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EXTERNAL DOSE RECONSTRUCTION IMPLEMENTATION GUIDELINE	Page 1 of 77
Approval: ___Signature on file_____ Date: _11/21/2007____ *J. W. Neton, Associate Director for Science* Concurrence: ____ __ Signature on file ___ Date: 11/21/2007 *L. J. Elliott, Director*	Supersedes: Rev 2

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Record of Issue/Revisions

Issue Authorization Date	Effective Date	Revision No.	Description
May 2002	May 2002	0	External Dose Reconstruction Implementation Guideline
August 2002	August 2002	1	Updated Photon Dose Conversion Factors (Appendix B) to be consistent with IREP version 5.2. The intermediate energy photons cutoff changed from 200 keV to 250 keV. Updated Occupational Medical Dose section (2.1.3) to include calculation of dose from x-ray machine parameters.
8/25/2006	8/25/2006	2	Major Revision. Includes several changes including but not limited to: - Correction factors for ROT and ISO DCF values for Bone (RM and Surf), Esophagus, and Lung - Clarification on the methodology for determination of missed dose. Provided policy on handling of recorded doses less than LOD. - Introduced the concept of using neutron/photon ratios to determine a neutron dose for some dose reconstructions.
11/21/2007	11/21/2007	3	Section 2.2.2.2.1 was modified to clarify the evaluation of missed neutron data

1.0 INTRODUCTION

The purpose of this document is to provide guidance on the components, standards, and methods of external radiation dose reconstruction for probability of causation calculations in support of the Energy Employees Occupational Illness Compensation Program Act (EEOICPA). It is to be used as a source to help provide specific guidance and methods which can be found in site profiles and other site-specific documents. External radiation dose results from exposure to a radiation source that is outside of the body. The photon or particle radiations travel through the air and are absorbed in a tissue of the body.

1.1 Dose Reconstruction Requirement

The first step in the photon dose reconstruction is to determine whether there was any potential for external radiation exposure at the facility. At most Department of Energy (DOE) facilities and Atomic Weapons Employers (AWE) there is a potential for radiation exposure. When no radioactive material was processed or stored, an external dose reconstruction is not necessary. The three groups of workers who require dose reconstruction are: 1) workers who were not monitored for radiation exposure; 2) workers who were monitored inadequately for radiation exposure; and, 3) workers whose monitoring records are incomplete or missing (42CFR82.3(a) 2002).

1.1.1 Adequately Monitored

In general, external monitoring data collected since the implementation of 10 CFR Part 835 could be considered adequately monitored. When a claimant has been monitored adequately using either film badge dosimetry or thermoluminescent dosimetry (TLD) in accordance with the Department of Energy Laboratory Accreditation Program (DOELAP), these data shall be used to compute the annual dose for the claimant. The associated uncertainty should be assumed to be normally distributed and should be obtained from the site dosimetry office.

1.1.2 Not Monitored

Many of the Atomic Weapons Employer (AWE) workers were not individually monitored for radiation exposure. At some facilities, radiation surveys were conducted and this data, in conjunction with frequency of exposure, should be used to estimate the annual dose. When no radiation monitoring data is available for a facility, scientifically reasonable estimates of exposure should be developed based on the source term or quantity of radioactive material handled at the facility.

1.1.3 Monitored Inadequately

At some facilities, only a small sample of the work force was monitored to ensure compliance with radiation exposure limits. As an example, although construction workers were often not monitored, it may be possible in some instances to use workers who received similar exposures, such as radiological control technicians who monitored the work activities, to estimate external dose. For workers at these sites, the highest recorded value for similar work group should be assigned to the unmonitored worker.

In addition to incomplete monitoring practices, most early workers at DOE facilities were monitored inadequately compared to modern standards. In most instances, the missed dose alone can exceed 500 mrem/year. At many facilities, routine monitoring for neutron exposures was not initiated until the late 1950s. In general, monitoring data prior to 1960 must be evaluated cautiously due to technological shortcomings and because monitoring programs were designed to ensure compliance with a 12 rem/year exposure limit compared to the 5 rem/year current standard. For these workers and others with uncertain dose information, an evaluation of their dosimetry (or monitoring) data in combination with estimates for missed dose, occupational medical exposures, and environmental on-site dose should be used to determine the total annual external dose.

1.1.4 Monitoring records incomplete or missing

When monitoring records are incomplete or missing, the monitoring data prior to and after the missing data can be used to interpolate the missing data. When only post monitoring data is available, extrapolation should be used with caution, accounting for engineering administrative changes that might have been instituted which reduced exposures. In addition, co-worker data can be used to fill in missing or incomplete records.

1.2 External Radiation Exposures

The absorbed dose is to be calculated for the organ where the primary cancer exists. Interactive RadioEpidemiological Program (IREP) is used to calculate the probability of causation for an individual worker. For external radiation, there are three types of exposure; photon, neutron, and electron. Photon exposures are divided into three energy categories (< 30 keV, 30-250 keV, and >250 keV). Neutrons are divided into 5 energy categories (< 10 keV, 10-100 keV, 100-2000 keV, 2-20 MeV, and >20 MeV). While there are two electron categories in IREP, only the > 15 keV is considered to be a source of external radiation. Electrons below 15 keV do not have sufficient energy to penetrate the epidermal layer of the skin and, therefore, are not considered an external radiation hazard. Typically, external electrons are primarily of interest in skin cancer claims, however, depending on the beta particle energy, the dose can be significant for the development of breast and testicular cancer as well.

1.2.1 Photon exposures

The four basic components of photon exposures are the individual's radiation monitoring data from dosimeters (D_D), the unrecorded or unmeasured dose commonly referred to as the missed dose (D_M), the occupational medical dose from medical monitoring x-rays (D_{OM}), and the environment dose primarily from stack emissions (D_{EN}). The sum of these doses in each calendar year comprises a worker's annual occupational photon dose (D_γ).

$$D_\gamma = D_D + D_M + D_{OM} + D_{EN}$$

1.2.1.1 Dosimeter Dose (D_D)

Most radiation workers have been routinely monitored for exposure to radiation to ensure compliance with health and safety standards. External radiation monitoring was typically conducted on an individual basis using pocket ionization chambers, film badges, and thermoluminescent dosimeters.

1.2.1.2 Missed Dose (D_M)

Missed Dose is the unrecorded or unmeasured external photon dose that is a result of relatively high detection limits in early years of radiation monitoring combined with short-monitoring durations or a high dosimeter exchange frequency. In some instances, the missed dose is not the result of a technological limitation, but results from a recording practice, which considered some doses *de minimus*, which resulted in positive readings below some threshold being recorded as zero. Missed dose is particularly problematic in early years of radiation monitoring. During this time interval, missed dose was considered relatively unimportant since the annual occupational limits for radiation exposure were quite high (12 rem/year). As annual exposure limits were reduced, and monitoring technology improved, the magnitude of the missed dose has significantly decreased such that when quarterly TLD monitoring was implemented, the missed dose is generally less than 40 mrem/year.

1.2.1.3 Occupational Medical Dose (D_{OM})

In early years, the latent effects of radiation exposure were not well understood, and short-term tolerance dose limits were believed to be protective. With improved technology came new screening techniques such as photofluorography. Medical personnel used these new techniques to screen and diagnose patients for diseases such as tuberculosis. In addition, these screening techniques were used to monitor for excess exposure to heavy metals such as uranium. According to Parker (1947), the entrance dose in photofluorography was about 1 R. Cardarelli et al (2001) noted that the bone marrow dose from photofluorography (≈ 800 mrad) was nearly two orders of magnitude greater than that of conventional diagnostic x-rays (≈ 10 mrad). At some facilities, photofluorography or other screening x-rays were required as part of the routine medical monitoring program. Since these examinations were required for employment, they are considered part of the occupational radiation exposure under EEOICPA. Primarily these exposures will be in either the < 30 keV or the 30-250 keV energy group. It should be noted that only medical exposures that were required as a condition of employment are included in the occupational medical dose. Diagnostic and therapeutic procedures not required for employment are not included.

1.2.1.4 Environmental Dose (D_{EN})

Typically, energy employees who were not categorized as radiation workers were not monitored using personal dosimeters, however, the work environment for these employees was often routinely monitored using area dosimeters or periodically monitored using survey instrumentation to measure the "background" environmental radiation levels. At many of these facilities, routine monitoring stations have recorded the average photon dose in a general area or at the plant boundaries. At several DOE facilities,

radioactive emissions from plant stacks have been known to significantly increase the "background" radiation levels on the plant site. In general, the dose from increased background is rather low.

The environmental dose at each facility should be evaluated. For example, during some operations such as the "green" runs at Hanford and INEEL, the release of fission products to the atmosphere significantly increased the ambient radiation levels well above natural background. At Hanford for instance, the environmental dose in May 1947 was reported as 21.7 mrep/month and 68.2 mrep/month for the 200-W and 200-E area respectively. The monthly environment gamma dose at the 100-B area was 12.4 mrep/month, which is near natural background levels. With prevailing winds from the west to east, clearly the downwind areas had significantly elevated radiation exposures. Since most routine emissions and even many of the non-routine emissions would not result in exposures exceeding the annual occupational limits, some workers at the facility, including security and construction workers, were not monitored for this exposure.

1.2.2 Neutron Exposures

The two basic components of the neutron dose are the individual's monitored dose from dosimeters (D_D) and the unrecorded or unmeasured dose commonly referred to as the missed dose (D_M). Since neutron exposures from man-made sources do not exist in the environment, nor are neutrons used in diagnostic or medical procedures, the later two categories are not included in the external radiation dose reconstruction.

$$D_N = D_D + D_M$$

1.2.2.1 Neutron Dosimeters (D_D)

Since the beginning of nuclear operations, neutrons have been monitored in the work place through radiation surveys, typically using either moderated boron tri-fluoride (BF_3) detectors or tissue equivalent proportional counters. Individual neutron exposures have typically been measured and recorded using specially designed pocket ionization chambers, nuclear track emulsion type A (NTA) film, and thermoluminescent dosimeters (TLD).

1.2.2.2 Neutron Missed Dose (D_M)

Neutron monitoring was not fully implemented at some sites until the late 1950s. Early use of NTA film resulted in relatively large missed doses for neutron exposure. For example, at Hanford, neutron film was read on a weekly basis with a stated limit of detection (LOD) of 90 mrem. At some sites, due to the difficulty in reading the film, many monitored workers' films were not read unless the photon dosimeter exceeded a certain threshold. This administrative practice has also resulted in some significant missed dose. This dose must be evaluated and added to the overall neutron dose.

1.2.3 Electron (Beta Particle) Exposures

Generally, external electron exposures are only important for surface tissue such as skin. Thus, for skin cancer, a dose reconstruction from exposure to electrons is required. The

exposure to skin can originate from either a strong unshielded electron source such as Sr-90/Y-90 or uranium daughters, or from skin contamination with beta/gamma emitters. The other two organs for which external electron exposure from high energy electrons (> 1 MeV) might be significant are the testes and the breast. For breast and testicular cancer, an evaluation of the maximum electron energy exposure should be conducted. Generally, if the electron energy is less than 1 MeV, the dose conversion factor (DCF) will be zero since the electron does not have sufficient energy to penetrate the outer layer of skin (ICRP 74, 1996.) In these cases a dose reconstruction is not necessary. As with neutron doses, there are typically only two components of the electron dose, dosimeter dose and missed dose. Electrons have not typically been used for diagnostic occupational medical monitoring. An electron environmental dose is also usually not applicable since immersion in a cloud would generally have been monitored. While occupational medical and environmental doses are not included in electron dose reconstruction, skin contamination from beta-gamma emitters poses a unique exposure scenario that should be included in skin cancer cases. The general form of the electron dose equation is as follows:

$$D_E = D_D + D_M + D_S$$

1.2.3.1 Dosimeter Dose (D_D)

In early years, beta exposures were monitored using an open window of a film dosimeter. In the mid 1970s TLDs replaced the film badges at most facilities. One major advantage of the TLD is that the detector is similar to tissue and a shallow dose could be measured more accurately.

1.2.3.2 Missed Dose (D_M)

As with most dosimeters, there was a limit of detection that has resulted in some missed dose. In addition to readings below a limit of detection, many early monitoring programs measured but did not record the open window dose in the official dose of record for the individual.

1.2.3.3 Skin Contamination (D_S)

While skin contamination can result in some deep dose from photons, the shallow dose from the electrons is usually several orders of magnitude greater and should be included in dose reconstruction for skin cancer. Data such as isotope, and quantity of activity from skin contamination incidents have typically been reported in a claimant's radiological file.

1.3 Dose Reconstruction - Hierarchy of Data

Generally, individual dosimeter data should be used whenever possible and given precedence over personal monitors, survey data or source term data. In some instances, dosimeters were not worn or, in the case of neutrons, the NTA film limit of detection (LOD) was relatively high compared to the pocket ionization chamber. In these circumstances, the personal monitor can be used, however caution should be employed to ensure the dose is not a false positive or the sum of the personal monitors exceeds the

LOD of the personal dosimeter. Table 1.1 outlines the general hierarchy of data sources that should be employed for dose reconstruction under EEOICPA.

Table 1.1 Hierarchy of Data Sources for Dose Reconstruction

Hierarchy	Data Source	Examples
1	Personal Dosimeter	Film Badge, TLD
2	Personal Monitors	Pocket Ionization Chambers
3	Co-Worker Data	Film Badge, TLD, Pocket Ionization Chambers, etc.
4	Area Monitoring	Work Place Radiation Surveys, Ambient Air room monitors, duration of exposure
5	Source Term	Source strength, distance from source, duration of exposure, and shielding information
6	Radiation Control Limits	Generally, workplace posting has been required when the dose rate exceeded 0.025 mSv/hr.

1.4 Initial Dose Assessment

In order to achieve the greatest efficiency in conducting external dose reconstruction, a health physicist should review the case to arrive at a rough estimate of exposure to determine if the case falls into either a very low or very high potential exposure category. External cumulative doses across numerous facilities have been observed to follow a log normal distribution with some very high exposures and some very low exposures. In some instances, particularly with short exposure durations, reasonable and conservative upper dose estimates can be developed based on relatively little data. Likewise, based on an initial review of exposure records, a health physicist should be able to identify workers with likely high doses and may only need to conduct a partial dose assessment to definitively place a worker's exposure into a high exposure. An initial dose assessment can greatly facilitate the throughput of dose reconstructions by conservatively overestimating a low dose exposure that would likely not result in a high probability of causation and underestimating a high dose exposure that would result in a high probability of causation.

1.4.1 Estimated Low Dose

This approach is most appropriate for short duration non-radiological workers who might have been exposed to low levels of environmental radiation. For example, an unmonitored clerical worker at a facility once walked through a radiological control area to deliver a message. The duration in the area was less than one hour and the maximum allowable dose rate in the area was 2.5 mrem/hr. Instead of using co-worker data, or actual survey data, the worker's dose can be estimated to be a maximum of 2.5 mrem.

1.4.2 Estimated High Dose

Some workers have exceeded occupational limits through radiological accidents or incidents. In order to expedite their claims, a partial dose reconstruction should be conducted, provided, the outcome results in a high probability of causation. In cases

where the probability of causation is not high, a more detailed dose reconstruction must be conducted.

1.5 Conversion to Organ Dose

For external dose reconstruction under EEOICPA, the organ or tissue which developed the cancer is the organ of interest. Implementing procedures will allow the dose reconstructor to identify the corresponding organ for which the external dose should be calculated using the ICD code.

Typically, film badge and TLDs were worn on the upper front torso of the body. Depending on the monitoring era, these devices were calibrated to measure either 1) exposure, 2) the ambient dose equivalent, or 3) the penetrating dose at 10 mm using a standard phantom. The 10 mm penetrating dose is commonly referred to as the $H_p(10)$. For film badge dosimetry calibrated to exposure in roentgens (R), the conversion to ambient dose equivalent ($H^*(10)$) can be found in ICRU 43 (1988).

In turn, the ambient dose equivalent ($H^*(10)$) can be converted to air KERMA (K_a) using data from ICRP 74 (1996). The personal dose equivalent ($H_p(10)$) can also be converted to air KERMA using data from ICRP 74 (1996). Once the monitoring data has been converted to air KERMA, the organ dose can be calculated based upon the most likely exposure geometry for each of the IREP radiation types and associated energy intervals. The methodology describing these conversions is further discussed in section 4.

While these calculations are straightforward, the conversion of early film badge data to exposure energy is not. Unless corrections were made, the calibration of the early film badges using a radium or Cs-137 (high energy) gamma source resulted in an overestimation of the low energy exposure received by a worker. Thus, when appropriate, low energy exposures should be corrected for this overestimation.

1.6 Uncertainty

The general approach to uncertainty in external dose reconstruction is to treat each variable as a distribution and then employ Monte Carlo sampling of each of the distributions to determine the overall uncertainty of the annual dose estimate. In general, the uncertainty in the measured dosimeter dose and the occupational medical dose is assumed to follow a normal distribution, while the uncertainty in the missed dose and the environmental dose is assumed to follow a log normal distribution. The uncertainty in the conversion of exposure or personal dose equivalent to organ dose is assumed to follow a triangular distribution with the upper and lower bounds determined by the most and least favorable geometry and energy.

2.0 EXTERNAL DOSE RECONSTRUCTION – MONITORING DATA

When monitoring data are available, the three types of exposure are the photon dose, neutron dose, and electron exposures. As previously discussed, electron exposures are usually relevant for skin cancer but for high-energy electron exposure, testicular and breast doses should be evaluated.

2.1 Photon Dose

As discussed in the introduction, the four components of photon dose are the dosimeter dose (D_D), the missed dose (D_M), the occupational medical dose (D_{OM}), and environmental dose (D_{EN}). The sum of these doses in each calendar year comprises a worker's annual occupational photon dose (D_γ).

2.1.1 Dosimeter Dose

2.1.1.1 Background

Since the beginning of nuclear weapons research and production, individual workers have been monitored using personal dosimeters at many facilities. Initial monitoring was conducted using film badges with various exchange frequencies. By the late 1970s most monitoring programs transitioned to TLDs. Through the years, technological developments have greatly improved the accuracy and sensitivity of the dosimeters.

2.1.1.2 Method

In general, the dosimeter dose is a summation of the individual dosimeter readings. As listed in Table 1.1, the following hierarchy should be used to determine an individual's dosimeter dose: personal dosimeter (film badge or TLD), pocket ionization chamber, group or co-worker dosimeter(s). Within the NIOSH-IREP probability of causation program, there are three photon energy bands; 1) below 30 keV, 2) 30 to 250 keV, and 3) above 250 keV. Therefore, some separation of the dose from each energy band is required.

At most of the larger facilities, multi-shielded film badges or multi-element TLDs have been used since the mid 1960s. Since only three energy bands are used in the probability of causation calculations, the differences between various filter doses can provide insight into the gross energy distribution at the facility. To the extent possible, these differences should be used to estimate the relative energy distributions in earlier years when only two element film badges were used. If individual energy distribution information is not available for two element film badges, the open window dose should be used as a claimant friendly estimate of the 30 to 250 keV dose. It is recognized that early film badges over-responded to low-energy photons, however corrections for this over-response are only recommended when scientific studies have been conducted and the exposure geometry and energy distribution are well known.

When monitoring data do not indicate the relative energy distribution, the distribution can be estimated based upon either the site radionuclide inventory or the relative energy

distribution which can be estimated for most facilities based upon a review of historical operations.

For modern radiological monitoring programs, especially DOELAP accredited laboratories, the energy distribution should be well characterized for the processing of the TLDs and this information should be readily available from the site dosimetry program.

2.1.1.3 Uncertainty

The general approach that follows may be used with site specific data, which has been collected for Technical Basis Document development, in order to develop the dosimetric uncertainty for that site.

