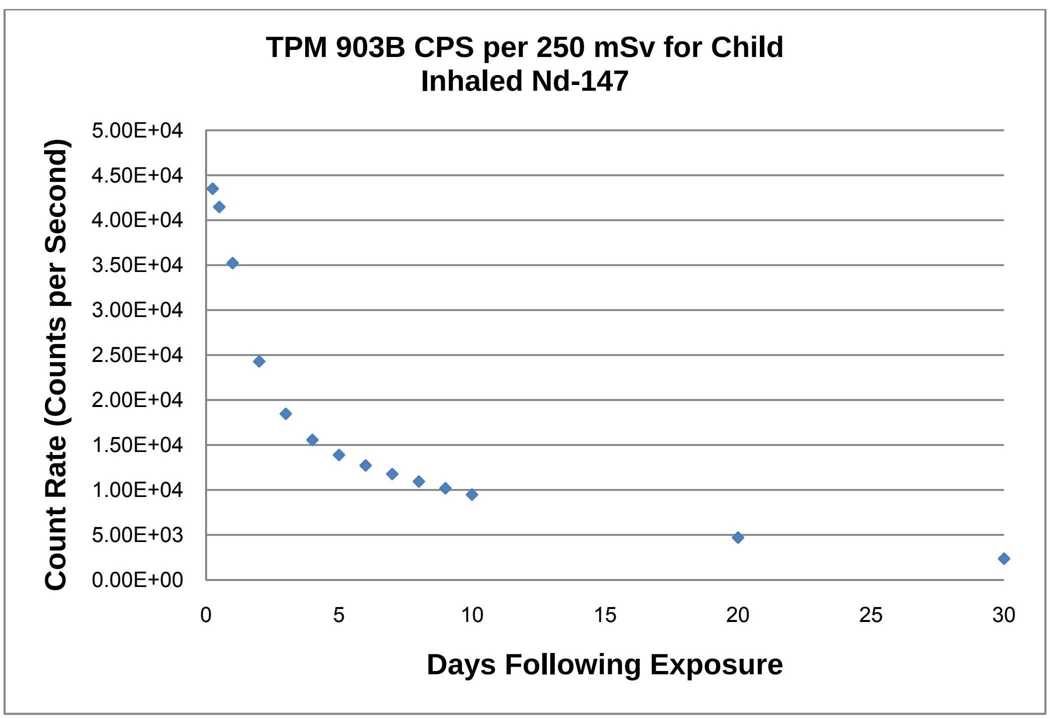

Figure C.36 Nd-147 count rate per 250 mSv for child

Table C.37 Pm-148m/Pm-148 count rate per 250 mSv for child

		Total Body Count
		cps per 250 mSv
	Class →	S
Days following exposure	0.25	3.64E+05
	0.5	3.51E+05
	1	3.04E+05
	2	2.19E+05
	3	1.73E+05
	4	1.52E+05
	5	1.42E+05
	6	1.37E+05
	7	1.32E+05
	8	1.29E+05
	9	1.26E+05
	10	1.22E+05
	20	9.63E+04
	30	7.66E+04