2.1.1.3.1 Film Badge Uncertainty
A technical committee appointed by the National Academy of Sciences outlined three components (laboratory, radiological, and environmental) of uncertainty in personal dosimetry for film badge dosimetry used during atmospheric nuclear tests (NRC 1989). The uncertainty in the environmental component is discussed in section 2.1.3, and the radiological component is discussed in the exposure geometry section 4.4. Thus the laboratory uncertainty is the only source of uncertainty addressed in this section.

The uncertainty for film badge measurements is a function of the film type or packet used at the facility. The laboratory film badge uncertainty is relatively dependent on the exposure. Brodsky et al. (1965) extensively studied the accuracy of film badge dosimeters and concluded that under good laboratory conditions, the uncertainty can be as low as 10% to 15%, even at low doses. However, at many facilities, the uncertainty was much greater at low doses. Fundamentally, the absolute uncertainty at the 95% confidence should not be less than the limit of detection (LOD). For simplicity, the approach outlined by the National Research Council (1989) will be employed for dose reconstruction under EEOICPA. However, the additional uncertainty discussed for exposures below 200 mR will not be employed, since routine monitoring is generally more precise than large sampling events such as atmospheric test monitoring (See Figure 2.1). This approach, in combination with available facility dosimetry data, may be adapted for use in the individual site profile development. The uncertainty associated with each dosimeter reading is assumed to be normally distributed, where the dosimeter reading is the mean and the upper 95% confidence dose is calculated by multiplying the uncertainty factor K(E) by each dosimeter reading using the following equations:

$$K(E) = 1 + 1.96\left[\frac{\sigma(E)}{E}\right]$$

$$\sigma(E) = \frac{\sigma^*}{D_\infty \gamma} e^{\gamma E}$$

where:
E = Exposure in roentgen
σ^* = Densitometer reading uncertainty typically 0.015 density units

D_∞ = Saturation Density of the Film (Dupont 502 = 2.8)
γ = film sensitivity (Dupont 502 ≈ 0.25)

2.1.1.3.2 TLD Uncertainty
The uncertainty of thermoluminescent dosimeters is generally lower than film badge dosimeters, however the uncertainty is still somewhat dependent on the dose. Several biases can occur that, when combined, contribute to the random error. The fading of the dosimeter, especially in high temperature environments, results in a slight decrease in the measured dose. Conversely, the annealing process can result in residual artificial dose and spurious luminescence from contaminants, thereby overestimating the true dose. A simple estimate of uncertainty based on Hirning (1992) is to divide exposure into two components with one part based on the limit of detection, which dominates in the low dose region, and the other based on a best estimate of overall dosimeter uncertainty (generally 5 - 10%). A key assumption is that the two components are uncorrelated. This is appropriate since the variance in the low dose region would be dominated by measurement or counting statistics (i.e. total counts above background on a photo multiplier tube (PMT)). Conversely, in the upper dose region, the variance from counting statistics plays a rather insignificant role, however the uncertainty associated with the calibration, energy response of the dosimeter, and fading begin to dominate. Generally the relative uncertainty associated with radiation monitoring has been less than 5 - 10% at relatively high dose levels. This uncertainty increases with decreasing dose from 10 - 15% in the hundreds of millirem (Hendee 1967; Wallace, Watkins 1968) to approximately 100% at the LOD.

2.1.1.3.3 Simplified Dosimetry Uncertainty
In the development of the site-specific Technical Basis Document, exposure data may be used to estimate the dosimetric uncertainty using the following simplified uncertainty method based on Hirning (1992).

The minimum detection level (*MDL*), sometimes called the critical limit (L_C), is generally defined as the point when the uncertainty of the reading at the 95% confidence level is ± 100%. The standard deviation at this level can be defined as:

$$\sigma_{MDL} = \frac{L_C}{k} = \frac{L_C}{1.96}$$

Assuming that $\sigma_{MDL} \approx \sigma_n$ (the standard deviation of the null readings) and that the standard deviation at the high dose level (σ_μ) is a constant relative percentage on the order of 10-20%, a simple estimate of uncertainty based on exposure level can be defined as:

$$\sigma(E) = \sqrt{\left(\frac{L_C}{1.96}\right)^2 + \left(\frac{\sigma^*}{100}(E)\right)^2}$$

where:

L_C = Critical Limit
σ^* = Estimated percent standard error
E = Exposure or Dose

Figure 2.1 demonstrates reasonable agreement between the 95% Uncertainty Factors, K(E) using the film badge methodology and the simplified method over a range of exposures. The simplified method was calculated using a 30 mrem detection threshold and a standard error of 10%.

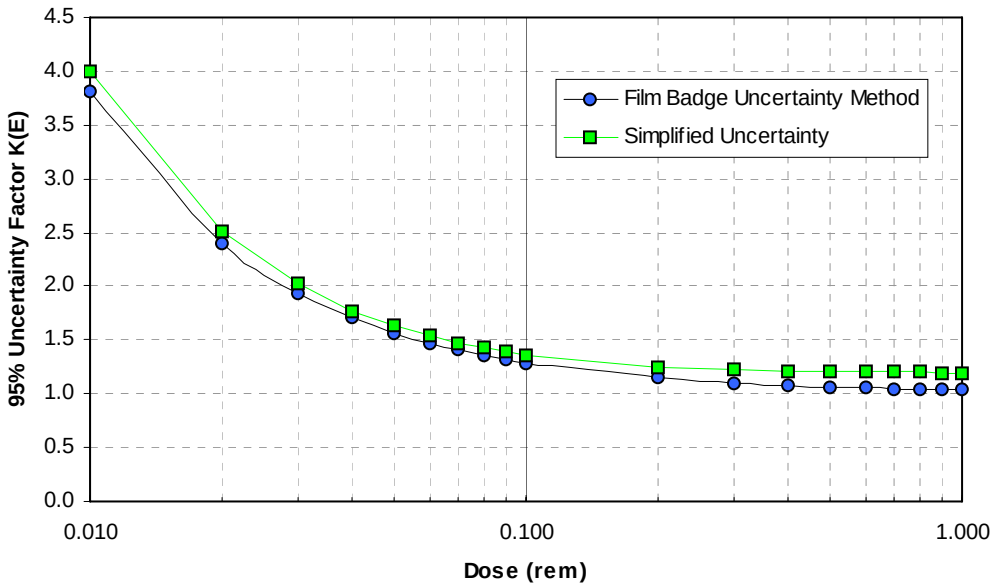

Figure 2.1 Comparison of film badge uncertainty to simplified uncertainty

2.1.1.3.4 Uncertainty Combination

The uncertainty from each film dosimeter should be calculated and the combined annual uncertainty should calculated using standard error propagation methodology (square root of the sum of the squares) as shown in the following equation.

$$\sigma_D^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2 + ...\sigma_i^2$$

where

σ_D = Uncertainty of Annual dose
σ_i = Uncertainty of a Single Dosimeter

2.1.2 Missed Dose

2.1.2.1 Background

In the scientific literature there are several different models that can be used to assess the missed dose (Strom 1988, Hornung and Reed 1990, Finklestein and Verma 2001). Recently, Taulbee, et al (2001) evaluated several models and concluded that the LOD/2 method resulted in a slightly positive bias (overestimate) of the true dose. While other missed dose methods might be more accurate on a large scale, for claimant friendly dose reconstruction, a bias which slightly overestimates the missed dose is acceptable.

2.1.2.2 Method

The National Research Council, in their evaluation of film badge dosimetry for compensation of atomic veterans, recommended the use of the Limit of Detection LOD/2 method. This scheme has been used in other compensation programs and has been shown to result in a slight positive bias. The method to be used for dose reconstruction related to EEOICPA is to assign a dose equal to the LOD divided by 2 for each dosimetry measurement (film badge, pocket ionization chamber or TLD) that is recorded as zero or if it is below the limit of detection divided by 2. Readings greater than or equal to LOD divided by 2 are to be used as recorded. See Table 2.1 as an example.

Table 2.1 Example of assigned dose based on dosimetry records

Site Recorded Value (mrem)	Limit of Detection (mrem)	LOD/2 (mrem)	Assigned Missed Dose (mrem)	Assigned or Recorded Dose[a] (mrem)
10	30	15	15	15
25	30	15		25
15	30	15		15
0	30	15	15	15

Note: This table is for illustrative purposes only and is not to be used for actual dose reconstructions.
a. Used in analysis of missed or measured dose, respectively.

2.1.2.3 Number of Zero Measurements is Unknown

When the number of zero measurements cannot be determined, the missed dose becomes more complicated. When only the annual dose is known, the number of zero doses should be estimated based on the dose level and the monthly, quarterly, or annual limits for that year, and the number of possible zero monitoring intervals. This would be the situation, for example, if an individual received a cumulative dose of 2140 mrem in a given year, at a facility that had a monthly monitoring frequency and the maximum permissible exposure limit was 1000 mrem per month. The minimum number of months in which this dose could have been received is 3. Therefore, the maximum number of missed dose months would be 9, and the minimum would be 0 since the dose could have been received evenly throughout the year. The central estimated number of months would be the median or 5, however the upper bound would be 9.

2.1.2.4 Uncertainty

The missed dose uncertainty will be combined with the measurement, energy and geometric uncertainties in a Monte Carlo sampling technique described in Section 1. Since the "true" missed dose is not known, there is some probability that the actual missed dose could be as great as the LOD times the number of zero measurements. Likewise, there is some probability that the "true" missed dose is actually zero. According to Strom (1988), and as verified by Taulbee et al (2001), the log normal distribution dominates in the low dose region. Therefore the log normal distribution should be used for the uncertainty distribution for missed dose

2.1.2.5 Multiple dosimetry monitoring

There are some individuals who, given their specific job function, might have worn multiple monitoring badges during a particular monitoring period. At some facilities these workers were classified as ROVER status. The central tendency of the missed dose for these individuals should be calculated using the same LOD/2 methodology, however, the number of zero measurements should be based on the number of routine monitoring intervals in a given year.

2.1.3 Occupational Medical Dose

2.1.3.1 Background

At many DOE facilities, physical examinations were required as a condition of employment. Some of these examinations included the use of diagnostic x-ray examinations. Because these were required, they are considered occupational dose for purposes of this program. Generally, these x-ray examinations result in a very small dose near the detection limit of film badge dosimetry. However in early years (< 1960) some facilities utilized photofluorography equipment that could deliver substantial doses. As early as 1947, radiological control programs recognized that the use of photofluorography would not be appropriate for radiological workers, however some clinics continued to use the procedure (Parker, 1947). While the typical bone marrow dose from a standard chest x-ray is approximately 10 mrem, a standard photofluorography unit delivered a bone marrow dose of approximately 800 mrem (Cardarelli et al, 2001).

2.1.3.2 Method

The calculation of the Occupational Medical Dose is straightforward. The most difficult component is determining site specific x-ray machine parameters and screening protocols. Organ doses are calculated using site specific or published information and dose conversion factors from ICRP Publication 34. Organ doses are provided in the individual site Technical Basis Documents or Technical Information Bulletins. X-rays in the diagnostic energy range consist of low energy photons (<250 keV). .

2.1.3.3 Uncertainty

The uncertainty distribution about each diagnostic procedure is assumed to follow a normal distribution with D_{OM} being the mean dose. If known, the standard deviation of the procedure should be used.

2.1.4 Environmental Dose

2.1.4.1 Background

Historically, radioactive stack emissions have substantially increased radiation levels around some facilities. Regulation of stack emissions has generally been designed to protect the general population or the environment with particular attention to dose rate levels near the site boundaries. Since the mid 1970s, stack emissions at most facilities have generally been low enough that these emissions have been negligible compared to occupational dose. However, early stack emissions were not negligible compared to modern occupational limits and therefore will be considered, where appropriate, as part of the worker's exposure. Unlike the previous three modes of external exposure, which could be either chronic or acute, the environmental dose is always assumed to be chronic.

2.1.4.2 Method

At large DOE facilities, the stack releases were fairly well documented and ambient air dose rates were measured at monitoring stations throughout the facility. Since detailed employment history is generally available either through facility records or through the Computer Assisted Telephone Interview (CATI), this history can be used in conjunction with area measurements to estimate the dose contribution from plant emissions. Generally the dose will be very low (< 10 mrem/month), but during some time periods at certain facilities, the dose rate could be as high as a 100 mrem/month. A review of historical plant records should be conducted to make this dose determination on a case-by-case basis. Since energy distributions are not generally known from the dose rate measurements, the entire measurement is assumed to be in the 30-250 keV energy range. The general equation to calculate the dose from plant emissions is given as:

$$D_{EN} = n\dot{D}_m O_f$$

n = number of months exposed
$\dot{D}_m$ = average monthly dose rate for year of interest
O_f = Occupancy Factor (% of time on plant site)

2.1.4.3 Uncertainty

Ideally, the annual uncertainty should be calculated based on the standard deviation of monthly average dose rates or the standard deviation of all of the measurements. However in most instances this data will be difficult to obtain, thus some approximation of the uncertainty would be more reasonable. Based on the occupancy factor alone, it is highly unlikely that an environmental dose would ever exceed 500 mrem in a year. Thus

this value can be used as a conservative (claimant friendly) upper bound (95%) with D_{EN} being the geometric mean of a log normal distribution.

2.2 Neutron Dose

For dose reconstruction under EEOICPA the dosimeter dose and the missed dose will be used to calculate an individual neutron dose.

As with photon exposures, the NIOSH-IREP program uses energy intervals to calculate the probability of causation from neutron exposures (Table 2.2). Neutrons, unlike photons, are high linear energy transfer (LET) radiation. In accordance with 42 CFR 82 (2002), ICRP 60 (1990) radiation weighting factors (w_R) will be used for dose reconstruction and reporting of dose.

Table 2.2: Neutron energy intervals and associated ICRP 60 weighting factor and some examples of exposures or facilities where the specific neutron energy might be encountered.

Neutron Energy (MeV)	ICRP 60 Radiation weighting factor, w_R	Typical Exposure Scenario
< 0.01	5	Low energy neutron exposures include thermal neutrons commonly found around nuclear reactors or moderated neutron sources. More prevalent around heavy water reactors.
0.01 – 0.10	10	Intermediate energy neutron exposures can also result from operation around nuclear reactors as high-energy neutrons are moderated to thermal energies.
0.10 – 2.00	20	Commonly called fission spectrum neutrons, this is the most typical energy range from operation of light water or graphite moderated reactors.
2.0 – 20.0	10	Reactions between alpha particles from materials such as plutonium or polonium and light materials such as beryllium can result in the production of neutrons. These reactions are commonly called (α,n) reactions. This neutron energy interval also includes 14 MeV neutrons from fusion reactions.
> 20.0	5	Exposures to neutrons greater than 20 MeV can result from work around accelerators.

2.2.1 Dosimeter Dose

2.2.1.1 Background

Prior to the early 1950s personal neutron monitoring was conducted using boron lined pocket ionization chambers at most facilities. In the early 1950s some facilities began using neutron track emulsion (NTA) film for measurements of fast neutrons, and in the 1960s, cadmium plates were used to distinguish between fast and slow neutrons. By the mid 1970s most facilities switched to TLDs, however several continued using NTA film.

The boron-lined pocket ionization chambers measured slow or thermal neutrons. Due to the large variability associated with the boron lined pocket ionization chambers, an absorbing material such as cadmium or gadolinium was placed in a film badge to

measure thermal neutrons. Thermal neutrons absorbed by the material emit low energy photons in a n,γ reaction. The additional darkening of the film from the low energy gamma rays of the n,γ reaction were then compared to the film behind a similar material with a low thermal neutron cross section. The difference was a relative measure of the thermal neutron exposure.

NTA film was far superior to the boron-lined pocket ionization chambers, however they suffered from an inability to accurately measure neutrons below about 500 keV (Griffith et al 1979). A variety of energy thresholds for NTA film dosimeters are cited in the scientific literature. Site specific information may be used to determine actual threshold values.
With the introduction of thermoluminescent albedo dosimetry in the 1970s, neutron measurements improved with lower detection limits, however the relative uncertainty at higher doses remained generally about the same.

2.2.1.2 Method

Dose from neutrons is the summation of each of the dosimeter readings for a given year. Review of site data is typically required to evaluate the neutron energy spectrum, the calibration and reported quantity, and the radiation quality factors used.

2.2.1.2.1 Neutron Energy
When no energy information can be found, the exposure scenarios discussed in Table 2.2 can be used to estimate the predominant energy.

2.2.1.2.2 Calibration and Reported Quantity
At some facilities, the calibration sources of the neutron dosimeters were changed thereby changing the response of the dosimeter. A determination of whether or not the radiological records were updated to reflect the change should be performed.

2.2.1.2.3 Quality Factor
In order to interpret site reported doses, some site-specific analysis of the quality factors used is required. Generally, since the 1950s, a quality factor of 10 has been applied to fast neutron exposures, however this has varied from 5 to 20 across facilities and time frames.

2.2.1.3 Uncertainty

The uncertainty associated with neutron monitoring is assumed to follow a normal distribution like the photon dosimeter dose. Several authors have reported general uncertainty to be about 20% to 30% (Oshino 1973, McDonald and Hadley (1985)).

Schimmerling and Sass (1968) reported the standard deviation of two groups of irradiated dosimeters analyzed by commercial vendors from 1964 to 1966. Group A was irradiated on the first day of the badge wear period or cycle while group B was irradiated on the last day of the wear period just prior to reading. The group A badges generally displayed a systematic under-response due to latent image fading, while the group B badges displayed an over-response resulting in an overestimation of the irradiated dose. Within

both of these groups, the uncertainty associated with reading the badges was provided. The reading uncertainty has been converted to the K(E) parameter in Figure 2.5.

McDonald and Hadley (1985) conducted one of the most comprehensive reviews of neutron dosimeter response uncertainty at 12 DOE sites. They evaluated the response of various neutron dosimeters which included the albedo TLDs and NTA film dosimeters. As noted previously, McDonald and Hadley (1985) reported the overall uncertainty was 10% to 25%. However, near the detection limit the uncertainty approached or exceeded 100%. Phase 1 of this study provided the most comprehensive review of routine monitoring at the DOE facilities. The relationship between uncertainty and dose is depicted in Figure 2.5, using the upper 95% dose limit methodology discussed in the photon section of this guide and the coefficient of variation data provided by McDonald and Hadley (1985).

Fix et al (1996) analyzed NTA film calibration data, which included reader uncertainty for the Hanford site from 1950 to 1961. Although these calibration doses were greater than 100 mrem, and all sources of uncertainty are not included, it is apparent that the observations reported by McDonald and Hadley in the 1980s should be reasonable approximations of the uncertainty over the monitoring time period from 1950-1990s. Note that this uncertainty factor does not account for any systematic bias that should be corrected for on a site-by-site basis as appropriate.

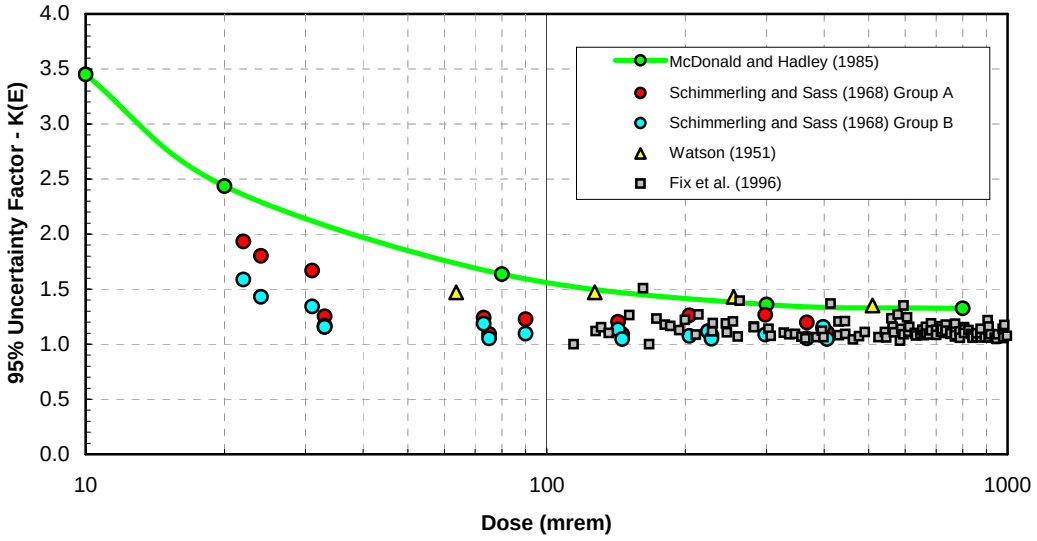

Figure 2.5 95% Uncertainty factor K(E) calculated from various data sets.

2.2.2 Missed Dose

2.2.2.1 Background

Neutron monitoring was not fully implemented, or was generally inadequate, until the late 1950s. As a result, missed neutron doses have the potential to contribute significantly to the annual occupational dose, especially in early years of the DOE weapons complex.

2.2.2.2 Method

2.2.2.2.1 Monitoring Data - Below Limit of Detection

Generally, neutron missed dose will be evaluated using the same method discussed for photons. However, when the neutron missed dose central estimate (nLOD/2) exceeds 75% of the photon dose (dosimeter dose + missed dose), the exposure should be evaluated to determine if it should be considered to be an unmonitored exposure. If so, some other dose reconstruction method may be used to estimate the neutron dose. These alternate methods include but are not limited to the use of a site or area specific neutron to photon dose ratio, or radiation survey data combined with stay times (frequency of exposure).

2.2.2.2.2 Unmonitored Neutron Energy Interval

A worker cannot have an exposure to fast neutrons without an exposure to intermediate (Group II) or thermal neutrons (Group I), since the human body acts as a moderator. However, a worker can be exposed to only low energy neutrons if a moderator shielded the neutron source. Generally, Group II neutrons have gone unmonitored and unreported unless they have been accounted for in site specific algorithms. When site/facility specific neutron spectrums are known, respective doses in each missing group can be determined using the ratio of the dose within each energy interval. When no specific neutron spectrum information is known ***and*** both the thermal and fast components have been reported, the Group II dose can be estimated by interpolating the neutron fluence between the opposing groups. The conversion from dose to fluence is necessary since the dose conversion factor is different for thermal and fast neutrons. Once the interpolated fluence is known, the midpoint of the energy interval can be used to estimate the dose.

2.2.2.3 Uncertainty

The uncertainty associated with missed neutron dose should be evaluated as described in section 2.1.2 using the lognormal distribution.

2.3 Electron Exposures

Low energy electron exposures or beta exposures are significant for cases of skin cancer, however if high-energy (> 1.0 MeV) electrons are encountered, high exposures can be significant for breast and testicular cancer. For purposes of this guide, all discussions are applicable to skin cancer only. Most workers were somewhat protected from electron exposures through the use of coveralls, gloves, or other anti contamination clothing. Low

energy electrons usually do not have sufficient energy to penetrate outer clothing, however exposed skin on the hands and face can receive significant exposure.

For skin cancer, the dose should be estimated for the cancer site. If the cancer started on the hand, then the extremity dose would be more appropriate than the film badge worn on the lapel. Conversely, for skin cancer originating on the face, the lapel dosimeter would be more appropriate for determining the dose. Professional judgment should be used to determine which measurements are most appropriate for the skin cancer site.

2.3.1 Dosimeter Dose

2.3.1.1 Background

Early practices of shallow dose conversion did not accurately reflect actual skin exposure. The open window of the film dosimeters was typically calibrated in units of exposure (R) using uranium, however at some facilities, an Sr-90/Y-90 source was used.

2.3.1.2 Method

As with photon and neutron exposures, the dosimeter dose is the simple summation of each dosimeter for a given year. The exposure is assumed to be equal to the shallow dose (H'(0.07)), recognizing that this is an overestimation of the true shallow dose.

2.3.1.3 Uncertainty

There has been very little published about the uncertainty of beta dosimetry. Considering the similar mechanisms between photon and beta film dosimetry, the methodology discussed in section 2.1.1.3 should be applied.

2.3.2 Missed Dose

2.3.2.1 Background

The combination of doses below the limit of detection in conjunction with early reporting criteria can result in significant missed dose.

2.3.2.2 Method

The missed dose will be calculated using the same method as that for photon and neutrons.

2.3.2.3 Uncertainty

The uncertainty for missed electron exposures is also assumed to follow a log normal distribution.

2.3.3 Skin Contamination

2.3.3.1 Background

Skin contamination can result in significant exposures. While frisking out of contamination areas, some workers might have triggered alarm levels such that decontamination of the skin was necessary. These skin contamination incidents have typically been recorded in the individual's radiological exposure records.

2.3.3.2 Method

2.3.3.2.1 Location of Contamination

To be included in the skin dose, the contamination must have occurred on a body part where the skin cancer originated.

2.3.3.2.2 Dose Calculation

For calculating the dose from skin contamination, a program such as VARSKIN[1] can be used to estimate the skin dose. The default skin depth should be 0.07 mm. If the area of the skin cancer is known, the dose should be calculated for that surface area. If the skin cancer area is unknown, the contamination area, if known, should be assumed to be the surface area of the skin cancer, however the surface area should not be less than 1 cm^2. The shielding effect of any personal protective equipment such as coveralls, gloves, plastics, etc. worn should be considered if known.

2.3.3.3 Uncertainty

When conducting dose reconstruction for skin cancer, there are multiple parameters which must be taken into consideration such as the activity, average area of the measurement probe, average area of the actual contamination, etc. Professional judgment should be used to determine the most probable exposure parameters in arriving at the central tendency of the log normal distribution of the dose. The maximum or 95% dose limit should be calculated assuming the most reasonable claimant friendly assumptions such as a minimum surface area of 1 cm^2, no protective clothing, negligible distance between contamination and skin, etc.

3.0 EXTERNAL DOSE RECONSTRUCTION – INCOMPLETE, MISSING OR NO MONITORING DATA

Incomplete or missing personal monitoring usually occurs either between two periods of monitoring data or at the beginning or end of a monitoring time period. When personal monitoring data is missing between two other periods of monitoring, interpolation between the two-monitored time periods may be reasonable. When the incomplete data is either before or after monitoring data, extrapolation may be reasonable, however caution should be used to properly account for any trends that may exist.

[1] This is not an endorsement of the VARSKIN program, and is presented as one example of a typical program that could assist in skin dose computations.

3.0.1 Interpolation of Missing Personal Monitoring Data

In some instances, dosimetry records might be missing for a portion of an individual's work history. However if the individual has sufficient monitoring data prior to and after the missing data, the dose can be interpolated by a simple average between the two monitoring periods. The interpolation would be considered reasonable providing the work practices, radiological protection measures, and the administrative and engineering controls did not change. In addition, interpolation may be conducted only if there is no indication, whether from the claimant or site radiological records, that a radiological incident resulting in a higher exposure occurred during the time period of missing data.

3.0.2 Extrapolation from Incomplete Personal Monitoring Data

At some sites, as the radiological monitoring practices were being developed, early dosimetry was rather crude and not all external radiation types were measured. As radiological monitoring programs became more sophisticated, more radiation types and energies were measured and recorded in personal monitoring records. Most programs started with measurements of high-energy photons and then added beta or electron measurements followed by neutrons. In order to reconstruct an individual's dose during these early time periods, some extrapolation from adjacent (near-by) time periods may be necessary. Caution must be used, however, to account for trends in exposure data resulting from differences in work practices, implementation of radiological, administrative, and/or engineering controls that might change the exposure pattern.

Uncertainty from either interpolation or extrapolation could be very difficult to accurately determine. Therefore claimant friendly upper bounds should be used.

3.0.3 No Personal Monitoring Data

When no personal monitoring data is available, the external radiation dose should be reconstructed based on 1) co-worker data, 2) radiation survey data or 3) source term information. As noted in section 1.4, Dose Reconstruction - Hierarchy of Data, co-worker data should be used prior to radiation surveys and survey data should be used before source term information. It should be recognized that dose reconstructions based on survey data will probably be biased, since monitoring practices tended to be recorded at the highest level to ensure compliance, but this is an acceptable bias in a claimant friendly compensation program. If no survey data is available, the dose should be estimated based on the activity of the source term, engineering and administrative controls, and work history.

3.1 Photon Exposures

3.1.1 Photon Dose Reconstruction – Co-worker Data

At some facilities, only a subset of workers was monitored for radiation exposure to demonstrate compliance with orders or regulations. In these instances, the claimant has been asked during the CATI for a list of co-workers who worked with the claimant. Data from the claimant's co-worker(s) should be used when monitoring data is incomplete or missing. In some instances, multiple co-workers were monitored and an average was reported for the remainder of the group. The benefit of the doubt should be given to the

claimant and the maximum reasonable worker dose within the group should be used. Since dosimetry data is being used, the methods discussed in Section 2.1 should be used for dose reconstructions.

3.1.2 Photon Dose Reconstruction – Survey Data

3.1.2.1 Background

Throughout the history of radiological operations, radiation surveys using ionization chambers, Geiger-Mueller detectors, and scintillation detectors have been conducted on a routine basis at most weapons production plants. These data have typically been reported in radiation survey reports or on radiation work permits in units of exposure rate or dose rate such as mR/hr, mrem/hr, etc. These data, in conjunction with the duration of exposure, should be utilized only when personal monitoring data is not available, however they should be used before source term data.

3.1.2.2 Method

The exposure or dose can be calculated by simply multiplying the exposure or dose rate by the duration of exposure or dose.

$$Dose = \dot{D} \times t$$

Exposure rate, in units of roentgen per hour (R/hr), has been reported on most early survey data sheets. In later years, when dose rate was reported, some consideration for the method of calibration of the instrument is necessary, although most will be ambient dose equivalent. Also, caution should be used to ensure the reported dose is not a shallow dose (i.e. open window).

From area survey data, the exposure rate was generally well known and access to areas with very high exposure rates was typically restricted. In addition, since most radiological jobs ***do not*** result in exposure 8 hours a day, 5 days a week and 50 weeks per year, time is one of the most important variables.

3.1.2.3 Uncertainty

Generally, when using survey data for dose reconstruction there are only two variables, the distribution of measurements in the work area, and the duration of the exposure. Unlike dosimetry measurements, the uncertainty associated with survey data will tend to result in rather large standard deviations. If a normal distribution were used, the lower bound could be less than zero in some cases. Since sampling is conducted for the final distribution, the log normal distribution is believed to be the most reasonable uncertainty distribution based on survey data.

3.1.3 Photon Dose Reconstruction – Source Term

3.1.3.1 Background

Dose reconstruction from a source term is relatively difficult and the associated uncertainty is relatively large. Before conducting a dose reconstruction based on source term data, an investigation should be conducted to determine if the process is sufficiently similar to another operation at a monitored facility such that other worker data or survey data could be used to estimate workplace exposure levels. When worker and survey data are not available and source term data is used for the dose reconstruction, all assumptions and parameters used in the calculation must be clearly stated and documented in the dose reconstruction report.

3.1.3.2 Method

The source term (S) can sometimes be determined through process or material receipt records, if available. However, facility-handling information is critical to determine the approximate time, distance, and shielding assumptions needed to adequately calculate a dose to a worker.

Generally, more complex calculations are required to account for the effects of geometry, self-shielding, multiple shielding and buildup.

Computer programs such as Microshield[2] can greatly facilitate the computations from source term information. In addition, these programs also enable some worst-case examples to be developed to bound the uncertainty of the most reasonable estimate. Received

3.1.3.2.1 Source Term

With knowledge of density, purity, isotopic content, weight and/or dimensions of the material, the quantity of activity can be calculated from health physics first principles.

3.1.3.2.2 Average Energy

Most radionuclides emit multiple gamma and x-rays at varying yields per disintegration. Since IREP uses three photon energy intervals and five neutron energy intervals, the energy of the emissions can be grouped accordingly and the yields determined by group.

3.1.3.2.3 Time of Exposure

As with the survey data dose reconstruction, the time or duration of the exposure is one of the most critical factors to be estimated. As with dose reconstruction using survey data, specific information on duration of exposure expressed as hours per day, days per week, and weeks per year will assist in a more accurate estimate of exposure duration.

[2] This is not an endorsement of the Microshield program, and is presented as one example of a program that could assist in the dose computations.

3.1.3.2.4 Distance from Source
The distance is another important parameter in estimating exposure to a radioactive material. At some facilities, workers were separated by tens of feet from radioactive materials due to engineering or administrative controls, while at other facilities, workers handled radioactive materials in bench top experiments such that the distance from the source was approximately 18 inches.

3.1.3.2.5 Shielding
For high-level sources, shielding was generally used as an engineering control to protect workers from excessive radiation exposure. In addition, some high-density radioactive materials such as uranium also shield a significant portion of the photons emitted.

3.1.3.3 Uncertainty

Dose uncertainty from source term estimates is relatively large. The most reasonable parameters of source strength, average distance, exposure duration, and shielding should be used to compute the most likely dose. Each of these parameters should then be reasonably estimated to maximize the dose (claimant friendly). Assuming a normal distribution, the most likely estimate should be the mean with the upper 95% limit being the claimant friendly estimate.

3.1.4 Photon Dose Reconstruction – Control Limits

3.1.4.1 Background

Dose reconstruction based only on administrative or radiological monitoring controls will result in a gross overestimation of the claimant's dose. Unfortunately, if no monitoring records of any type can be found and the source term is unknown, an upper external dose estimate can be developed using occupational radiation protection limits. This of course assumes that appropriate controls were in place to prevent exposures in excess of occupational limits. When conducting a dose reconstruction using control limits, all assumptions must be clearly stated in the dose reconstruction report.

3.1.4.2 Method

There are three radiological control limits that can be used for dose reconstruction: threshold for required monitoring; radiation posting limits; and annual radiation dose limits.

3.1.4.2.1 Monitoring Not Required
This method is most appropriate for office workers who were not monitored due to the low potential for exposure. In these instances, the central point estimate should be the threshold level for monitoring. At most facilities, this value was 100 mrem/year.

3.1.4.2.2 Posted Control Limits
This method is most appropriate for short duration exposures when an unmonitored person entered a radiological controlled area without proper monitoring. In these instances, the midpoint dose rate between posted areas should be used as a reasonable

estimate. This midpoint dose rate multiplied by the number of hours of exposure will provide the central dose estimate. The upper bound of the posted area multiplied by the number of hours in the areas will result in the upper 95% dose estimate.

3.1.4.2.3 Annual Radiation Dose Limits
The dose assigned is the maximum allowable monthly dose times the number of months worked. Since a worker could have received the annual limit in a short time frame, the acute exposure should be used. Since dose reconstruction using annual limits will yield unreasonably large exposure estimates some restrictions apply to the use of annual limits. The method should only be used for short employment durations of less than one year.

3.1.4.3 Uncertainty

As indicated in section 3.1.3.4, the midpoint of the dose range should be used as the most likely estimate with the maximum being the upper 95% of a lognormal distribution. Although DOE orders have specified, weekly, monthly, and quarterly dose limits, workers have been allowed to exceed these administrative limits as long as they did not exceed the annual limits. Generally the central estimate a dose distribution can be developed using the weekly, monthly, or quarterly exposure limit with the upper 95% confidence interval being the annual radiation dose limit. However, when the annual radiation dose limit is used for dose reconstruction, this dose should be considered the maximum dose. Therefore a constant should be used and thus there is no distribution.

3.2 Neutron Exposures

As with photon exposures, estimating neutron exposures without personal monitoring data is relatively difficult. The use of neutron to photon ratios is an acceptable method to assign a neutron dose to workers using site-specific data. Co-worker data, survey data, and/or source term data are useful in the determination of neutron exposures.

3.2.1 Neutron Dose Reconstruction - Co-worker Data

After individual monitoring data, co-worker data is considered the next most accurate indicator of exposure. This data should be used whenever individual monitoring data for the claimant is not available. When job category (co-worker) data is available, the benefit of the doubt should be given to the claimant and the maximum reasonable worker dose within the job category should be used. Since dosimetry data is being used, the methods discussed in Section 2.2 should be used for dose reconstruction from co-worker data.

3.2.2 Neutron Dose Reconstruction – Survey Data

3.2.2.1 Background

Neutron monitoring has been conducted using proportional counters such as BF_3 detectors and recently, tissue equivalent proportional counters (TEPC). Around nuclear reactors, neutron measurements have been conducted to verify adequate shielding of the reactor, thus survey data should be available to estimate exposures.

3.2.2.2 Method

The general equation is the same as described in section 3.1.2 and is provided as follows.

$$Dose = \dot{D} \times t$$

where: $\dot{D}$ = dose rate or fluence
t = duration of the exposure

Generally, an average of the dose rate measurements in the workplace should be used for the central estimate.

3.2.2.3 Uncertainty

As with most exposure discussions in this guide, the central estimate should be an average of the survey data. The upper bound should be estimated by applying the maximum work time period with the maximum recorded dose rate for the area. Generally, survey data follow a lognormal distribution, therefore this distribution should be used for the uncertainty distribution. In addition, since the uncertainty is expected to be relatively large, a significant percent of the data could be negative if a normal distribution were used.

3.2.3 Neutron Dose Reconstruction - Source Term Data

3.2.3.1 Background

Dose reconstruction from a neutron source term should only be conducted when no survey data is available and relatively simple exposure geometries are appropriate. NCRP 38 (1971) provides general guidance for radiological protection against neutron radiation.

3.2.3.2 Method

This methodology described in NCRP 38 (1971) should be used when estimating neutron exposures from various shielded sources. The general point source equation is similar to the photon point source equation in section 3.1.3, however the attenuation coefficient is replaced with a neutron removal cross section. NCRP 38 discusses criteria for which the removal cross section is a valid assumption.

Additional removal cross sections can be calculated using the methodology discussed in NCRP (1971) Report 38.

3.2.3.3 Uncertainty

The uncertainty associated with dose estimation from source term data is relatively large and could vary by an order of magnitude or more. As with the photon measurements there are several sources of uncertainty; including the duration of the exposure, the distance from the source, variations in the shielding thickness, and the uncertainty of the initial neutron fluence. The most reasonable value of each parameter should be used to

determine the central estimate, while claimant friendly assumptions should be made to estimate the upper bound of the distribution. Generally, a normal distribution should be applied, however if the upper bound uncertainty (2σ) subtracted from the central estimate is less than zero, a lognormal distribution should be used.

3.3 Electron Exposures

Electron exposures are only important for certain cancer sites such as the skin, breast, and possibly for the testes, depending on the electron energy and shielding. Electron exposures do not need to be calculated for deep organs.

In the absence of co-worker data, survey data can be used. Source term data can also be used. Generally, administrative dose limits for skin exposures are very large, however contamination control limits could be used to estimate the upper bound of low-level exposures for initial dose assessment.

3.3.1 Electron Dose Reconstruction - Co-worker Data

Generally whole body dosimetry would be a good measure of exposure. Differences in job functions, proximity to the source and duration of exposure make extremity dosimetry highly uncertain and should not be used, unless the identical job function is performed, and the proximity to the source is identical and relative fractions of exposure time can be clearly established.

3.3.2 Electron Dose Reconstruction - Survey Data

3.3.2.1 Background

Open window GM detectors or thin window ionization chambers have been used to measure the beta dose rate, however, in some instances, only contamination survey data is available in units of activity. The method section is subdivided into dose rate surveys and contamination surveys.

3.3.2.2 Method

3.3.2.2.1 Electron Dose Rate Data

Electron or beta dose rate survey data in conjunction with duration of exposure can be used to estimate electron dose, using the standard equation discussed in section 3.1.2 and 3.2.2.

$$Dose = \dot{D} \times t$$

where: $\dot{D}$ = dose rate usually in mrad/hr
t = duration of the exposure

3.3.2.2.2 Contamination Survey Data

In some instances contamination survey data could be used to estimate the beta dose rate. For these computations, the computer program VARSKIN may be used as it integrates

the Berger (1971) point kernel equation. The computational methods and details can be found in NUREG/CR-5873 (Durham, 1992). Basic inputs to VARSKIN include source geometry, activity, source size, air gap, protective layer thickness, and density of the protective layer. While the VARSKIN program was designed for skin contamination, by varying the air gap, it can be utilized for external electron skin doses. When utilizing contamination survey data, a large disc source is recommended and minimum averaged dose area should be no less than 1 cm^2.