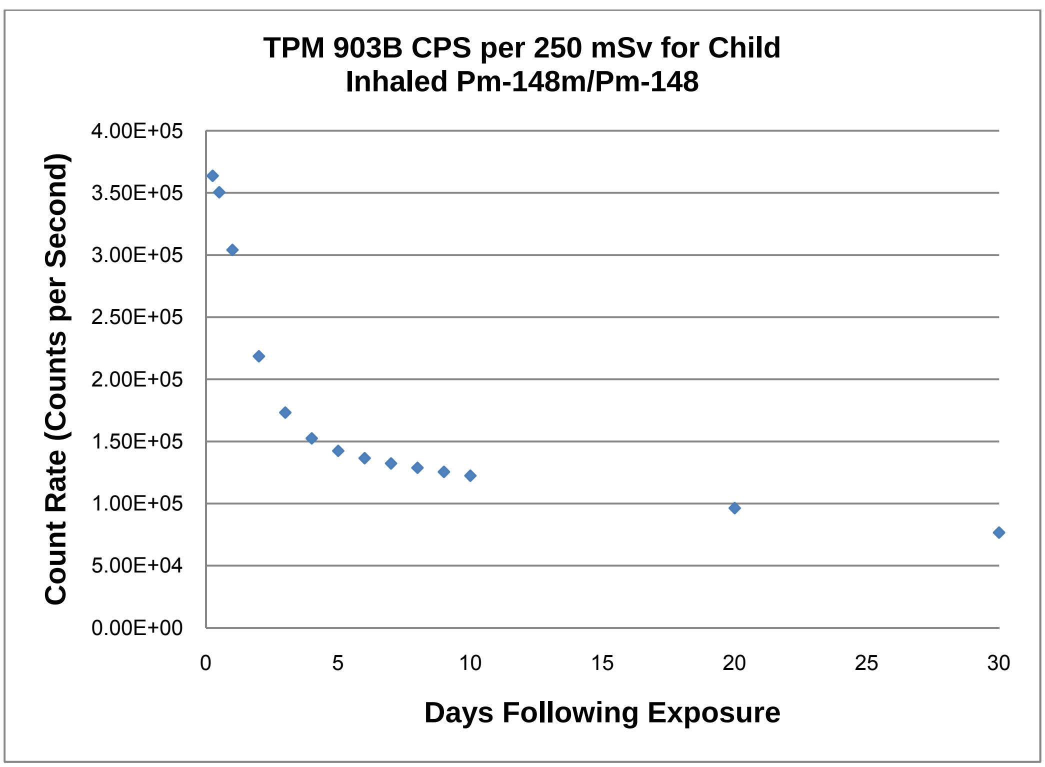

Figure C.37 Pm-148m/Pm-148 count rate per 250 mSv for child

Table C.38 Pm-148 count rate per 250 mSv for child

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	S
	0.25	1.24E+05
	0.5	1.16E+05
	1	9.53E+04
	2	6.09E+04
	3	4.30E+04
	4	3.37E+04
	5	2.81E+04
	6	2.41E+04
	7	2.09E+04
	8	1.82E+04
	9	1.58E+04
	10	1.38E+04
	20	3.53E+03
	30	9.13E+02

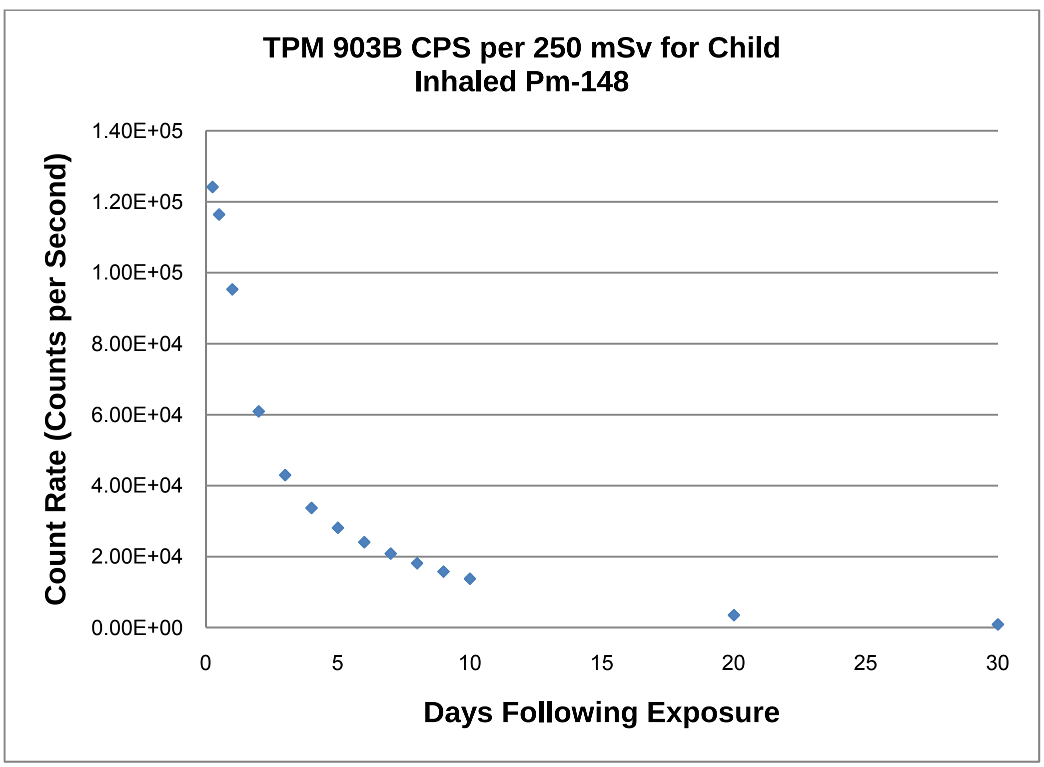

Figure C.38 Pm-148 count rate per 250 mSv for child

Table C.39 Ru-103 count rate per 250 mSv for child

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	S
	0.25	1.80E+05
	0.5	1.76E+05
	1	1.54E+05
	2	1.14E+05
	3	9.20E+04
	4	8.17E+04
	5	7.65E+04
	6	7.32E+04
	7	7.08E+04
	8	6.87E+04
	9	6.68E+04
	10	6.49E+04
	20	4.99E+04
	30	3.90E+04