3.3.2.3 Uncertainty

As with previous uncertainty calculations, the average reading or most likely reading for dose rate measurements or activity measurements should be used as the central estimate. The highest recorded value should be used to calculate the upper 95% bound. The duration should also be varied to determine the upper 95% bound of the log normal distribution.

3.3.3 Electron Dose Reconstruction - Source Term

3.3.3.1 Background

This type of dose reconstruction should not be conducted unless detailed information about the source, encapsulation, duration of exposure or contamination levels are known or can be adequately bounded. The most applicable scenario would be to use this method for unencapsulated bare metal such as uranium.

3.3.3.2 Method

As with the surface contamination methodology, the skin dose rate can be calculated from various geometries using source term activity and a program such as VARSKIN. The dose rate can be combined with exposure time to calculate the central dose estimate as shown in the following equation.

$$Dose = \dot{D} \times t$$

where: $\dot{D}$ = dose rate usually in mrad/hr
t = duration of the exposure

3.3.3.3 Uncertainty

As with other source term dose reconstructions, the time, distance, and shielding can be varied to develop the upper dose limit. The electron dose distribution is assumed to follow a log normal distribution. Professional judgment should be used to estimate the most probable exposure, with claimant friendly and clearly stated assumptions, such as no shielding, close distance and maximum exposure time to estimate the 95% upper dose limit. For multiple skin contamination incidents in a single year, the uncertainty should be combined using the square root of the sum of the squares methodology as described in section 2.1.1.3.4.

4.0 CONVERSION TO ORGAN DOSE

The purpose of this section is to provide guidance on the conversion from individual monitoring data to organ dose. For photon exposures, the organ dose conversion coefficients in ICRP 74 convert from free-air KERMA to absorbed dose in the organ of interest. A conversion from monitored dose to free-air KERMA is needed to complete the organ dose conversion. Neutron organ dose conversion factors in ICRP 74 are tabulated per neutron fluence. While some monitoring data has been reported in terms of fluence, traditionally, neutron doses have been reported as either ambient dose at 10mm ($H^*(10)$) or personal dose at 10 mm ($H_{p,slab}(10)$). Since skin is the primary target tissue for electron doses, the dose conversion factors should be calculated for a skin depth of 0.07 mm.

The assumption of a 100% AP exposure geometry, together with the corresponding AP DCFs in APPENDIX A, does not, in general, result in an underestimate of organ dose in the great majority of cases. There is a relatively small percentage of cases for which organ dose underestimates could occur if the true exposure geometry was not 100% AP. It is recommended that any modification be based on a dosimeter location adjustment factor (see Table 4.1a), rather than adjusting the organ DCF in APPENDIX A. However, if a default assumption of 100% AP exposure geometry is deemed inappropriate, it can be shown that application of dosimeter location adjustment factors would actually reduce the dose estimate for many organs compared to the current approach (ORAU 2005). It is therefore recommended to use a dosimeter location adjustment factor on DCFs associated with those organs for which rotational and isotropic geometries are predominantly claimant favorable. Four organs have DCF's for which ISO or ROT geometries are generally 10% or more favorable. Correction factors for the appropriate geometries are listed section 4.4.

The relative angular response of the dosimeter with respect to the incident beam is of little significance for un-filtered film or TLD's, so long as the mean free path of the photon or beta particle is greater than the absorber (Attix 1966). Hence open-window readings can generally be considered independent of exposure angle. Lower energy photons (<250 keV) are affected the most by angle and filtration thickness, with the reduction in response proportional to the cosine of the incidence angle. However, for energies < 30keV the open-window is the region of interest for shallow dose and is independent of angle. Therefore, the energy range between 30 keV and 250 keV has the greatest variability for each filtered portion of the film/TLD and must be addressed in the dose reconstruction. How this is done will rely on the job performed and the types of radiation involved. Specific guidance on orientation is found in the individual site Technical Basis Document.

4.1 Photon Dose

The two basic types of data involved in converting photon doses to organ dose are monitored individual doses, and survey or source term dose rate data.

4.1.1 Development of the Monitored Exposure/Dose to Organ dose factor

4.1.1.1 Exposure (R) to free-air KERMA (K_a)

Most early monitoring data was reported in units of exposure and not a deep dose at 10 mm. Using figure 4.3 in ICRU 43 (1988), and the ambient deep dose (H*(10)) from ICRP 74 (1996), the conversion factor from exposure to free-air KERMA can be calculated. Table 4.1 provides the conversion factors used in calculations to develop the organ dose conversion factors.

$$E \rightarrow K_a = \frac{H^*(10)}{K_a} \times \frac{1}{\frac{H^*(10)}{E}} = \frac{E}{K_a}$$

where

$E = Exposure$

$H^*(10) = Ambient\ Dose$

$K_a = free-air\ KERMA$

Table 4.1 Conversion factors used in organ dose calculations.

Photon Energy (MeV)	Ambient Dose Equivalent H*(10) - cSv / Exposure (R)[1]	Ambient Dose Equivalent H*(10) - cSv / free-air KERMA (K_a)[2]	Exposure (R) / free-air KERMA (K_a)
0.015	0.25	0.26	1.04
0.020	0.60	0.61	1.02
0.030	1.00	1.10	1.10
0.040	1.30	1.47	1.13
0.050	1.46	1.67	1.14
0.060	1.55	1.74	1.12
0.070	1.53	1.73	1.13
0.080	1.51	1.72	1.14
0.100	1.43	1.65	1.15
0.150	1.30	1.49	1.15
0.200	1.20	1.40	1.17
0.300	1.13	1.31	1.16
0.400	1.09	1.26	1.16
0.500	1.05	1.23	1.17
0.600	1.04	1.21	1.16
0.800	1.01	1.19	1.18
1.000	1.00	1.17	1.17
2.000	0.96	1.14	1.19
4.000	0.95	1.12	1.18
6.000	0.95	1.11	1.17
8.000	0.95	1.11	1.17
10.000	0.95	1.10	1.16

[1] *Data extracted from Figure 4.3 ICRU 43 (1988)*

[2] *Data from ICRP 74 (1996)*

4.1.1.2 Photon Dose Equivalent H(10) and $H_p(10)$ to free-air KERMA*

Table A.21 in ICRP 74 (1996) lists the conversion coefficients from ambient dose equivalent (H*(10)) to free-air KERMA (K_a) by photon energy. Table A.24 in ICRP 74 (1996) lists the conversion coefficients from personal dose equivalent ($H_p(10)$) to air KERMA (K_a). Once the dose is converted to free-air KERMA, the organ dose is a straightforward multiplication of the dose conversion factors (D_T/K_a) listed in Tables A.2 – A.20 of ICRP 74 (1996).

$$DCF_{Hp(10)\rightarrow D_T} = \frac{1}{\frac{H_p(10)}{K_a}} \times \frac{D_T}{K_a}$$

where:

D_T = Absorbed Dose in Target Tissue

$H_p(10)$ = Personal Dose Equivalent

K_a = free - air KERMA

4.1.2 Area survey or source term data to Organ Dose

Generally, radiation survey data have been reported in units of exposure (R) in free air. For these data, the exposure methodology discussed in section 4.1.1.1 should be used. Area survey dose rates or those calculated from source term information should generally be assumed to be the ambient dose at 10 mm or $H^*(10)$.

4.1.3 Dose Conversion Factor Simplification

The Dose Conversion Factors (DCF) in ICRP 74 are listed by tissue of interest, exposure geometry, and radiation energy. As noted previously, NIOSH-IREP uses energy intervals for the probability of causation calculation. Since ICRP 74 lists the dose conversion factor for multiple energies, some simplification is needed for dose reconstruction under EEOICPA. As shown in Figure 4.1, the dose conversion coefficient is a continuous function of energy. For simplification, the area under the curve from the beginning to the end of the energy interval divided by the range will be used as the simplified dose conversion coefficient. A simple function *(f(E))* was fitted for each energy interval to integrate the area under the curve. The example below is for red bone marrow dose from photons between 30 and 250 keV.

$$DCF_{\gamma,30-250keV} = \frac{\int_{30}^{250} f(E)dx}{Range} = 0.479 \frac{\text{Bone Marrow - Gy}}{\text{H}_\text{p}(10)\,\text{Gy}}$$

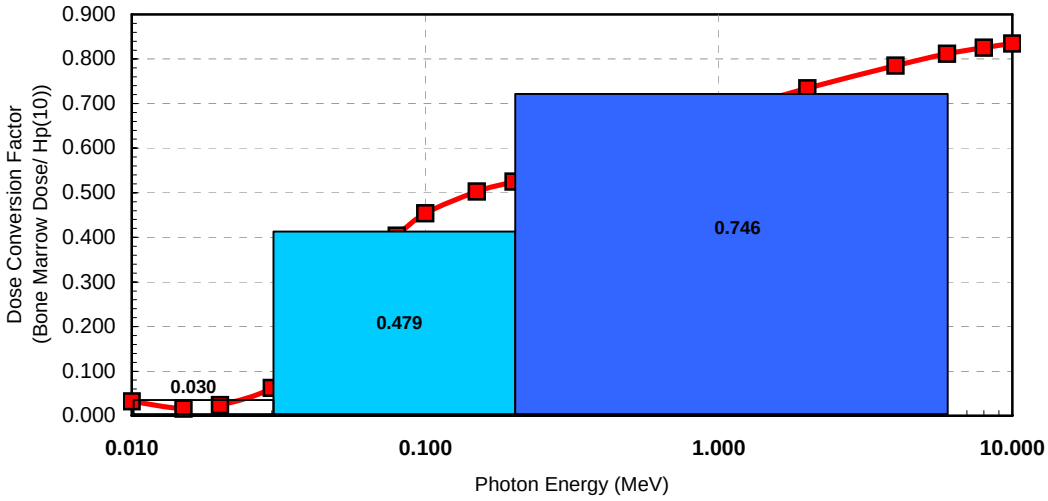

Figure 4.1 Chart of red bone marrow Dose Conversion Factor (DCF) versus photon energy, fitted curve, and associated simplified dose conversion factor for energy band.

Appendix A lists the simplified dose conversion factors by reporting unit (exposure, ambient dose ($H^*(10)$), or personal dose equivalent ($H_p(10)$)) for the three photon energy bands. It should be noted that the upper bound used in the calculation of the high-energy group for photons is truncated at 6 MeV. This method was employed since there are very few operations at DOE which result in photon exposures greater than 6 MeV.

4.2 Neutron Dose Conversion

4.2.1 Area Monitoring Data to Organ Dose

Area monitoring data has been reported in several different formats. Some earlier measurements report the fluence, with energy information provided, while other measurements are reported in absorbed dose (rad), or dose equivalent (rem).

4.2.1.1 Fluence Data to Organ Dose

When fluence data are provided, the conversion to organ dose is straightforward using tables A.26 through A.40 in ICRP 74 (1996). As with the photon dose conversion factors, the ICRP 74 (1996) tables have been compressed into the five neutron energy intervals for use in the IREP program. These compressed tables can be found in Appendix A of this guide.

4.2.1.2 Ambient Dose (H(10)) to Organ Dose Equivalent*

When ambient dose ($H_S^*(10)$) has been reported (typically in survey data), the site specific quality factor (Q_s) must be removed such that absorbed dose is the fundamental unit. Current ICRP 60 (1990) radiation weighting factors *(w_R)* should then be multiplied by the absorbed dose to develop the standard ambient dose equivalent (H*(10)). From

the standard ambient dose equivalent the conversion factors in Appendix A are then applied to determine organ dose equivalent. The conversion from site specific ambient dose to organ dose is illustrated in the following equation.

$$H_T = \frac{H_S^*(10)}{Q_S} \times w_R \times DCF_{H_T / H^*(10)}$$

4.2.2 Personal Monitoring Data to Organ Dose

When routine personal monitoring began, the reported quantity has usually been in dose equivalent. Currently, the standard for personal monitoring neutron data is the personal dose equivalent at 10 mm calibrated using the ICRU slab phantom ($H_{p,slab}(10)$).

4.2.2.1 Neutron Dose Equivalent ($H_{p,slab}(10)$) to Organ Dose Equivalent

Appendix A lists the personal dose equivalent to organ dose equivalent conversion factors. As with the ambient dose, the site specific quality factor (Q_S) should be removed prior to dose calculations and the ICRP 60 (1990) weighting factor *(w_R)* applied before the conversion to organ dose.

4.2.3 Special Dose Conversion Factor for Plutonium

Organ dose conversion factors are tabulated by averaging the energy specific values from ICRP 74 (1996) over the IREP photon energy range. The lowest photon energy interval in Interactive RadioEpidemiological Program (IREP) is categorized as less than 30 keV. Plutonium emits several x-rays in this energy range; however, a simple average as used in the previous sections may not result in the most accurate dose conversion factor. For Plutonium work, the average x-ray energy is approximately 17 keV. As a result, using 20 keV as a claimant favorable single point estimate is appropriate. Since the low energy photon dose from glove box work, for example, is predominately in the anterior-posterior (AP) geometry, single point estimate values were calculated for 16 organs listed in ICRP 74. When estimating the low energy photon organ dose, the values in Table 4.1a should be used.

Table 4.1a Special Dose Conversion Factors (DCF's) for Plutonium. These were calculated assuming AP geometry and 20 keV mono-energetic photons.

Organ	Personal Dose Equivalent ($H_p(10)$) – Organ Dose (H_T)	Ambient Dose Equivalent ($H^*(10)$) – Organ Dose (H_T)	Exposure (R) – Organ Dose (H_T)
Bladder	0.146	0.147	0.088
Bone (Red Marrow)	0.024	0.024	0.014
Bone (Surfaces)	0.165	0.166	0.099
Breast (Female)	0.761	0.762	0.457
Colon	0.024	0.024	0.015
Esophagus	*	*	*
Eye	1.493	1.495	0.897
Ovaries	*	*	*
Testes	0.823	0.825	0.495
Liver	0.068	0.069	0.041
Lung	0.050	0.050	0.030
Remainder	0.053	0.053	0.032
Stomach	0.144	0.144	0.087
Thymus	0.264	0.264	0.158
Thyroid	0.586	0.587	0.352
Uterus	0.002	0.002	0.001

* 20 keV values not listed in ICRP 74[8] – Use < 30 keV DCF's from OCAS-IG-001[7] or an appropriate surrogate organ

4.3 Electron Dose Conversion Factors

ICRP 74 (1996) list energy specific organ dose conversion factor from fluence. It is anticipated that relatively few dose measurements will have been reported in this manner. ICRP 74 indicates that the dose conversion factor is highly dependant on the electron energy. Since most electron exposures will be a continuum of energies, the site-specific dose conversion factor should generally be used. The shallow dose at 0.07 mm can be assumed to be the skin organ dose.

4.4 Exposure Energy and Geometry

There are six basic exposure geometries discussed in ICRP 74 (1996); the anterior to posterior (AP), posterior to anterior (PA), left lateral (LLAT), right lateral (RLAT), rotational (ROT) and isotropic (ISO) (Figure 4.2). Of these, only four (AP, PA, ROT, and ISO) are of primary interest in dose reconstruction. The AP geometry is typically the most representative geometry experienced by workers because the source of radiation is directly viewed and relatively closer to the worker. However, there are specific job functions in certain types of facilities, which would tend to lead to a different geometry.

The AP DCF values in Appendix A are not the most claimant favorable for bone (surface), bone (red marrow), esophagus, and lung when the dosimeter is worn on the chest. For these organs, if the dosimeter is worn on the chest, multiply the Appendix A values of ROT and ISO by the factors in Table 4.1a instead of using the AP value. In these cases, the ROT or ISO geometries are more claimant favorable than the AP value in Appendix A. However, the correction factors need not be applied if it is determined that the most representative geometry is 100% AP or other compensating claimant favorable determinations have been made in dose reconstruction.

Table 4.1a Correction factors for ROT and ISO DCF values for Bone (RM and Surf), Esophagus, and Lung

Photon Energy Range	Rotational Conversion Factor	Isotropic Conversion. Factor
30-250 keV	1.45	1.58
> 250 keV	1.18	1.28

Note 1: Based upon dosimeter location being on the chest.
Note 2: Based upon dosimeter correction factors in Thierry-Chef (2002)

4.4.1 Dosimeter and Missed Dose Geometry

For dose reconstruction, professional judgment should be used to determine the most credible geometry or geometry weighting factors *(w_g)* from multiple geometries based upon an individual's work history and the CATI. The work-related Dose Conversion Factor (DCF_W) should be calculated as follows:

$$DCF_W = w_{AP} DCF_{AP} + w_{PA} DCF_{PA} + w_{ROT} DCF_{ROT} + w_{ISO} DCF_{ISO}$$

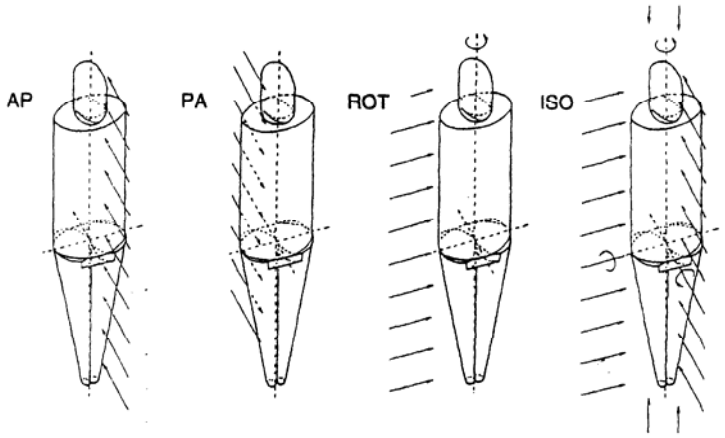

Figure 4.2 Exposure geometries of an anthropomorphic phantom extracted from ICRP 74 (1996)

For example, the isotropic geometry would be reasonable for a general laborer in a uranium manufacturing storage facility, while a lathe worker in the same facility would be more likely to receive the majority of their exposure in an anterior-posterior fashion. A reactor worker refueling a graphite reactor would likely receive their exposure in both the AP and ROT geometry. Table 4.2 provides some general guidance on percentages of exposure geometries.

Table 4.2 Common exposure geometries for various jobs and facilities.

Facility	Job	Geometry	Percentage
Uranium Facility	General Laborer	ISO	75%
		AP	25%
	Machinist	AP	75%
		ISO	25%
	Supervisor	AP	50%
		ISO	50%
Reactor	Fuel Handler	AP	50%
		ROT	50%
	Reactor Operator	ROT	75%
		ISO	25%
Chemical Separations	Glovebox Chemist	AP	90%
		ROT	10%
	Maintenance Worker	AP	50%
		ROT	50%
	Security Guard	ROT	50%
		ISO	50%

4.4.2 Occupational Medical Exposure Geometry

Generally, the exposure geometry for occupational medical chest x-ray exposures is the PA geometry. There are, however, other screening procedures in which the exposure geometry will be different and these should be applied as appropriate.

4.4.3 Environmental Exposure Geometry

The exposure geometry for environmental doses is almost always isotropic in nature. This assumption should be applied to all environmental doses unless another geometry is more appropriate and has been clearly justified.

4.5 Dose Conversion Uncertainty

4.5.1 Energy Uncertainty

The uncertainty resulting from the energy simplification is assumed to follow a uniform distribution using the dose conversion factor lower and upper bounds within the energy interval for the specific exposure geometry. Table 4.3 provides an example using the bone marrow with the anterior-posterior geometry for photons (Figure 4.1).

Table 4.3: Photon Bone Marrow Energy Uncertainty using AP geometry

Photon Energy Band	Effective Dose Conversion Factor	Minimum Dose Conversion Factor	Maximum Dose Conversion Factor
< 30 keV	0.030	0.016	0.063
30 – 250 keV	0.479	0.063	0.540
> 250 keV	0.746	0.540	0.834

4.5.2 Geometry Uncertainty

There is often considerable uncertainty as to the position from which the claimant received radiation exposure. As noted in section 4.3, there maybe some information about job function and position of exposure when handling radioactive materials. Since

the "true" exposure geometry is almost never known, an uncertainty distribution about the dose conversion factor is appropriate. Since likely exposure geometry can be calculated for most jobs, a uniform distribution appears to be inappropriate. However, a triangular distribution with the effective DCF being the most likely geometry, the lower bound being the geometry that would result in the lowest organ dose (or dose conversion factor) and the upper bound being the geometry resulting in the highest organ dose (highest dose conversion factor) maybe appropriate.

5.0 ANNUAL ORGAN DOSE & DISTRIBUTION

5.1 Organ Dose Computation

5.1.1 Organ Dose Estimate

5.1.1.1 Background

The main purpose of this section is to provide guidance on converting the measured dose into an organ dose and to combine each dose component into a single annual dose estimate for entry into the IREP program.

5.1.1.2 Method

The organ dose for each radiation type and energy are compiled by summing the organ dose components calculated by multiplying the dose or exposure component by the appropriate dose conversion factor. When multiple variations have been reported such as ambient dose equivalent and personal dose equivalent, the conversion should be conducted before the summation. The general equation is as follows:

$$D_{radiation,tissue} = D_D(DCF_W) + D_M(DCF_W) + D_{OM}(DCF_{AP}) + D_E(DCF_{ISO})$$

5.1.2 Uncertainty Distribution

5.1.2.1 Background

The uncertainty associated with the organ dose is computed through random sampling (Monte Carlo) of each distribution used to compute the central organ dose estimate. By using these distributions, the overall organ dose uncertainty can be determined with reasonable precision. For simple computations a minimum of 1000 iterations can be used, however, a larger number of iterations may be necessary to determine whether the tendency of the distribution is normal or lognormal.

5.1.2.2 Method

Since different exposure geometries are more appropriate for different dose components, the individual dose components (dosimeter dose, missed dose, occupational medical dose, and environmental dose) each must be converted to organ dose. The total radiation

energy interval uncertainty is then calculated by sampling from each of the organ dose distributions.

5.2 Dose Distribution Determination/Categorization

The compiled distribution is likely to be either normally or log normally distributed. The tendency will most likely be highly dependent on the ratio between the missed dose (log normal distribution) and the dosimeter dose (normal distribution). Therefore some statistical test should be applied to determine which distribution is more appropriate. The statistical test can be conducted manually using any variety of methods or by using standard statistical software. Since the sampled dose distribution is likely not to fall strictly into one distribution or another, some professional judgment should be used to determine the best fit to the data. As Kumazawa (1988) found, low level doses tend to follow a log normal distribution while higher level doses near occupational exposure limits tend to follow a normal distribution.

5.3 IREP-Excel Reporting Format

To assist in probability of causation calculations, the annual dose information should be entered into the IREP-EXCEL spreadsheet. The format for this spreadsheet can be found in Appendix B of this guide.

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APPENDIX A – PHOTON DOSE CONVERSION FACTORS (DCF)

Organ: Bladder

Photon Exposures

Personal Dose Equivalent ($H_p(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.166** (0.000-0.426)	**0.006** (0.000-0.035)	**0.046** (0.000-0.141)	**0.030** (0.000-0.100)	***0.000***	***0.426***
30 - 250 keV	**0.873** (0.426-0.914)	**0.419** (0.035-0.500)	**0.491** (0.141-0.553)	**0.379** (0.100-0.432)	***0.035***	***0.914***
>250 Kev	**0.913** (0.876-0.929)	**0.720** (0.500-0.753)	**0.764** (0.553-0.846)	**0.672** (0.432-0.755)	***0.432***	***0.929***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.168** (0.000-0.431)	**0.007** (0.000-0.036)	**0.046** (0.000-0.143)	**0.030** (0.000-0.101)	***0.000***	***0.431***
30 - 250 keV	**0.940** (0.431-1.007)	**0.452** (0.036-0.527)	**0.528** (0.143-0.583)	**0.408** (0.101-0.456)	***0.036***	***1.007***
>250 Kev	**0.911** (0.885-0.947)	**0.719** (0.527-0.751)	**0.763** (0.583-0.855)	**0.671** (0.456-0.763)	***0.456***	***0.947***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.175** (0.008-0.431)	**0.010** (0.000-0.036)	**0.054** (0.001-0.143)	**0.036** (0.001-0.101)	***0.000***	***0.431***
30 - 250 keV	**1.244** (0.431-1.523)	**0.590** (0.036-0.684)	**0.695** (0.143-0.809)	**0.536** (0.101-0.613)	***0.036***	***1.523***
>250 Kev	**0.883** (0.840-1.103)	**0.694** (0.607-0.713)	**0.736** (0.661-0.812)	**0.647** (0.523-0.725)	***0.523***	***1.103***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.193** (0.008-0.474)	**0.005** (0.000-0.039)	**0.056** (0.001-0.157)	**0.038** (0.001-0.111)	***0.000***	***0.474***
30 - 250 keV	**1.434** (0.474-1.732)	**0.682** (0.039-0.789)	**0.799** (0.157-0.922)	**0.618** (0.111-0.704)	***0.039***	***1.732***
>250 Kev	**1.043** (0.973-1.284)	**0.818** (0.704-0.841)	**0.866** (0.772-0.940)	**0.762** (0.606-0.839)	***0.606***	***1.284***

Organ: Bone (Red Marrow)

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.030** (0.016-0.063)	**0.068** (0.030-0.154)	**0.036** (0.015-0.084)	**0.028** (0.012-0.066)	***0.012***	***0.154***
30 - 250 keV	**0.479** (0.063-0.540)	**0.704** (0.154-0.791)	**0.483** (0.084-0.573)	**0.395** (0.066-0.475)	***0.063***	***0.791***
>250 keV	**0.746** (0.540-0.834)	**0.864** (0.791-0.906)	**0.760** (0.573-0.846)	**0.692** (0.475-0.800)	***0.475***	***0.906***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.030** (0.016-0.063)	**0.069** (0.030-0.155)	**0.036** (0.016-0.085)	**0.028** (0.012-0.067)	***0.012***	***0.155***
30 - 250 keV	**0.479** (0.063-0.570)	**0.758** (0.155-0.842)	**0.520** (0.085-0.605)	**0.425** (0.067-0.501)	***0.063***	***0.842***
>250 keV	**0.746** (0.570-0.843)	**0.861** (0.826-0.915)	**0.758** (0.605-0.855)	**0.690** (0.501-0.808)	***0.501***	***0.915***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.025** (0.004-0.063)	**0.061** (0.008-0.155)	**0.033** (0.004-0.085)	**0.027** (0.003-0.067)	***0.003***	***0.155***
30 - 250 keV	**0.626** (0.063-0.712)	**0.996** (0.155-1.167)	**0.681** (0.085-0.780)	**0.557** (0.067-0.632)	***0.063***	***1.167***
>250 keV	**0.720** (0.645-0.801)	**0.834** (0.815-0.973)	**0.732** (0.674-0.812)	**0.666** (0.570-0.768)	***0.570***	***0.973***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.028** (0.000-0.070)	**0.067** (0.000-0.171)	**0.036** (0.000-0.093)	**0.028** (0.000-0.073)	***0.000***	***0.171***
30 - 250 keV	**0.721** (0.070-0.822)	**1.147** (0.171-1.347)	**0.784** (0.093-0.900)	**0.641** (0.073-0.729)	***0.070***	***1.347***
>250 keV	**0.849** (0.755-0.927)	**0.982** (0.968-1.132)	**0.863** (0.789-0.940)	**0.785** (0.665-0.889)	***0.665***	***1.132***

Organ: Bone (Surface)

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.215** (0.094-0.483)	**0.283** (0.127-0.624)	**0.224** (0.101-0.485)	**0.170** (0.075-0.379)	***0.075***	***0.624***
30 - 250 keV	**0.850** (0.483-1.161)	**0.988** (0.624-1.383)	**0.794** (0.485-1.087)	**0.649** (0.379-0.878)	***0.379***	***1.383***
>250 keV	**0.792** (0.685-0.852)	**0.831** (0.759-0.882)	**0.769** (0.642-0.845)	**0.702** (0.540-0.797)	***0.540***	***0.882***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.218** (0.095-0.488)	**0.287** (0.129-0.631)	**0.227** (0.102-0.490)	**0.173** (0.076-0.384)	***0.076***	***0.631***
30 - 250 keV	**0.915** (0.488-1.283)	**1.063** (0.631-1.519)	**0.854** (0.490-1.201)	**0.698** (0.384-0.970)	***0.384***	***1.519***
>250 keV	**0.791** (0.708-0.861)	**0.832** (0.779-0.891)	**0.767** (0.667-0.854)	**0.700** (0.564-0.805)	***0.564***	***0.891***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.209** (0.024-0.488)	**0.278** (0.032-0.631)	**0.217** (0.026-0.490)	**0.162** (0.019-0.384)	***0.019***	***0.631***
30 - 250 keV	**1.229** (0.488-1.962)	**1.433** (0.631-2.331)	**1.150** (0.490-1.838)	**0.938** (0.384-1.484)	***0.384***	***2.331***
>250 keV	**0.764** (0.732-0.865)	**0.803** (0.782-0.973)	**0.742** (0.697-0.811)	**0.681** (0.603-0.764)	***0.603***	***0.973***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.217** (0.001-0.537)	**0.286** (0.002-0.694)	**0.223** (0.002-0.539)	**0.173** (0.001-0.422)	***0.001***	***0.694***
30 - 250 keV	**1.415** (0.537-2.219)	**1.644** (0.694-2.628)	**1.323** (0.539-2.078)	**1.079** (0.422-1.678)	***0.422***	***2.628***
>250 keV	**0.903** (0.863-1.006)	**0.943** (0.924-1.132)	**0.875** (0.821-0.941)	**0.799** (0.706-0.885)	***0.706***	***1.132***

Organ: Breast (Female)

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.873** (0.705-2.478)	**0.009** (0.000-0.044)	**0.351** (0.283-0.966)	**0.310** (0.252-0.848)	***0.000***	***2.478***
30 - 250 keV	**0.894** (0.862-0.918)	**0.340** (0.044-0.452)	**0.545** (0.404-0.604)	**0.503** (0.380-0.563)	***0.044***	***0.918***
>250 keV	**0.966** (0.918-0.971)	**0.763** (0.452-0.821)	**0.798** (0.604-0.837)	**0.768** (0.563-0.820)	***0.452***	***0.971***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.901** (0.715-2.788)	**0.009** (0.000-0.044)	**0.360** (0.287-1.086)	**0.332** (0.255-0.954)	***0.000***	***2.788***
30 - 250 keV	**0.960** (0.871-0.973)	**0.366** (0.044-0.476)	**0.587** (0.408-0.637)	**0.540** (0.385-0.594)	***0.044***	***0.973***
>250 keV	**0.966** (0.947-0.969)	**0.762** (0.476-0.828)	**0.794** (0.637-0.845)	**0.768** (0.594-0.828)	***0.476***	***0.969***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.561** (0.179-0.871)	**0.012** (0.000-0.044)	**0.249** (0.072-0.408)	**0.232** (0.064-0.385)	***0.000***	***0.871***
30 - 250 keV	**1.266** (0.871-1.488)	**0.477** (0.044-0.554)	**0.769** (0.408-0.852)	**0.708** (0.385-0.776)	***0.044***	***1.488***
>250 keV	**0.930** (0.900-1.128)	**0.735** (0.554-0.787)	**0.769** (0.729-0.803)	**0.741** (0.681-0.787)	***0.554***	***1.128***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.614** (0.022-0.958)	**0.012** (0.000-0.049)	**0.272** (0.009-0.449)	**0.252** (0.008-0.423)	***0.000***	***0.958***
30 - 250 keV	**1.460** (0.958-1.683)	**0.549** (0.049-0.644)	**0.884** (0.449-0.971)	**0.815** (0.423-0.883)	***0.049***	***1.683***
>250 keV	**1.099** (1.042-1.313)	**0.865** (0.644-0.911)	**0.903** (0.851-0.930)	**0.874** (0.794-0.911)	***0.644***	***1.313***

Organ: Colon

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.060** (0.000-0.226)	**0.011** (0.000-0.059)	**0.018** (0.000-0.085)	**0.012** (0.000-0.056)	***0.000***	***0.226***
30 - 250 keV	**0.747** (0.226-0.798)	**0.541** (0.059-0.624)	**0.485** (0.085-0.560)	**0.364** (0.056-0.426)	***0.056***	***0.798***
>250 keV	**0.874** (0.798-0.891)	**0.785** (0.624-0.824)	**0.746** (0.560-0.799)	**0.659** (0.426-0.751)	***0.426***	***0.891***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.061** (0.000-0.228)	**0.011** (0.000-0.060)	**0.019** (0.000-0.086)	**0.012** (0.000-0.056)	***0.000***	***0.228***
30 - 250 keV	**0.803** (0.228-0.859)	**0.583** (0.060-0.659)	**0.522** (0.086-0.591)	**0.392** (0.056-0.449)	***0.056***	***0.859***
>250 keV	**0.872** (0.839-0.890)	**0.783** (0.659-0.832)	**0.744** (0.591-0.807)	**0.658** (0.449-0.758)	***0.449***	***0.890***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.075** (0.000-0.228)	**0.017** (0.000-0.060)	**0.024** (0.000-0.086)	**0.016** (0.000-0.056)	***0.000***	***0.228***
30 - 250 keV	**1.060** (0.228-1.276)	**0.767** (0.060-0.898)	**0.684** (0.086-0.792)	**0.515** (0.056-0.591)	***0.056***	***1.276***
>250 keV	**0.844** (0.829-0.981)	**0.754** (0.732-0.790)	**0.720** (0.664-0.767)	**0.634** (0.520-0.720)	***0.520***	***0.981***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.081** (0.000-0.251)	**0.014** (0.000-0.066)	**0.025** (0.000-0.095)	**0.015** (0.000-0.062)	***0.000***	***0.251***
30 - 250 keV	**1.221** (0.251-1.454)	**0.882** (0.066-1.036)	**0.789** (0.095-0.907)	**0.593** (0.062-0.677)	***0.062***	***1.454***
>250 keV	**0.995** (0.978-1.142)	**0.891** (0.857-0.915)	**0.847** (0.778-0.888)	**0.747** (0.603-0.834)	***0.603***	***1.142***

Organ: Esophagus

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.010** (0.000-0.053)	**0.006** (0.000-0.039)	**0.008** (0.000-0.046)	**0.005** (0.000-0.028)	***0.000***	***0.053***
30 - 250 keV	**0.486** (0.053-0.573)	**0.598** (0.039-0.688)	**0.470** (0.046-0.552)	**0.354** (0.028-0.426)	***0.028***	***0.688***
>250 keV	**0.772** (0.573-0.849)	**0.813** (0.688-0.841)	**0.778** (0.552-0.865)	**0.678** (0.426-0.775)	***0.426***	***0.865***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.011** (0.000-0.053)	**0.006** (0.000-0.040)	**0.009** (0.000-0.046)	**0.005** (0.000-0.029)	***0.000***	***0.053***
30 - 250 keV	**0.523** (0.053-0.605)	**0.644** (0.040-0.727)	**0.506** (0.046-0.582)	**0.381** (0.029-0.450)	***0.029***	***0.727***
>250 keV	**0.770** (0.605-0.857)	**0.812** (0.724-0.845)	**0.776** (0.582-0.874)	**0.677** (0.450-0.783)	***0.450***	***0.874***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.014** (0.000-0.053)	**0.007** (0.000-0.040)	**0.013** (0.000-0.046)	**0.007** (0.000-0.029)	***0.000***	***0.053***
30 - 250 keV	**0.688** (0.053-0.803)	**0.854** (0.040-0.986)	**0.661** (0.046-0.767)	**0.500** (0.029-0.576)	***0.029***	***0.986***
>250 keV	**0.745** (0.694-0.814)	**0.782** (0.761-0.846)	**0.743** (0.658-0.830)	**0.654** (0.524-0.744)	***0.524***	***0.846***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.010** (0.000-0.059)	**0.005** (0.000-0.044)	**0.010** (0.000-0.051)	**0.005** (0.000-0.031)	***0.000***	***0.059***
30 - 250 keV	**0.792** (0.059-0.926)	**0.975** (0.044-1.138)	**0.764** (0.051-0.885)	**0.575** (0.031-0.665)	***0.031***	***1.138***
>250 keV	**0.877** (0.809-0.943)	**0.923** (0.897-0.984)	**0.883** (0.766-0.961)	**0.770** (0.607-0.861)	***0.607***	***0.984***

Organ: Eye

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**3.624** (1.076-33.778)	**0.000** (0.000-0.000)	**1.477** (0.529-12.667)	**1.199** (0.470-9.744)	***0.000***	***33.778***
30 - 250 keV	**0.879** (0.789-1.076)	**0.126** (0.000-0.196)	**0.595** (0.449-0.683)	**0.527** (0.420-0.600)	***0.000***	***1.076***
>250 Kev	**0.908** (0.838-0.958)	**0.573** (0.196-0.750)	**0.854** (0.683-0.957)	**0.788** (0.600-0.867)	***0.196***	***0.958***

*Upper limit should be truncated at 6.816 unless the photon energy is less than 12.5 keV

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**3.862** (1.088-38.000)	**0.000** (0.000-0.000)	**1.562** (0.535-14.250)	**1.264** (0.475-10.963)	***0.000***	***38.000***
30 - 250 keV	**0.945** (0.850-1.088)	**0.136** (0.000-0.206)	**0.640** (0.472-0.721)	**0.567** (0.435-0.633)	***0.000***	***1.088***
>250 Kev	**0.908** (0.846-0.978)	**0.572** (0.206-0.757)	**0.853** (0.721-0.966)	**0.787** (0.633-0.875)	***0.206***	***0.978***

**Upper limit should be truncated at 7.275 unless the photon energy is less than 12.5 keV

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.936** (0.638-1.088)	**0.000** (0.000-0.000)	**0.437** (0.276-0.535)	**0.383** (0.227-0.475)	***0.000***	***1.088***
30 - 250 keV	**1.236** (1.088-1.361)	**0.174** (0.000-0.240)	**0.840** (0.535-0.893)	**0.742** (0.475-0.786)	***0.000***	***1.361***
>250 Kev	**0.880** (0.804-1.134)	**0.549** (0.240-0.719)	**0.825** (0.771-0.918)	**0.759** (0.710-0.832)	***0.240***	***1.134***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.859** (0.304-1.197)	**0.000** (0.000-0.000)	**0.397** (0.114-0.588)	**0.340** (0.088-0.523)	***0.000***	***1.197***
30 - 250 keV	**1.421** (1.197-1.550)	**0.201** (0.000-0.279)	**0.966** (0.588-1.030)	**0.854** (0.523-0.907)	***0.000***	***1.550***
>250 Kev	**1.036** (0.931-1.319)	**0.648** (0.279-0.833)	**0.971** (0.908-1.063)	**0.894** (0.835-0.963)	***0.279***	***1.319***

Organ: Gonads (female-ovaries)