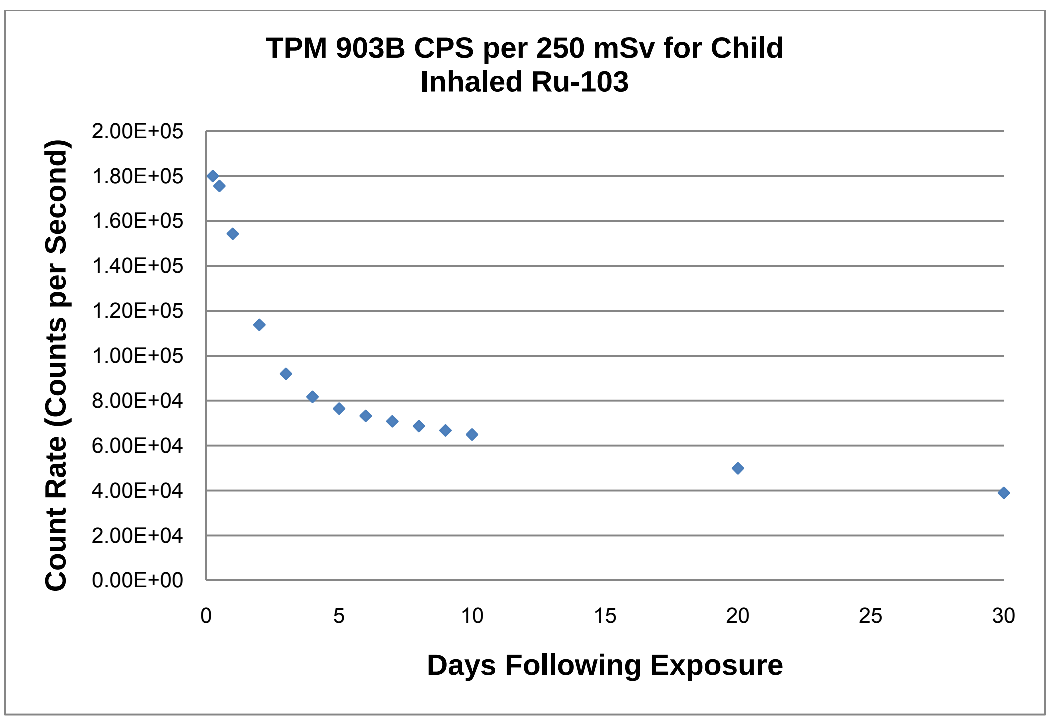

Figure C.39 Ru-103 count rate per 250 mSv for child

Table C.40 Ru-106/Rh-106 count rate per 250 mSv for child

		Total Body Count
		cps per 250 mSv
	Class →	S
Days following exposure	0.25	2.96E+03
	0.5	2.90E+03
	1	2.57E+03
	2	1.93E+03
	3	1.59E+03
	4	1.43E+03
	5	1.36E+03
	6	1.33E+03
	7	1.30E+03
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	9	1.27E+03
	10	1.25E+03
	20	1.12E+03
	30	1.03E+03