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.034** (0.000-0.142)	**0.013** (0.000-0.071)	**0.012** (0.000-0.059)	**0.005** (0.000-0.032)	***0.000***	***0.142***
30 - 250 keV	**0.672** (0.142-0.742)	**0.626** (0.071-0.698)	**0.495** (0.059-0.578)	**0.348** (0.032-0.411)	***0.032***	***0.742***
>250 keV	**0.849** (0.742-0.950)	**0.803** (0.698-0.833)	**0.759** (0.578-0.869)	**0.651** (0.411-0.752)	***0.411***	***0.950***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.031** (0.000-0.144)	**0.014** (0.000-0.071)	**0.012** (0.000-0.060)	**0.005** (0.000-0.032)	***0.000***	***0.144***
30 - 250 keV	**0.726** (0.144-0.795)	**0.674** (0.071-0.749)	**0.532** (0.060-0.610)	**0.375** (0.032-0.434)	***0.032***	***0.795***
>250 keV	**0.848** (0.771-0.960)	**0.800** (0.735-0.842)	**0.758** (0.610-0.878)	**0.650** (0.434-0.760)	***0.434***	***0.960***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.047** (0.000-0.144)	**0.019** (0.000-0.071)	**0.022** (0.000-0.060)	**0.009** (0.000-0.032)	***0.000***	***0.144***
30 - 250 keV	**0.955** (0.144-1.111)	**0.888** (0.071-1.069)	**0.702** (0.060-0.803)	**0.494** (0.032-0.577)	***0.032***	***1.111***
>250 keV	**0.819** (0.782-0.913)	**0.775** (0.762-0.858)	**0.732** (0.668-0.834)	**0.626** (0.505-0.722)	***0.505***	***0.913***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.030** (0.000-0.158)	**0.015** (0.000-0.079)	**0.012** (0.000-0.066)	**0.007** (0.000-0.035)	***0.000***	***0.158***
30 - 250 keV	**1.102** (0.158-1.282)	**1.022** (0.079-1.234)	**0.805** (0.066-0.926)	**0.566** (0.035-0.666)	***0.035***	***1.282***
>250 keV	**0.966** (0.918-1.062)	**0.913** (0.905-0.999)	**0.862** (0.786-0.966)	**0.736** (0.586-0.836)	***0.586***	***1.062***

Organ: Gonads (male-testes)

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.978** (0.739-3.244)	**0.008** (0.000-0.037)	**0.278** (0.216-0.827)	**0.235** (0.169-0.621)	***0.000***	***3.244***
30 - 250 keV	**1.011** (0.983-1.026)	**0.350** (0.037-0.461)	**0.519** (0.343-0.568)	**0.451** (0.303-0.501)	***0.037***	***1.026***
>250 keV	**0.973** (0.904-1.010)	**0.737** (0.461-0.796)	**0.763** (0.568-0.846)	**0.720** (0.501-0.804)	***0.461***	***1.010***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.918** (0.750-3.650)	**0.008** (0.000-0.037)	**0.277** (0.220-0.930)	**0.246** (0.172-0.699)	***0.000***	***3.650***
30 - 250 keV	**1.090** (0.994-1.135)	**0.376** (0.037-0.487)	**0.557** (0.346-0.600)	**0.483** (0.306-0.528)	***0.037***	***1.135***
>250 keV	**0.974** (0.913-1.056)	**0.734** (0.487-0.804)	**0.758** (0.600-0.855)	**0.715** (0.528-0.812)	***0.487***	***1.056***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.622** (0.188-0.994)	**0.011** (0.000-0.037)	**0.204** (0.055-0.346)	**0.179** (0.043-0.306)	***0.000***	***0.994***
30 - 250 keV	**1.434** (0.994-1.734)	**0.491** (0.037-0.566)	**0.732** (0.346-0.831)	**0.632** (0.306-0.715)	***0.037***	***1.734***
>250 keV	**0.941** (0.867-1.231)	**0.709** (0.566-0.763)	**0.735** (0.665-0.812)	**0.693** (0.612-0.771)	***0.566***	***1.231***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.516** (0.029-1.093)	**0.008** (0.000-0.041)	**0.169** (0.007-0.381)	**0.144** (0.006-0.337)	***0.000***	***1.093***
30 - 250 keV	**1.649** (1.093-1.961)	**0.564** (0.041-0.658)	**0.843** (0.381-0.946)	**0.729** (0.337-0.815)	***0.041***	***1.961***
>250 keV	**1.108** (1.004-1.432)	**0.835** (0.658-0.884)	**0.866** (0.779-0.940)	**0.818** (0.710-0.893)	***0.658***	***1.432***

Organ: Liver

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.095** (0.000-0.286)	**0.039** (0.000-0.143)	**0.042** (0.000-0.143)	**0.027** (0.000-0.098)	***0.000***	***0.286***
30 - 250 keV	**0.748** (0.286-0.794)	**0.576** (0.143-0.645)	**0.516** (0.143-0.578)	**0.402** (0.098-0.462)	***0.098***	***0.794***
>250 keV	**0.886** (0.794-0.904)	**0.807** (0.645-0.843)	**0.766** (0.578-0.818)	**0.691** (0.462-0.753)	***0.462***	***0.904***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.092** (0.000-0.289)	**0.040** (0.000-0.145)	**0.042** (0.000-0.145)	**0.028** (0.000-0.099)	***0.000***	***0.289***
30 - 250 keV	**0.805** (0.289-0.850)	**0.620** (0.145-0.680)	**0.556** (0.145-0.610)	**0.432** (0.099-0.488)	***0.099***	***0.850***
>250 keV	**0.884** (0.835-0.904)	**0.805** (0.680-0.848)	**0.764** (0.610-0.826)	**0.690** (0.488-0.761)	***0.488***	***0.904***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.106** (0.003-0.289)	**0.048** (0.001-0.145)	**0.050** (0.001-0.145)	**0.033** (0.000-0.099)	***0.000***	***0.289***
30 - 250 keV	**1.064** (0.289-1.269)	**0.816** (0.145-0.951)	**0.731** (0.145-0.852)	**0.568** (0.099-0.653)	***0.099***	***1.269***
>250 keV	**0.845** (0.844-0.976)	**0.780** (0.749-0.806)	**0.740** (0.680-0.785)	**0.665** (0.564-0.723)	***0.564***	***0.976***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.086** (0.000-0.318)	**0.037** (0.000-0.159)	**0.039** (0.000-0.159)	**0.027** (0.000-0.109)	***0.000***	***0.318***
30 - 250 keV	**1.221** (0.318-1.446)	**0.938** (0.159-1.083)	**0.841** (0.159-0.970)	**0.654** (0.109-0.744)	***0.109***	***1.446***
>250 keV	**1.007** (0.994-1.135)	**0.917** (0.881-0.935)	**0.870** (0.795-0.909)	**0.784** (0.654-0.837)	***0.654***	***1.135***

Organ: Lung

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.082** (0.000-0.267)	**0.109** (0.000-0.324)	**0.052** (0.000-0.180)	**0.035** (0.000-0.127)	***0.000***	***0.324***
30 - 250 keV	**0.695** (0.267-0.750)	**0.754** (0.324-0.813)	**0.552** (0.180-0.615)	**0.441** (0.127-0.503)	***0.127***	***0.813***
>250 keV	**0.870** (0.750-0.884)	**0.909** (0.813-0.917)	**0.802** (0.615-0.845)	**0.730** (0.503-0.804)	***0.503***	***0.917***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.083** (0.000-0.270)	**0.109** (0.000-0.327)	**0.053** (0.000-0.182)	**0.035** (0.000-0.128)	***0.000***	***0.327***
30 - 250 keV	**0.749** (0.270-0.792)	**0.812** (0.327-0.858)	**0.595** (0.182-0.649)	**0.475** (0.128-0.531)	***0.128***	***0.858***
>250 keV	**0.866** (0.792-0.883)	**0.906** (0.858-0.914)	**0.801** (0.649-0.854)	**0.727** (0.531-0.812)	***0.531***	***0.914***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.100** (0.002-0.270)	**0.120** (0.003-0.327)	**0.055** (0.001-0.182)	**0.042** (0.001-0.128)	***0.001***	***0.327***
30 - 250 keV	**0.986** (0.270-1.168)	**1.077** (0.327-1.260)	**0.779** (0.182-0.912)	**0.625** (0.128-0.717)	***0.128***	***1.260***
>250 keV	**0.842** (0.834-0.922)	**0.875** (0.860-1.000)	**0.773** (0.732-0.811)	**0.706** (0.614-0.771)	***0.614***	***1.000***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.076** (0.000-0.297)	**0.098** (0.000-0.360)	**0.049** (0.000-0.200)	**0.033** (0.000-0.141)	***0.000***	***0.360***
30 - 250 keV	**1.133** (0.297-1.331)	**1.230** (0.360-1.435)	**0.899** (0.200-1.039)	**0.718** (0.141-0.817)	***0.141***	***1.435***
>250 keV	**0.989** (0.971-1.073)	**1.034** (0.999-1.163)	**0.911** (0.856-0.939)	**0.828** (0.712-0.893)	***0.712***	***1.163***

Organ: Remainder Organs

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.078** (0.024-0.192)	**0.080** (0.024-0.191)	**0.052** (0.017-0.131)	**0.036** (0.012-0.094)	***0.012***	***0.192***
30 - 250 keV	**0.621** (0.192-0.681)	**0.623** (0.191-0.688)	**0.498** (0.131-0.569)	**0.393** (0.094-0.459)	***0.094***	***0.688***
>250 keV	**0.815** (0.681-0.841)	**0.818** (0.688-0.853)	**0.761** (0.569-0.824)	**0.689** (0.459-0.770)	***0.459***	***0.853***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.079** (0.025-0.195)	**0.081** (0.025-0.193)	**0.052** (0.017-0.133)	**0.036** (0.012-0.095)	***0.012***	***0.195***
30 - 250 keV	**0.668** (0.195-0.719)	**0.670** (0.193-0.726)	**0.536** (0.133-0.600)	**0.423** (0.095-0.484)	***0.095***	***0.726***
>250 keV	**0.814** (0.719-0.847)	**0.815** (0.726-0.862)	**0.759** (0.600-0.833)	**0.686** (0.484-0.777)	***0.484***	***0.862***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.071** (0.006-0.195)	**0.075** (0.006-0.193)	**0.050** (0.004-0.133)	**0.035** (0.003-0.095)	***0.003***	***0.195***
30 - 250 keV	**0.879** (0.195-1.033)	**0.885** (0.193-1.033)	**0.705** (0.133-0.808)	**0.555** (0.095-0.629)	***0.095***	***1.033***
>250 keV	**0.787** (0.773-0.837)	**0.793** (0.775-0.846)	**0.735** (0.678-0.791)	**0.663** (0.561-0.738)	***0.561***	***0.846***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.060** (0.001-0.214)	**0.061** (0.001-0.212)	**0.040** (0.000-0.146)	**0.028** (0.000-0.104)	***0.000***	***0.214***
30 - 250 keV	**1.014** (0.214-1.177)	**1.017** (0.212-1.177)	**0.812** (0.146-0.925)	**0.639** (0.104-0.719)	***0.104***	***1.177***
>250 keV	**0.927** (0.911-0.974)	**0.929** (0.913-0.984)	**0.864** (0.794-0.916)	**0.781** (0.650-0.855)	***0.650***	***0.984***

Organ: Skin

Photon Exposures

Deep Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)
If Hp(10) was measured the shallow dose equivalent Hp(0.07) should also be available and should be used for skin dose.

Ambient Dose Equivalent (H(10)) to Organ Dose (H_T)*

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**1.839** (0.595-29.375)	**1.798** (0.589-29.625)	**1.580** (0.528-25.000)	**1.989** (0.495-21.500)	***0.495***	***3.785****
30 - 250 keV	**0.677** (0.550-0.744)	**0.674** (0.541-0.741)	**0.608** (0.486-0.676)	**0.564** (0.448-0.622)	***0.448***	***0.744***
>250 keV	**0.863** (0.744-0.893)	**0.860** (0.741-0.902)	**0.822** (0.676-0.864)	**0.787** (0.622-0.835)	***0.622***	***0.902***

*Upper level truncated at 12.5 keV (midpoint between last two data points). If photon energy is less than 12.5 kev, the data in this The data in this table cannot be used.

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.504** (0.363-0.595)	**0.502** (0.363-0.589)	**0.447** (0.318-0.528)	**0.418** (0.291-0.495)	***0.291***	***0.595***
30 - 250 keV	**0.892** (0.595-0.974)	**0.885** (0.589-0.962)	**0.799** (0.528-0.861)	**0.731** (0.495-0.778)	***0.495***	***0.974***
>250 keV	**0.835** (0.823-0.866)	**0.837** (0.821-0.863)	**0.796** (0.768-0.820)	**0.759** (0.711-0.793)	***0.711***	***0.866***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.473** (0.235-0.654)	**0.470** (0.237-0.648)	**0.418** (0.200-0.581)	**0.388** (0.172-0.544)	***0.172***	***0.654***
30 - 250 keV	**1.027** (0.654-1.109)	**1.019** (0.648-1.096)	**0.920** (0.581-0.981)	**0.841** (0.544-0.886)	***0.544***	***1.109***
>250 keV	**0.986** (0.970-1.007)	**0.987** (0.966-1.004)	**0.941** (0.899-0.953)	**0.895** (0.832-0.919)	***0.832***	***1.007***

Organ: Stomach

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.167** (0.001-0.434)	**0.008** (0.000-0.044)	**0.052** (0.000-0.152)	**0.034** (0.000-0.110)	***0.000***	***0.434***
30 - 250 keV	**0.881** (0.434-0.914)	**0.437** (0.044-0.520)	**0.513** (0.152-0.576)	**0.401** (0.110-0.459)	***0.044***	***0.914***
>250 Kev	**0.915** (0.902-0.919)	**0.736** (0.520-0.795)	**0.775** (0.576-0.841)	**0.690** (0.459-0.763)	***0.459***	***0.919***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.167** (0.001-0.439)	**0.008** (0.000-0.044)	**0.053** (0.000-0.154)	**0.035** (0.000-0.111)	***0.000***	***0.439***
30 - 250 keV	**0.950** (0.439-1.012)	**0.470** (0.044-0.548)	**0.551** (0.154-0.607)	**0.431** (0.111-0.484)	***0.044***	***1.012***
>250 keV	**0.916** (0.908-0.958)	**0.735** (0.548-0.803)	**0.773** (0.607-0.849)	**0.690** (0.484-0.771)	***0.484***	***0.958***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.182** (0.008-0.439)	**0.011** (0.000-0.044)	**0.058** (0.002-0.154)	**0.040** (0.001-0.111)	***0.000***	***0.439***
30 - 250 keV	**1.251** (0.439-1.534)	**0.618** (0.044-0.706)	**0.725** (0.154-0.853)	**0.566** (0.111-0.648)	***0.044***	***1.534***
>250 keV	**0.885** (0.863-1.117)	**0.710** (0.637-0.763)	**0.747** (0.685-0.807)	**0.664** (0.556-0.732)	***0.556***	***1.117***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.143** (0.000-0.483)	**0.008** (0.000-0.049)	**0.046** (0.000-0.169)	**0.032** (0.000-0.122)	***0.000***	***0.483***
30 - 250 keV	**1.441** (0.483-1.740)	**0.710** (0.049-0.815)	**0.838** (0.169-0.972)	**0.652** (0.122-0.739)	***0.049***	***1.740***
>250 keV	**1.044** (1.002-1.299)	**0.836** (0.738-0.883)	**0.879** (0.803-0.934)	**0.783** (0.644-0.848)	***0.644***	***1.299***

Organ: Thymus

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.273** (0.000-0.629)	**0.000** (0.000-0.007)	**0.077** (0.000-0.201)	**0.051** (0.000-0.143)	***0.000***	***0.629***
30 - 250 keV	**0.991** (0.629-1.030)	**0.273** (0.007-0.345)	**0.528** (0.201-0.598)	**0.434** (0.143-0.498)	***0.007***	***1.030***
>250 keV	**0.922** (0.840-0.999)	**0.593** (0.345-0.732)	**0.764** (0.598-0.839)	**0.708** (0.498-0.788)	***0.345***	***0.999***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.274** (0.000-0.636)	**0.000** (0.000-0.007)	**0.077** (0.000-0.204)	**0.051** (0.000-0.145)	***0.000***	***0.636***
30 - 250 keV	**1.065** (0.636-1.131)	**0.292** (0.007-0.364)	**0.568** (0.204-0.631)	**0.467** (0.145-0.525)	***0.007***	***1.131***
>250 keV	**0.922** (0.848-1.054)	**0.590** (0.364-0.739)	**0.763** (0.631-0.847)	**0.707** (0.525-0.795)	***0.364***	***1.054***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.288** (0.015-0.636)	**0.000** (0.000-0.007)	**0.083** (0.003-0.204)	**0.057** (0.002-0.145)	***0.000***	***0.636***
30 - 250 keV	**1.408** (0.636-1.692)	**0.381** (0.007-0.441)	**0.746** (0.204-0.846)	**0.614** (0.145-0.692)	***0.007***	***1.692***
>250 keV	**0.892** (0.806-1.229)	**0.566** (0.422-0.702)	**0.737** (0.705-0.805)	**0.682** (0.606-0.756)	***0.422***	***1.229***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.226** (0.000-0.700)	**0.001** (0.000-0.008)	**0.067** (0.000-0.224)	**0.045** (0.000-0.159)	***0.000***	***0.700***
30 - 250 keV	**1.620** (0.700-1.926)	**0.444** (0.008-0.505)	**0.859** (0.224-0.974)	**0.706** (0.159-0.788)	***0.008***	***1.926***
>250 keV	**1.052** (0.933-1.429)	**0.672** (0.489-0.813)	**0.868** (0.831-0.932)	**0.804** (0.703-0.875)	***0.489***	***1.429***

Organ: Thyroid

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.538** (0.140-0.818)	**0.000** (0.000-0.010)	**0.193** (0.032-0.368)	**0.087** (0.013-0.185)	***0.000***	***0.818***
30 - 250 keV	**1.017** (0.818-1.042)	**0.298** (0.010-0.385)	**0.684** (0.368-0.757)	**0.453** (0.185-0.522)	***0.010***	***1.042***
>250 keV	**1.003** (0.906-1.066)	**0.684** (0.385-0.809)	**0.927** (0.757-0.961)	**0.740** (0.522-0.842)	***0.385***	***1.066***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.545** (0.158-0.827)	**0.000** (0.000-0.010)	**0.192** (0.036-0.372)	**0.089** (0.015-0.187)	***0.000***	***0.827***
30 - 250 keV	**1.091** (0.827-1.135)	**0.321** (0.010-0.406)	**0.735** (0.372-0.799)	**0.487** (0.187-0.551)	***0.010***	***1.135***
>250 keV	**1.004** (0.915-1.089)	**0.683** (0.406-0.817)	**0.925** (0.799-0.967)	**0.739** (0.551-0.850)	***0.406***	***1.089***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.473** (0.093-0.827)	**0.003** (0.000-0.010)	**0.183** (0.022-0.372)	**0.087** (0.009-0.187)	***0.000***	***0.827***
30 - 250 keV	**1.440** (0.827-1.702)	**0.420** (0.010-0.475)	**0.965** (0.372-1.083)	**0.639** (0.187-0.718)	***0.010***	***1.702***
>250 keV	**0.972** (0.870-1.269)	**0.663** (0.472-0.776)	**0.894** (0.868-0.930)	**0.714** (0.637-0.808)	***0.472***	***1.269***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.377** (0.001-0.910)	**0.001** (0.000-0.011)	**0.146** (0.000-0.409)	**0.068** (0.000-0.206)	***0.000***	***0.910***
30 - 250 keV	**1.660** (0.910-1.938)	**0.483** (0.011-0.549)	**1.112** (0.409-1.234)	**0.735** (0.206-0.818)	***0.011***	***1.938***
>250 keV	**1.143** (1.007-1.477)	**0.777** (0.549-0.899)	**1.054** (1.019-1.082)	**0.841** (0.739-0.935)	***0.549***	***1.477***