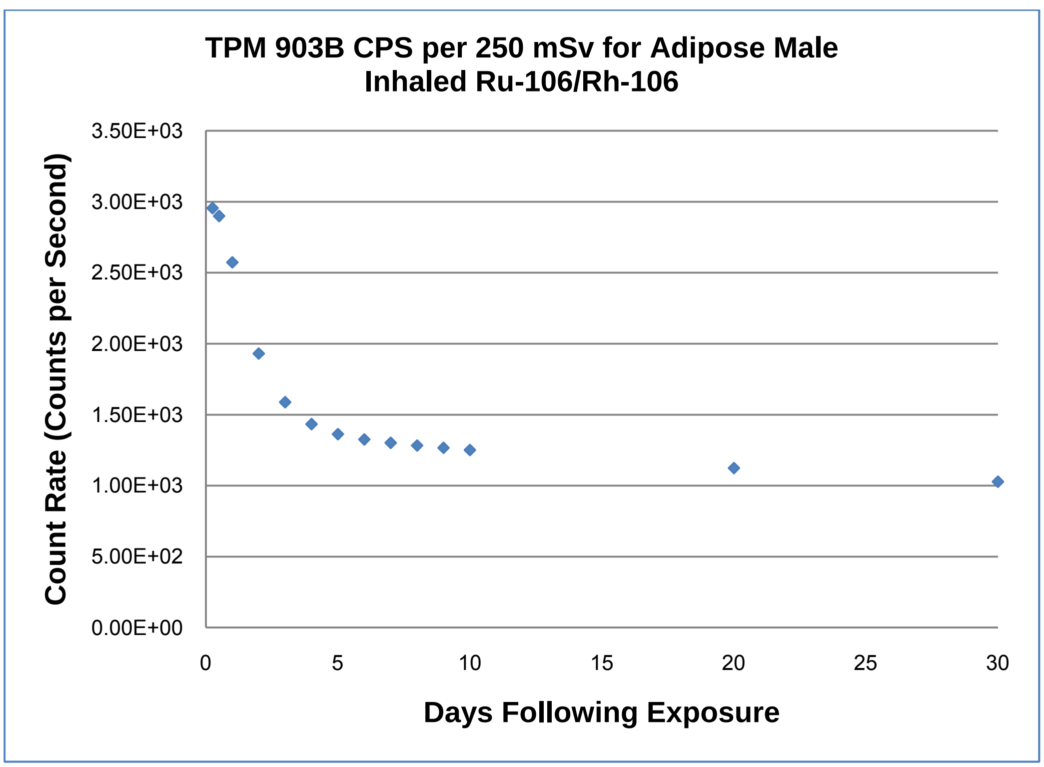

Figure C.40 Ru-106/Rh-106 count rate per 250 mSv for child

Table C.41 Sb-125 count rate per 250 mSv for child

		Total Body Count
		cps per 250 mSv
	Class →	M
Days following exposure	0.25	1.41E+05
	0.5	1.41E+05
	1	1.31E+05
	2	1.07E+05
	3	9.19E+04
	4	8.33E+04
	5	7.77E+04
	6	7.35E+04
	7	7.02E+04
	8	6.73E+04
	9	6.49E+04
	10	6.27E+04
	20	4.99E+04
	30	4.45E+04

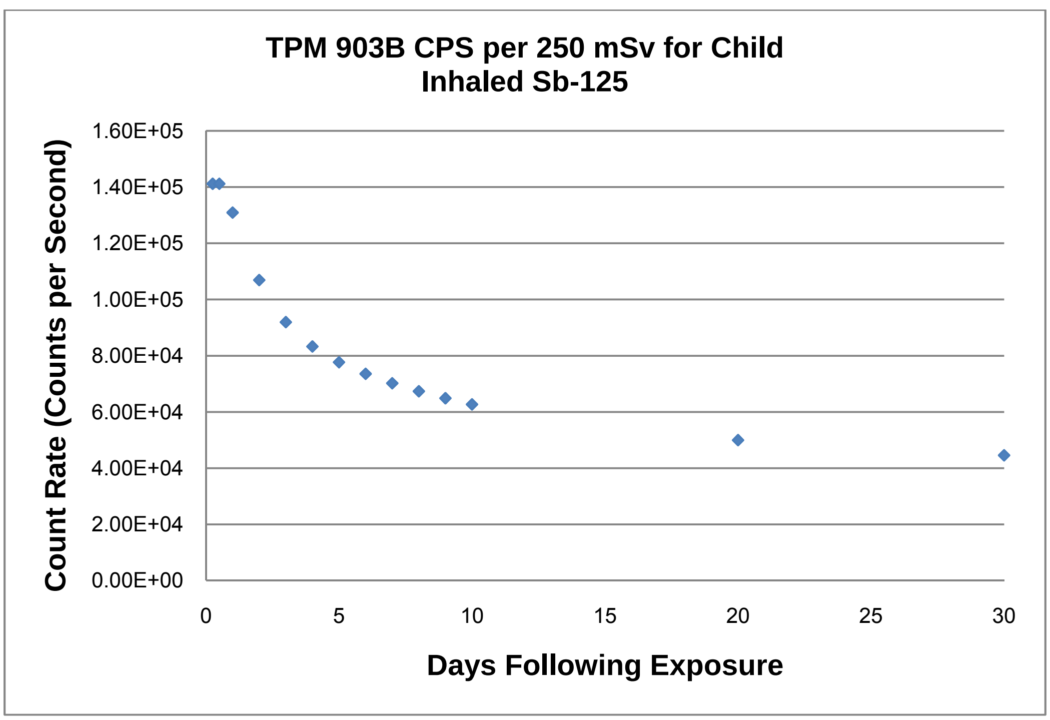

Figure C.41 Sb-125 count rate per 250 mSv for child

Table C.42 Te-127m/Te-127 count rate per 250 mSv for child

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	M
	0.25	1.19E+03
	0.5	1.20E+03
	1	1.09E+03
	2	9.08E+02
	3	8.12E+02
	4	7.67E+02
	5	7.44E+02
	6	7.31E+02
	7	7.21E+02
	8	7.12E+02
	9	7.05E+02
	10	6.97E+02
	20	6.32E+02
	30	5.79E+02

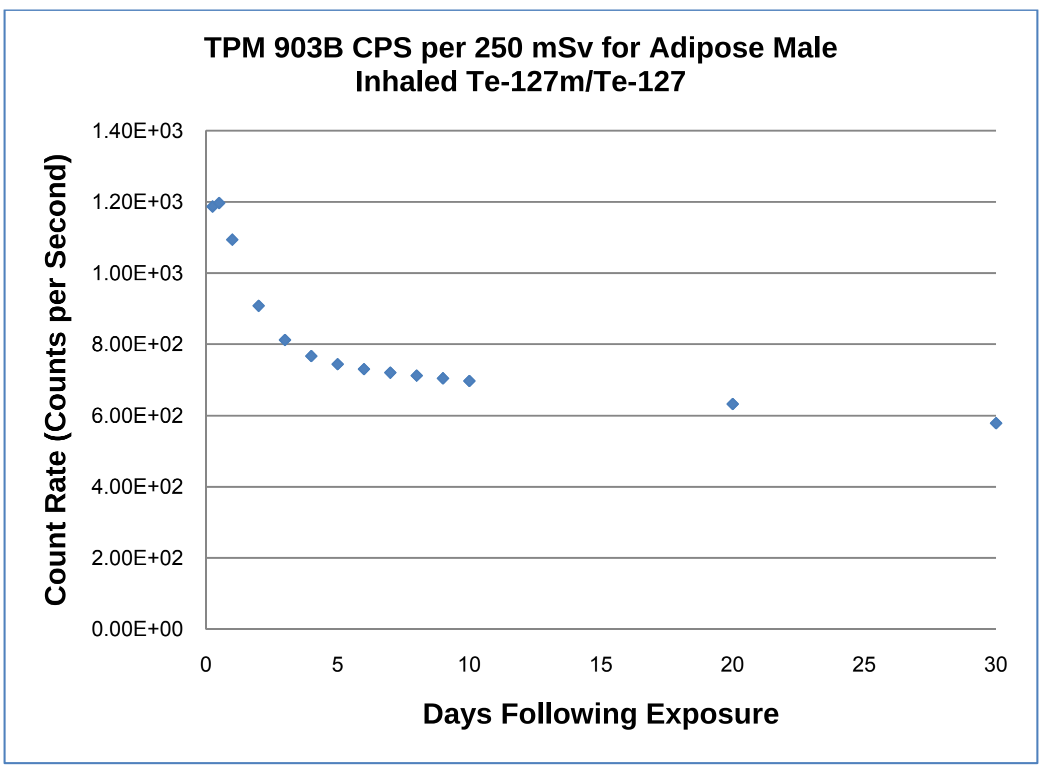

Figure C.42 Te-127m/Te-127 count rate per 250 mSv for child

Table C.43 Te-127 count rate per 250 mSv for child

		Total Body Count
		cps per 250 mSv
	Class →	M
Days following exposure	0.25	3.43E+04
	0.5	2.26E+04
	1	8.52E+03
	2	1.20E+03
	3	1.82E+02
	4	2.93E+01
	5	4.82E+00
	6	8.04E-01
	7	1.35E-01
	8	2.26E-02
	9	3.80E-03
	10	6.39E-04
	20	1.16E-11
	30	3.45E-20