Organ: Uterus

Photon Exposures

Personal Dose Equivalent ($H_P(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.044** (0.000-0.195)	**0.012** (0.000-0.063)	**0.013** (0.000-0.068)	**0.009** (0.000-0.044)	***0.000***	***0.195***
30 - 250 keV	**0.711** (0.195-0.762)	**0.546** (0.063-0.621)	**0.461** (0.068-0.530)	**0.343** (0.044-0.402)	***0.044***	***0.762***
>250 keV	**0.812** (0.754-0.820)	**0.757** (0.621-0.782)	**0.713** (0.530-0.778)	**0.628** (0.402-0.729)	***0.402***	***0.820***

Ambient Dose Equivalent ($H^*(10)$) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.045** (0.000-0.197)	**0.013** (0.000-0.064)	**0.015** (0.000-0.069)	**0.009** (0.000-0.045)	***0.000***	***0.197***
30 - 250 keV	**0.765** (0.197-0.834)	**0.588** (0.064-0.656)	**0.497** (0.069-0.559)	**0.369** (0.045-0.424)	***0.045***	***0.834***
>250 keV	**0.811** (0.784-0.817)	**0.758** (0.656-0.781)	**0.711** (0.559-0.785)	**0.627** (0.424-0.736)	***0.424***	***0.817***

Exposure (R) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.061** (0.000-0.197)	**0.017** (0.000-0.064)	**0.019** (0.000-0.069)	**0.012** (0.000-0.045)	***0.000***	***0.197***
30 - 250 keV	**1.011** (0.197-1.212)	**0.774** (0.064-0.913)	**0.653** (0.069-0.757)	**0.485** (0.045-0.553)	***0.045***	***1.212***
>250 keV	**0.786** (0.764-0.928)	**0.734** (0.724-0.764)	**0.688** (0.633-0.746)	**0.604** (0.485-0.700)	***0.485***	***0.928***

Kerma (K_a) to Organ Dose (H_T)

Photon Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<30 keV	**0.045** (0.000-0.217)	**0.010** (0.000-0.070)	**0.014** (0.000-0.076)	**0.009** (0.000-0.049)	***0.000***	***0.217***
30 - 250 keV	**1.163** (0.217-1.381)	**0.890** (0.070-1.054)	**0.751** (0.076-0.874)	**0.558** (0.049-0.636)	***0.049***	***1.381***
>250 keV	**0.924** (0.885-1.079)	**0.863** (0.853-0.888)	**0.809** (0.739-0.864)	**0.712** (0.562-0.810)	***0.562***	***1.079***

APPENDIX A – NEUTRON DOSE CONVERSION FACTORS (DCF)

Organ: Bladder

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**2.214E-09** (6.40E-10 - 2.51E-9)	**9.388E-10** (2.50E-10 - 1.08E-9)	**9.704E-10** (2.75E-10 - 1.11E-9)	**6.945E-10** (2.30E-10 - 7.97E-10)	***2.30E-10***	***2.51E-09***
10 - 100 keV	**5.175E-09** (2.51E-9 - 7.23E-9)	**2.133E-09** (1.08E-9 - 3.05E-9)	**2.286E-09** (1.11E-9 - 3.29E-9)	**1.779E-09** (7.97E-10 - 2.57E-9)	***7.97E-10***	***7.23E-09***
0.1 - 2.0 Mev	**3.119E-08** (7.23E-9 - 4.47E-8)	**8.458E-09** (3.05E-9 - 1.42E-8)	**1.273E-08** (3.29E-9 - 1.98E-8)	**9.070E-09** (2.57E-9 - 1.46E-8)	***2.57E-09***	***4.47E-08***
2.0 - 20.0 Mev	**5.462E-08** (4.47E-8 - 5.64E-8)	**3.377E-08** (1.42E-8 - 4.00E-8)	**3.502E-08** (1.98E-8 - 3.96E-8)	**2.853E-08** (1.46E-8 - 3.25E-8)	***1.42E-08***	***5.64E-08***
> 20.0 Mev	**4.607E-08** (4.20E-8 - 5.32E-8)	**5.276E-08** (4.00E-8 - 6.97E-8)	**4.925E-08** (3.96E-8 - 5.91E-8)	n/a	***3.96E-08***	***6.97E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**2.633** (0.906-2.755)	**1.114** (0.361-1.161)	**1.153** (0.372-1.195)	**0.826** (0.311-0.852)	***0.311***	***2.755***
10 - 100 keV	**1.291** (0.822-2.392)	**0.558** (0.346-1.030)	**0.575** (0.374-1.060)	**0.438** (0.292-0.759)	***0.292***	***2.392***
0.1 - 2.0 Mev	**0.822** (0.661-1.065)	**0.229** (0.168-0.346)	**0.333** (0.258-0.471)	**0.243** (0.184-0.348)	***0.168***	***1.065***
2.0 - 20.0 Mev	**1.170** (0.887-1.401)	**0.708** (0.338-0.813)	**0.740** (0.471-0.850)	**0.601** (0.348-0.685)	***0.338***	***1.401***
> 20.0 Mev	**1.488** (0.887-1.767)	**1.790** (0.666-2.789)	**1.653** (0.660-2.365)	n/a	***0.660***	***2.789***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**2.301** (0.781-2.355)	**0.974** (0.305-0.992)	**1.007** (0.336-1.022)	**0.720** (0.281-0.733)	***0.281***	***2.355***
10 - 100 keV	**1.268** (0.798-2.243)	**0.549** (0.336-0.966)	**0.570** (0.363-0.994)	**0.432** (0.283-0.712)	***0.283***	***2.243***
0.1 - 2.0 Mev	**0.796** (0.626-1.012)	**0.216** (0.163-0.336)	**0.326** (0.247-0.447)	**0.234** (0.177-0.331)	***0.163***	***1.012***
2.0 - 20.0 Mev	**1.105** (0.887-1.325)	**0.670** (0.321-0.740)	**0.698** (0.447-0.780)	**0.568** (0.331-0.629)	***0.321***	***1.325***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Bone (Red Marrow)

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**9.868E-10** (3.05E-10 - 1.15E-9)	**1.568E-09** (5.70E-10 - 1.82E-9)	**9.450E-10** (3.10E-10 - 1.10E-9)	**6.618E-10** (2.40E-10 - 7.66E-10)	***2.40E-10***	***1.82E-09***
10 - 100 keV	**2.676E-09** (1.15E-9 - 3.95E-9)	**4.282E-09** (1.82E-9 - 6.46E-9)	**2.506E-09** (1.10E-9 - 3.72E-9)	**1.914E-09** (7.66E-10 - 2.86E-9)	***7.66E-10***	***6.46E-09***
0.1 - 2.0 Mev	**1.415E-08** (3.95E-9 - 2.22E-8)	**2.709E-08** (6.46E-9 - 3.90E-8)	**1.600E-08** (3.72E-9 - 2.41E-8)	**1.200E-08** (2.86E-9 - 1.79E-8)	***2.86E-09***	***3.90E-08***
2.0 - 20.0 Mev	**3.587E-08** (2.22E-8 - 3.83E-8)	**4.567E-08** (3.90E-8 - 4.73E-8)	**3.504E-08** (2.41E-8 - 3.66E-8)	**2.897E-08** (1.79E-8 - 3.28E-8)	***1.79E-08***	***4.73E-08***
> 20.0 Mev	**4.183E-08** (3.74E-8 - 4.86E-8)	**4.025E-08** (3.89E-8 - 4.40E-8)	**3.999E-08** (3.59E-8 - 4.66E-8)	n/a	***3.59E-08***	***4.86E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.167** (0.422-1.209)	**1.861** (0.759-1.930)	**1.113** (0.443-1.161)	**0.786** (0.335-0.811)	***0.335***	***1.930***
10 - 100 keV	**0.659** (0.448-1.091)	**1.042** (0.735-1.729)	**0.615** (0.423-1.048)	**0.455** (0.324-0.729)	***0.324***	***1.729***
0.1 - 2.0 Mev	**0.375** (0.279-0.528)	**0.716** (0.585-0.929)	**0.422** (0.336-0.574)	**0.316** (0.253-0.425)	***0.253***	***0.929***
2.0 - 20.0 Mev	**0.761** (0.528-0.891)	**0.980** (0.733-1.179)	**0.745** (0.574-0.872)	**0.611** (0.425-0.682)	***0.425***	***1.179***
> 20.0 Mev	**1.395** (0.633-1.942)	**1.320** (0.733-1.700)	**1.334** (0.606-1.863)	n/a	***0.606***	***1.942***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.023** (0.372-1.033)	**1.635** (0.696-1.650)	**0.980** (0.379-0.992)	**0.688** (0.293-0.693)	***0.293***	***1.650***
10 - 100 keV	**0.651** (0.436-1.022)	**1.028** (0.713-1.621)	**0.607** (0.411-0.983)	**0.452** (0.315-0.683)	***0.315***	***1.621***
0.1 - 2.0 Mev	**0.361** (0.268-0.502)	**0.690** (0.554-0.883)	**0.407** (0.318-0.545)	**0.305** (0.240-0.404)	***0.240***	***0.883***
2.0 - 20.0 Mev	**0.720** (0.502-0.825)	**0.927** (0.733-1.125)	**0.705** (0.545-0.814)	**0.578** (0.404-0.629)	***0.404***	***1.125***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Bone (Surface)

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.045E-09** (3.85E-10 - 1.21E-9)	**1.245E-09** (4.70E-10 - 1.43E-9)	**8.755E-10** (3.35E-10 - 1.02E-9)	**6.340E-10** (2.70E-10 - 7.47E-10)	***2.70E-10***	***1.43E-09***
10 - 100 keV	**2.671E-09** (1.21E-9 - 4.03E-9)	**3.354E-09** (1.43E-9 - 5.07E-9)	**2.400E-09** (1.02E-9 - 3.66E-9)	**1.834E-09** (7.47E-10 - 2.81E-9)	***7.47E-10***	***5.07E-09***
0.1 - 2.0 Mev	**1.696E-08** (4.03E-9 - 2.41E-8)	**2.056E-08** (5.07E-9 - 2.88E-8)	**1.633E-08** (3.66E-9 - 2.34E-8)	**1.301E-08** (2.81E-9 - 1.87E-8)	***2.81E-09***	***2.88E-08***
2.0 - 20.0 Mev	**3.364E-08** (2.41E-8 - 3.62E-8)	**3.688E-08** (2.88E-8 - 3.85E-8)	**3.214E-08** (2.34E-8 - 3.41E-8)	**2.765E-08** (1.87E-8 - 3.08E-8)	***1.87E-08***	***3.85E-08***
> 20.0 Mev	**4.179E-08** (3.62E-8 - 4.84E-8)	**3.990E-08** (3.82E-8 - 4.21E-8)	**3.996E-08** (3.41E-8 - 4.62E-8)	n/a	***3.41E-08***	***4.84E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.239** (0.519-1.292)	**1.479** (0.632-1.525)	**1.038** (0.472-1.072)	**0.752** (0.340-0.776)	***0.340***	***1.525***
10 - 100 keV	**0.666** (0.457-1.151)	**0.817** (0.576-1.362)	**0.586** (0.416-0.970)	**0.441** (0.319-0.711)	***0.319***	***1.362***
0.1 - 2.0 Mev	**0.451** (0.373-0.574)	**0.547** (0.455-0.685)	**0.433** (0.351-0.557)	**0.343** (0.273-0.446)	***0.273***	***0.685***
2.0 - 20.0 Mev	**0.714** (0.574-0.818)	**0.785** (0.641-0.903)	**0.682** (0.557-0.787)	**0.586** (0.446-0.680)	***0.446***	***0.903***
> 20.0 Mev	**1.394** (0.603-1.934)	**1.315** (0.641-1.686)	**1.335** (0.569-1.849)	n/a	***0.569***	***1.934***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.083** (0.470-1.104)	**1.292** (0.574-1.312)	**0.908** (0.409-0.916)	**0.657** (0.311-0.667)	***0.311***	***1.312***
10 - 100 keV	**0.656** (0.444-1.079)	**0.807** (0.559-1.277)	**0.577** (0.404-0.909)	**0.435** (0.310-0.667)	***0.310***	***1.277***
0.1 - 2.0 Mev	**0.436** (0.353-0.545)	**0.529** (0.433-0.651)	**0.417** (0.332-0.530)	**0.332** (0.259-0.424)	***0.259***	***0.651***
2.0 - 20.0 Mev	**0.675** (0.545-0.758)	**0.743** (0.641-0.848)	**0.646** (0.530-0.731)	**0.554** (0.424-0.629)	***0.424***	***0.848***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Breast (Female)

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.366E-09** (8.40E-10 - 1.66E-9)	**4.783E-10** (1.40E-10 - 5.50E-10)	**6.798E-10** (3.45E-10 - 8.22E-10)	**5.023E-10** (2.95E-10 - 6.14E-10)	***1.40E-10***	***1.66E-09***
10 - 100 keV	**4.905E-09** (1.66E-9 - 8.28E-9)	**1.073E-09** (5.50E-10 - 1.52E-9)	**2.362E-09** (8.22E-10 - 3.85E-9)	**2.099E-09** (6.14E-10 - 3.66E-9)	***5.50E-10***	***8.28E-09***
0.1 - 2.0 Mev	**4.469E-08** (8.28E-9 - 5.71E-8)	**6.863E-09** (1.52E-9 - 1.34E-8)	**2.323E-08** (3.85E-9 - 3.09E-8)	**2.143E-08** (3.66E-9 - 3.00E-8)	***1.52E-09***	***5.71E-08***
2.0 - 20.0 Mev	**5.514E-08** (5.08E-8 - 5.77E-8)	**3.134E-08** (1.34E-8 - 3.73E-8)	**3.619E-08** (3.09E-8 - 3.81E-8)	**3.668E-08** (3.00E-8 - 3.93E-8)	***1.34E-08***	***5.77E-08***
> 20.0 Mev	**3.153E-08** (2.48E-8 - 5.08E-8)	**4.586E-08** (3.73E-8 - 5.31E-8)	**2.902E-08** (2.73E-8 - 3.64E-8)	n/a	***2.48E-08***	***5.31E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.612** (0.938-1.676)	**0.569** (0.172-0.591)	**0.803** (0.419-0.838)	**0.595** (0.333-0.611)	***0.172***	***1.676***
10 - 100 keV	**1.117** (0.941-1.585)	**0.276** (0.173-0.524)	**0.548** (0.437-0.783)	**0.472** (0.416-0.584)	***0.173***	***1.585***
0.1 - 2.0 Mev	**1.180** (0.940-1.358)	**0.180** (0.106-0.318)	**0.611** (0.437-0.735)	**0.563** (0.414-0.714)	***0.106***	***1.358***
2.0 - 20.0 Mev	**1.185** (0.846-1.412)	**0.657** (0.318-0.758)	**0.789** (0.607-0.884)	**0.779** (0.642-0.878)	***0.318***	***1.412***
> 20.0 Mev	**0.982** (0.846-1.050)	**1.534** (0.622-2.122)	**0.928** (0.607-1.223)	n/a	***0.607***	***2.122***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.411** (0.925-1.486)	**0.498** (0.155-0.505)	**0.709** (0.408-0.734)	**0.525** (0.320-0.548)	***0.155***	***1.486***
10 - 100 keV	**1.111** (0.914-1.486)	**0.271** (0.168-0.491)	**0.545** (0.425-0.734)	**0.471** (0.404-0.548)	***0.168***	***1.486***
0.1 - 2.0 Mev	**1.145** (0.892-1.291)	**0.173** (0.101-0.302)	**0.592** (0.420-0.698)	**0.542** (0.393-0.679)	***0.101***	***1.291***
2.0 - 20.0 Mev	**1.121** (0.846-1.355)	**0.622** (0.302-0.690)	**0.729** (0.607-0.817)	**0.737** (0.642-0.839)	***0.302***	***1.355***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Colon

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.697E-09** (4.45E-10 - 1.94E-9)	**1.264E-09** (3.85E-10 - 1.46E-9)	**9.216E-10** (2.65E-10 - 1.05E-9)	**7.074E-10** (2.00E-10 - 8.10E-10)	***2.00E-10***	***1.94E-09***
10 - 100 keV	**3.688E-09** (1.94E-9 - 5.13E-9)	**2.988E-09** (1.46E-9 - 4.28E-9)	**2.297E-09** (1.05E-9 - 3.10E-9)	**1.717E-09** (8.10E-10 - 2.44E-9)	***8.10E-10***	***5.13E-09***
0.1 - 2.0 Mev	**1.926E-08** (5.13E-9 - 3.02E-8)	**1.324E-08** (4.28E-9 - 2.18E-8)	**1.086E-08** (3.10E-9 - 1.80E-8)	**7.476E-09** (2.44E-9 - 1.24E-8)	***2.44E-09***	***3.02E-08***
2.0 - 20.0 Mev	**4.539E-08** (3.02E-8 - 4.78E-8)	**3.879E-08** (2.18E-8 - 4.44E-8)	**3.307E-08** (1.80E-8 - 3.79E-8)	**2.723E-08** (1.24E-8 - 3.25E-8)	***1.24E-08***	***4.78E-08***
> 20.0 Mev	**4.888E-08** (4.78E-8 - 4.94E-8)	**5.055E-08** (4.44E-8 - 5.36E-8)	**4.593E-08** (3.79E-8 - 5.66E-8)	n/a	***3.79E-08***	***5.66E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**2.012** (0.589-2.102)	**1.500** (0.533-1.559)	**1.090** (0.367-1.134)	**0.837** (0.278-0.872)	***0.278***	***2.102***
10 - 100 keV	**0.961** (0.583-1.850)	**0.767** (0.487-1.386)	**0.554** (0.352-1.000)	**0.431** (0.277-0.771)	***0.277***	***1.850***
0.1 - 2.0 Mev	**0.504** (0.375-0.718)	**0.355** (0.262-0.520)	**0.283** (0.208-0.429)	**0.200** (0.152-0.295)	***0.152***	***0.718***
2.0 - 20.0 Mev	**0.967** (0.718-1.127)	**0.818** (0.520-0.925)	**0.698** (0.429-0.791)	**0.573** (0.295-0.668)	***0.295***	***1.127***
> 20.0 Mev	**1.606** (0.797-2.016)	**1.673** (0.740-2.154)	**1.543** (0.632-2.264)	n/a	***0.632***	***2.264***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.758** (0.532-1.797)	**1.310** (0.470-1.333)	**0.955** (0.324-0.978)	**0.734** (0.244-0.746)	***0.244***	***1.797***
10 - 100 keV	**0.947** (0.567-1.734)	**0.753** (0.473-1.299)	**0.546** (0.342-0.938)	**0.425** (0.269-0.723)	***0.269***	***1.734***
0.1 - 2.0 Mev	**0.490** (0.361-0.683)	**0.338** (0.254-0.494)	**0.274** (0.200-0.408)	**0.193** (0.146-0.280)	***0.146***	***0.683***
2.0 - 20.0 Mev	**0.912** (0.683-1.049)	**0.775** (0.494-0.851)	**0.659** (0.408-0.725)	**0.541** (0.280-0.612)	***0.280***	***1.049***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Esophagus