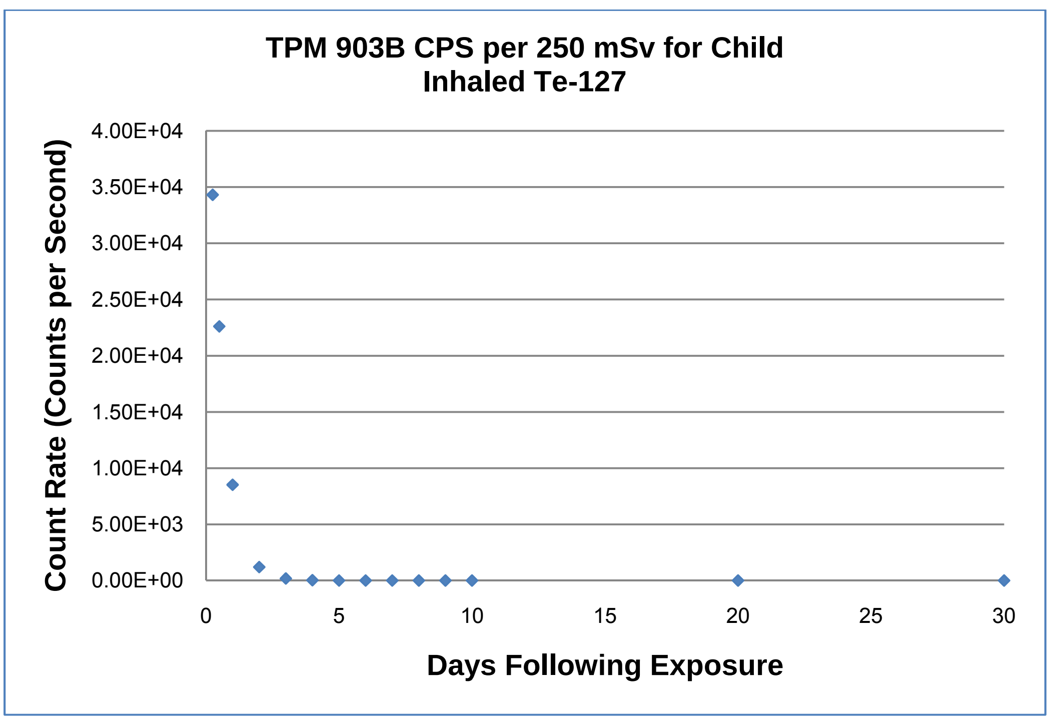

Figure C.43 Te-127 count rate per 250 mSv for child

Table C.44 Te-129m/Te-129 count rate per 250 mSv for child

Days following exposure		Total Body Count
		cps per 250 mSv
	Class →	M
	0.25	1.83E+04
	0.5	1.83E+04
	1	1.66E+04
	2	1.36E+04
	3	1.20E+04
	4	1.11E+04
	5	1.06E+04
	6	1.03E+04
	7	1.00E+04
	8	9.76E+03
	9	9.52E+03
	10	9.28E+03
	20	7.30E+03
	30	5.79E+03

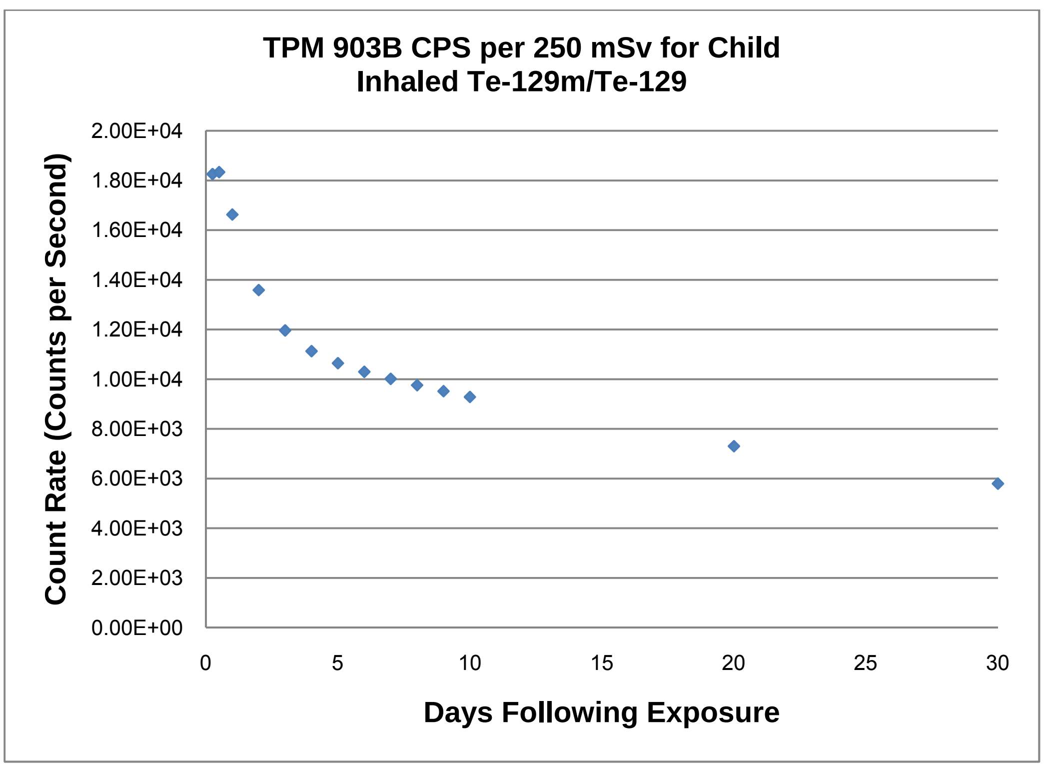

Figure C.44 Te-129m/Te-129 count rate per 250 mSv for child

Table C.45 Te-129 count rate per 250 mSv for child

		Total Body Count
		cps per 250 mSv
	Class →	M
Days following exposure	0.25	4.62E+04
	0.5	1.49E+03
	1	1.05E+00
	2	5.20E-07
	3	2.76E-13
	4	0.00E+00
	5	0.00E+00
	6	0.00E+00
	7	0.00E+00
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	9	0.00E+00
	10	0.00E+00
	20	0.00E+00
	30	0.00E+00

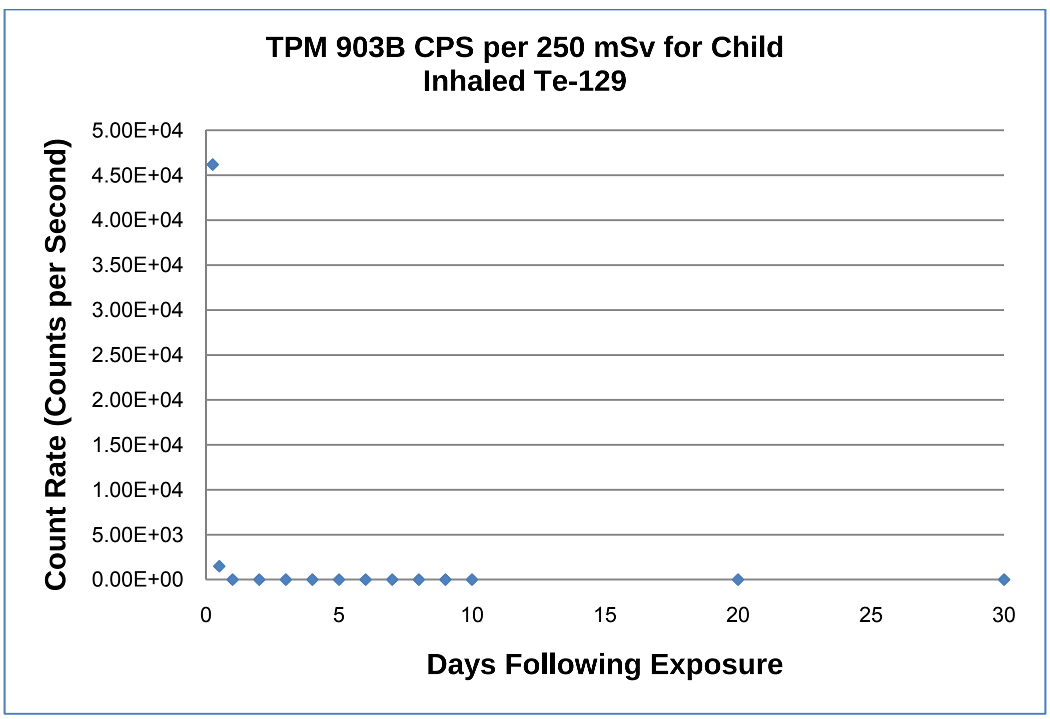

Figure C.45 Te-129 count rate per 250 mSv for child

Table C.46 Zr-95/Nb-95m/Nb-95 count rate per 250 mSv for child

		Total Body Count
		cps per 250 mSv
	Class →	M
Days following exposure	0.25	3.94E+05
	0.5	3.99E+05
	1	3.83E+05
	2	3.30E+05
	3	2.97E+05
	4	2.79E+05
	5	2.68E+05
	6	2.61E+05
	7	2.55E+05
	8	2.49E+05
	9	2.45E+05
	10	2.40E+05
	20	2.09E+05
	30	1.90E+05

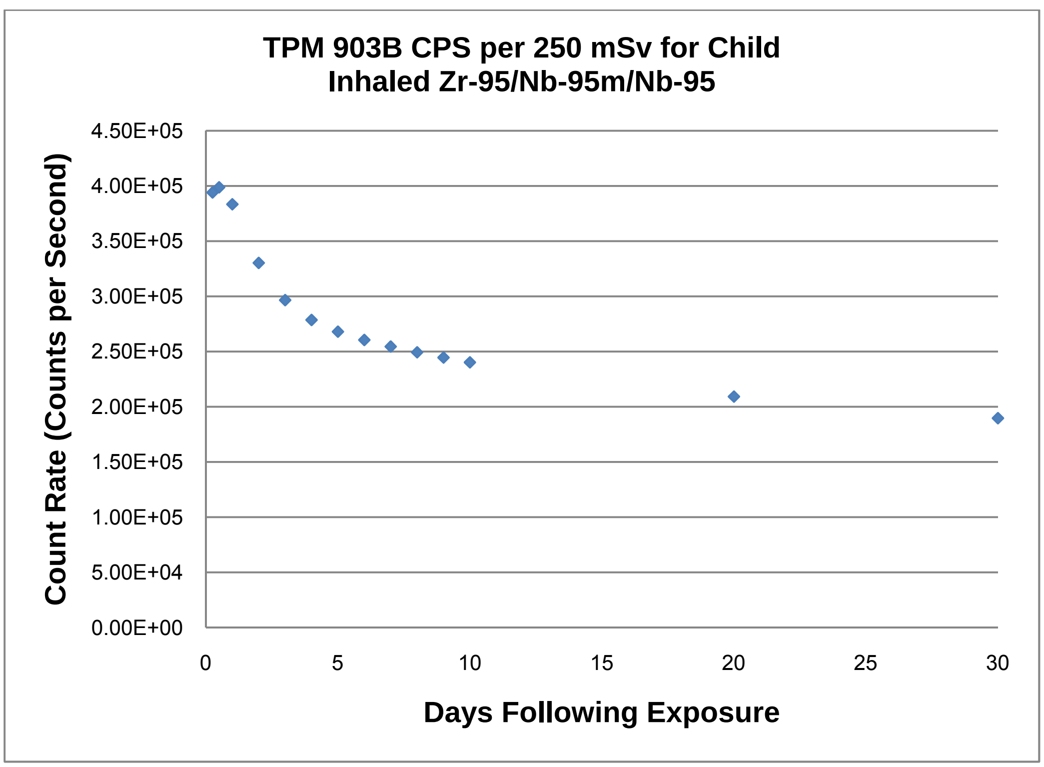

Figure C.46 Zr-95/Nb-95m/Nb-95 count rate per 250 mSv for child

APPENDIX D:

DERIVATION OF SUMMATION OF FISSION PRODUCTS FOR INHALATION

The computation of the count rate for the mixture of fission products in Group 1 is shown in Equation D.1.

$$C_{Mix} = \frac{\sum_F A_F * RF_F * C_F}{\sum_F A_F * RF_F} \quad \text{(D.1)}$$

where A_F represents the activity of the fission product, RF_F represents the release fraction of the fission product and C_F is the count rate in CPS, per 1 Bq of the fission product. The calculation of the effective dose coefficient for the mixture of the fission products is shown in Equation D.2

$$DC_{eff} = \frac{\sum_F A_F * RF_F * DC_F}{\sum_F A_F * RF_F} \quad \text{(D.2)}$$

where the dose coefficient, DC_F, is in units of mSv/Bq. The multiplication of the count rate for the mixture and the effective dose coefficient for the mixture result in the count rate per mSv for the mixture of fission products. This is shown in Equation D.3.

$$\frac{C_{Mix}}{mSv} = C_{mix} / DC_{eff} = \frac{\left[\frac{\sum_F A_F * RF_F * C_F}{\sum_F A_F * RF_F}\right]}{\left[\frac{\sum_F A_F * RF_F * DC_F}{\sum_F A_F * RF_F}\right]} = \frac{\sum_F A_F * RF_F * C_F}{\sum_F A_F * RF_F * DC_F} \quad \text{(D.3)}$$

In order to scale the count rate to the committed effective dose threshold of 250 mSv, Equation D.3 is multiplied by 250. See Equation D.4.

$$\frac{C_{mix}}{250mSv} = \left[\frac{\sum_F A_F * RF_F * C_F}{\sum_F A_F * RF_F * DC_F}\right] * 250 \quad \text{(D.4)}$$

This is equivalent to Equation 4.32 described in the body of this report.

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