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.328E-09** (2.50E-10 - 1.55E-9)	**1.681E-09** (4.75E-10 - 1.90E-9)	**1.010E-09** (2.65E-10 - 1.16E-9)	**7.175E-10** (2.00E-10 - 8.35E-10)	***2.00E-10***	***1.90E-09***
10 - 100 keV	**3.045E-09** (1.55E-9 - 4.22E-9)	**3.742E-09** (1.90E-9 - 5.21E-9)	**2.371E-09** (1.16E-9 - 3.26E-9)	**1.683E-09** (8.35E-10 - 2.39E-9)	***8.35E-10***	***5.21E-09***
0.1 - 2.0 Mev	**1.612E-08** (4.22E-9 - 2.77E-8)	**1.661E-08** (5.21E-9 - 2.46E-8)	**1.068E-08** (3.26E-9 - 1.82E-8)	**7.644E-09** (2.39E-9 - 1.32E-8)	***2.39E-09***	***2.77E-08***
2.0 - 20.0 Mev	**4.303E-08** (2.77E-8 - 4.52E-8)	**4.062E-08** (2.46E-8 - 4.48E-8)	**3.679E-08** (1.82E-8 - 4.08E-8)	**2.863E-08** (1.32E-8 - 3.32E-8)	***1.32E-08***	***4.52E-08***
> 20.0 Mev	**4.874E-08** (4.18E-8 - 5.96E-8)	**4.707E-08** (4.37E-8 - 5.31E-8)	**4.712E-08** (4.08E-8 - 5.61E-8)	n/a	***4.08E-08***	***5.96E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.575** (0.379-1.656)	**1.996** (0.613-2.075)	**1.201** (0.356-1.250)	**0.851** (0.264-0.886)	***0.264***	***2.075***
10 - 100 keV	**0.787** (0.479-1.476)	**0.949** (0.592-1.814)	**0.585** (0.370-1.109)	**0.425** (0.272-0.795)	***0.272***	***1.814***
0.1 - 2.0 Mev	**0.427** (0.277-0.661)	**0.445** (0.349-0.592)	**0.283** (0.197-0.434)	**0.204** (0.154-0.313)	***0.154***	***0.661***
2.0 - 20.0 Mev	**0.919** (0.661-1.101)	**0.859** (0.586-0.986)	**0.785** (0.434-0.910)	**0.601** (0.313-0.670)	***0.313***	***1.101***
> 20.0 Mev	**1.634** (0.718-2.385)	**1.560** (0.746-2.122)	**1.572** (0.679-2.243)	n/a	***0.679***	***2.385***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.378** (0.305-1.415)	**1.746** (0.567-1.786)	**1.047** (0.321-1.069)	**0.750** (0.241-0.757)	***0.241***	***1.786***
10 - 100 keV	**0.775** (0.466-1.384)	**0.937** (0.575-1.700)	**0.591** (0.359-1.039)	**0.421** (0.264-0.746)	***0.264***	***1.700***
0.1 - 2.0 Mev	**0.412** (0.267-0.628)	**0.430** (0.336-0.575)	**0.271** (0.190-0.412)	**0.196** (0.148-0.298)	***0.148***	***0.628***
2.0 - 20.0 Mev	**0.869** (0.628-1.037)	**0.812** (0.557-0.907)	**0.735** (0.412-0.837)	**0.569** (0.298-0.619)	***0.298***	***1.037***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Lung

Nuetrons Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.283E-09** (3.85E-10 - 1.46E-9)	**1.381E-09** (4.05E-10 - 1.58E-9)	**9.128E-10** (2.90E-10 - 1.04E-9)	**6.722E-10** (2.35E-10 - 7.72E-10)	***2.35E-10***	***1.58E-09***
10 - 100 keV	**2.943E-09** (1.46E-9 - 4.20E-9)	**3.349E-09** (1.58E-9 - 4.81E-9)	**2.172E-09** (1.04E-9 - 3.19E-9)	**1.650E-09** (7.72E-10 - 2.42E-9)	***7.72E-10***	***4.81E-09***
0.1 - 2.0 Mev	**2.218E-08** (4.20E-9 - 3.42E-8)	**2.669E-08** (4.81E-9 - 4.09E-8)	**1.648E-08** (3.19E-9 - 2.60E-8)	**1.196E-08** (2.42E-9 - 1.99E-8)	***2.42E-09***	***4.09E-08***
2.0 - 20.0 Mev	**4.709E-08** (3.42E-8 - 4.87E-8)	**5.132E-08** (4.09E-8 - 5.26E-8)	**3.974E-08** (2.60E-8 - 4.20E-8)	**3.282E-08** (1.99E-8 - 3.63E-8)	***1.99E-08***	***5.26E-08***
> 20.0 Mev	**4.563E-08** (4.54E-8 - 4.77E-8)	**4.487E-08** (4.32E-8 - 5.06E-8)	**4.474E-08** (4.18E-8 - 4.91E-8)	n/a	***4.18E-08***	***5.06E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.523** (0.524-1.587)	**1.646** (0.583-1.711)	**1.070** (0.400-1.120)	**0.795** (0.297-0.824)	***0.297***	***1.711***
10 - 100 keV	**0.751** (0.478-1.392)	**0.820** (0.547-1.506)	**0.541** (0.363-0.994)	**0.410** (0.275-0.735)	***0.275***	***1.506***
0.1 - 2.0 Mev	**0.579** (0.405-0.813)	**0.699** (0.496-0.974)	**0.429** (0.296-0.619)	**0.310** (0.203-0.475)	***0.203***	***0.974***
2.0 - 20.0 Mev	**1.004** (0.794-1.183)	**1.097** (0.844-1.310)	**0.845** (0.619-0.984)	**0.694** (0.475-0.787)	***0.475***	***1.310***
> 20.0 Mev	**1.492** (0.794-1.858)	**1.453** (0.844-1.771)	**1.481** (0.700-1.963)	n/a	***0.700***	***1.963***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.332** (0.470-1.358)	**1.436** (0.495-1.462)	**0.847** (0.354-0.966)	**0.697** (0.276-0.708)	***0.276***	***1.462***
10 - 100 keV	**0.737** (0.464-1.305)	**0.802** (0.531-1.412)	**0.533** (0.352-0.932)	**0.406** (0.267-0.689)	***0.267***	***1.412***
0.1 - 2.0 Mev	**0.557** (0.383-0.773)	**0.671** (0.470-0.926)	**0.414** (0.280-0.588)	**0.300** (0.192-0.451)	***0.192***	***0.926***
2.0 - 20.0 Mev	**0.950** (0.773-1.115)	**1.040** (0.844-1.238)	**0.798** (0.588-0.916)	**0.656** (0.451-0.738)	***0.451***	***1.238***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Gonads (female - ovaries)

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.610E-09** (3.75E-10 - 1.86E-9)	**1.492E-09** (4.00E-10 - 1.71E-9)	**9.845E-10** (2.50E-10 - 1.13E-9)	**6.959E-10** (1.90E-10 - 8.10E-10)	***1.90E-10***	***1.86E-09***
10 - 100 keV	**3.702E-09** (1.86E-9 - 5.08E-9)	**3.224E-09** (1.71E-9 - 4.97E-9)	**2.425E-09** (1.13E-9 - 3.43E-9)	**1.756E-09** (8.10E-10 - 2.49E-9)	***8.10E-10***	***5.08E-09***
0.1 - 2.0 Mev	**1.659E-08** (5.08E-9 - 2.69E-8)	**1.755E-08** (4.97E-9 - 2.72E-8)	**1.026E-08** (3.43E-9 - 1.87E-8)	**6.955E-09** (2.49E-9 - 1.18E-8)	***2.49E-09***	***2.72E-08***
2.0 - 20.0 Mev	**4.500E-08** (2.69E-8 - 4.79E-8)	**4.564E-08** (2.72E-8 - 5.07E-8)	**3.594E-08** (1.87E-8 - 3.97E-8)	**2.873E-08** (1.18E-8 - 3.27E-8)	***1.18E-08***	***5.07E-08***
> 20.0 Mev	**5.053E-08** (4.55E-8 - 5.96E-8)	**4.746E-08** (4.65E-8 - 5.07E-8)	**5.011E-08** (3.97E-8 - 5.71E-8)	n/a	***3.97E-08***	***5.96E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.910** (0.556-1.999)	**1.775** (0.528-1.841)	**1.168** (0.379-1.209)	**0.825** (0.239-0.859)	***0.239***	***1.999***
10 - 100 keV	**0.950** (0.578-1.771)	**0.886** (0.565-1.627)	**0.606** (0.390-1.072)	**0.440** (0.283-0.771)	***0.283***	***1.771***
0.1 - 2.0 Mev	**0.439** (0.310-0.640)	**0.437** (0.321-0.648)	**0.277** (0.189-0.446)	**0.187** (0.143-0.283)	***0.143***	***0.648***
2.0 - 20.0 Mev	**0.955** (0.640-1.127)	**0.966** (0.648-1.115)	**0.758** (0.446-0.887)	**0.605** (0.280-0.707)	***0.280***	***1.127***
> 20.0 Mev	**1.684** (0.784-2.385)	**1.549** (0.845-1.902)	**1.677** (0.661-2.284)	n/a	***0.661***	***2.385***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.670** (0.458-1.709)	**1.549** (0.476-1.574)	**1.020** (0.305-1.036)	**0.727** (0.216-0.734)	***0.216***	***1.709***
10 - 100 keV	**0.935** (0.561-1.661)	**0.875** (0.549-1.525)	**0.599** (0.379-1.005)	**0.436** (0.274-0.723)	***0.274***	***1.661***
0.1 - 2.0 Mev	**0.424** (0.298-0.608)	**0.423** (0.309-0.616)	**0.265** (0.184-0.424)	**0.181** (0.138-0.274)	***0.138***	***0.616***
2.0 - 20.0 Mev	**0.903** (0.608-1.042)	**0.913** (0.616-1.040)	**0.717** (0.424-0.820)	**0.571** (0.266-0.649)	***0.266***	***1.042***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Gonads (male - testes)

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.964E-09** (1.00E-9 - 2.33E-9)	**6.421E-10** (1.80E-10 - 7.28E-10)	**7.823E-10** (3.40E-10 - 9.17E-10)	**6.032E-10** (3.25E-10 - 7.09E-10)	***1.80E-10***	***2.33E-09***
10 - 100 keV	**6.309E-09** (2.33E-9 - 1.04E-8)	**1.448E-09** (7.28E-10 - 2.00E-9)	**2.300E-09** (9.17E-10 - 3.61E-9)	**1.932E-09** (7.09E-10 - 3.16E-9)	***7.09E-10***	***1.04E-08***
0.1 - 2.0 Mev	**5.070E-08** (1.04E-8 - 6.36E-8)	**6.101E-09** (2.00E-9 - 1.12E-8)	**1.845E-08** (3.61E-9 - 2.65E-8)	**1.739E-08** (3.16E-9 - 2.45E-8)	***2.00E-09***	***6.36E-08***
2.0 - 20.0 Mev	**6.001E-08** (5.43E-8 - 6.39E-8)	**3.333E-08** (1.12E-8 - 4.06E-8)	**3.626E-08** (2.65E-8 - 3.90E-8)	**3.320E-08** (2.45E-8 - 3.71E-8)	***1.12E-08***	***6.39E-08***
> 20.0 Mev	**3.278E-08** (2.78E-8 - 5.43E-8)	**5.090E-08** (4.06E-8 - 6.42E-8)	**4.318E-08** (3.79E-8 - 5.15E-8)	n/a	***2.78E-08***	***6.42E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**2.311** (1.283-2.411)	**0.757** (0.259-0.790)	**0.915** (0.458-0.955)	**0.711** (0.382-0.735)	***0.259***	***2.411***
10 - 100 keV	**1.478** (1.181-2.223)	**0.373** (0.228-0.693)	**0.556** (0.410-0.874)	**0.450** (0.359-0.675)	***0.228***	***2.223***
0.1 - 2.0 Mev	**1.349** (1.147-1.515)	**0.163** (0.113-0.265)	**0.483** (0.378-0.632)	**0.456** (0.348-0.582)	***0.113***	***1.515***
2.0 - 20.0 Mev	**1.293** (0.906-1.550)	**0.695** (0.265-0.791)	**0.772** (0.632-0.884)	**0.702** (0.582-0.777)	***0.265***	***1.550***
> 20.0 Mev	**1.030** (0.906-1.135)	**1.718** (0.677-2.567)	**1.442** (0.650-2.062)	n/a	***0.650***	***2.567***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**2.034** (1.206-2.084)	**0.666** (0.220-0.679)	**0.808** (0.415-0.819)	**0.624** (0.355-0.633)	***0.220***	***2.084***
10 - 100 keV	**1.466** (1.147-2.084)	**0.363** (0.221-0.650)	**0.550** (0.398-0.819)	**0.448** (0.349-0.633)	***0.221***	***2.084***
0.1 - 2.0 Mev	**1.307** (1.089-1.440)	**0.152** (0.110-0.252)	**0.470** (0.357-0.600)	**0.440** (0.330-0.553)	***0.110***	***1.440***
2.0 - 20.0 Mev	**1.222** (0.906-1.490)	**0.658** (0.252-0.721)	**0.729** (0.600-0.825)	**0.664** (0.553-0.723)	***0.252***	***1.490***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Liver

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.715E-09** (4.90E-10 - 1.95E-9)	**1.294E-09** (3.50E-10 - 1.48E-9)	**1.079E-09** (3.05E-10 - 1.24E-9)	**7.280E-10** (2.30E-10 - 8.35E-10)	***2.30E-10***	***1.95E-09***
10 - 100 keV	**3.960E-09** (1.95E-9 - 5.63E-9)	**2.869E-09** (1.48E-9 - 4.23E-9)	**2.511E-09** (1.24E-9 - 3.59E-9)	**1.826E-09** (8.35E-10 - 2.63E-9)	***8.35E-10***	***5.63E-09***
0.1 - 2.0 Mev	**2.520E-08** (5.63E-9 - 3.71E-8)	**1.617E-08** (4.23E-9 - 2.55E-8)	**1.509E-08** (3.59E-9 - 2.36E-8)	**1.008E-08** (2.63E-9 - 1.70E-8)	***2.63E-09***	***3.71E-08***
2.0 - 20.0 Mev	**4.904E-08** (3.71E-8 - 5.09E-8)	**4.108E-08** (2.55E-8 - 4.42E-8)	**3.797E-08** (2.36E-8 - 4.08E-8)	**3.059E-08** (1.70E-8 - 3.44E-8)	***1.70E-08***	***5.09E-08***
> 20.0 Mev	**4.413E-08** (4.31E-8 - 4.89E-8)	**4.623E-08** (4.29E-8 - 5.20E-8)	**4.569E-08** (4.08E-8 - 4.92E-8)	n/a	***4.08E-08***	***5.20E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**2.038** (0.667-2.116)	**1.536** (0.511-1.594)	**1.275** (0.394-1.333)	**0.860** (0.311-0.893)	***0.311***	***2.116***
10 - 100 keV	**0.997** (0.640-1.856)	**0.753** (0.481-1.410)	**0.631** (0.408-1.181)	**0.452** (0.299-0.795)	***0.299***	***1.856***
0.1 - 2.0 Mev	**0.664** (0.508-0.884)	**0.421** (0.314-0.607)	**0.391** (0.291-0.562)	**0.268** (0.182-0.404)	***0.182***	***0.884***
2.0 - 20.0 Mev	**1.047** (0.816-1.231)	**0.873** (0.607-1.008)	**0.806** (0.562-0.941)	**0.644** (0.404-0.723)	***0.404***	***1.231***
> 20.0 Mev	**1.442** (0.816-1.809)	**1.532** (0.735-2.082)	**1.516** (0.680-1.970)	n/a	***0.680***	***2.082***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.778** (0.598-1.815)	**1.349** (0.427-1.370)	**1.121** (0.356-1.139)	**0.754** (0.281-0.767)	***0.281***	***1.815***
10 - 100 keV	**0.983** (0.621-1.740)	**0.743** (0.467-1.322)	**0.623** (0.397-1.107)	**0.447** (0.290-0.746)	***0.290***	***1.740***
0.1 - 2.0 Mev	**0.641** (0.481-0.840)	**0.407** (0.301-0.577)	**0.381** (0.276-0.534)	**0.259** (0.175-0.384)	***0.175***	***0.840***
2.0 - 20.0 Mev	**0.990** (0.816-1.157)	**0.825** (0.577-0.935)	**0.761** (0.534-0.870)	**0.609** (0.384-0.669)	***0.384***	***1.157***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Remainder Organs

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.285E-09** (4.00E-10 - 1.50E-9)	**1.345E-09** (4.25E-10 - 1.57E-9)	**9.441E-10** (2.85E-10 - 1.10E-9)	**6.383E-10** (2.20E-10 - 7.47E-10)	***2.20E-10***	***1.57E-09***
10 - 100 keV	**3.355E-09** (1.50E-9 - 4.97E-9)	**3.799E-09** (1.57E-9 - 5.58E-9)	**2.414E-09** (1.10E-9 - 3.53E-9)	**1.911E-09** (7.47E-10 - 2.76E-9)	***7.47E-10***	***5.58E-09***
0.1 - 2.0 Mev	**2.057E-08** (4.97E-9 - 3.09E-8)	**2.272E-08** (5.58E-9 - 3.40E-8)	**1.622E-08** (3.53E-9 - 2.53E-8)	**1.189E-08** (2.76E-9 - 1.92E-8)	***2.76E-09***	***3.40E-08***
2.0 - 20.0 Mev	**4.422E-08** (3.09E-8 - 4.64E-8)	**4.633E-08** (3.40E-8 - 4.79E-8)	**3.875E-08** (2.53E-8 - 4.10E-8)	**3.273E-08** (1.92E-8 - 3.65E-8)	***1.92E-08***	***4.79E-08***
> 20.0 Mev	**4.906E-08** (4.63E-8 - 5.20E-8)	**4.916E-08** (4.61E-8 - 5.41E-8)	**4.797E-08** (4.10E-8 - 5.61E-8)	n/a	***4.10E-08***	***5.61E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.524** (0.556-1.587)	**1.595** (0.599-1.656)	**1.120** (0.400-1.168)	**0.756** (0.316-0.783)	***0.316***	***1.656***
10 - 100 keV	**0.830** (0.565-1.428)	**0.905** (0.634-1.494)	**0.600** (0.401-1.048)	**0.439** (0.314-0.711)	***0.314***	***1.494***
0.1 - 2.0 Mev	**0.540** (0.426-0.735)	**0.595** (0.470-0.809)	**0.422** (0.309-0.603)	**0.314** (0.241-0.458)	***0.241***	***0.809***
2.0 - 20.0 Mev	**0.942** (0.735-1.096)	**0.990** (0.785-1.157)	**0.824** (0.603-0.960)	**0.692** (0.458-0.784)	***0.458***	***1.157***
> 20.0 Mev	**1.620** (0.773-2.092)	**1.627** (0.785-2.163)	**1.604** (0.684-2.243)	n/a	***0.684***	***2.243***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.331** (0.488-1.356)	**1.397** (0.519-1.415)	**0.982** (0.348-0.998)	**0.666** (0.269-0.669)	***0.269***	***1.415***
10 - 100 keV	**0.819** (0.549-1.339)	**0.895** (0.616-1.401)	**0.592** (0.389-0.983)	**0.435** (0.305-0.667)	***0.305***	***1.401***
0.1 - 2.0 Mev	**0.525** (0.407-0.698)	**0.577** (0.452-0.769)	**0.409** (0.292-0.573)	**0.301** (0.230-0.435)	***0.230***	***0.769***
2.0 - 20.0 Mev	**0.889** (0.698-1.021)	**0.934** (0.769-1.094)	**0.778** (0.573-0.892)	**0.655** (0.435-0.733)	***0.435***	***1.094***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Skin

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**9.326E-10** (6.75E-10 - 1.23E-9)	**9.267E-10** (6.50E-10 - 1.22E-9)	**7.056E-10** (5.00E-10 - 9.49E-10)	**5.190E-10** (3.95E-10 - 6.96E-10)	***3.95E-10***	***1.23E-09***
10 - 100 keV	**4.398E-09** (1.23E-9 - 7.57E-9)	**4.382E-09** (1.22E-9 - 7.54E-9)	**3.671E-09** (9.49E-10 - 6.40E-9)	**3.376E-09** (6.96E-10 - 6.00E-9)	***6.96E-10***	***7.57E-09***
0.1 - 2.0 Mev	**3.294E-08** (7.57E-9 - 4.14E-8)	**3.282E-08** (7.54E-9 - 4.14E-8)	**3.012E-08** (6.40E-9 - 3.85E-8)	**2.776E-08** (6.00E-9 - 3.59E-8)	***6.00E-09***	***4.14E-08***
2.0 - 20.0 Mev	**4.545E-08** (4.14E-8 - 4.75E-8)	**4.543E-08** (4.14E-8 - 4.75E-8)	**4.270E-08** (3.85E-8 - 4.43E-8)	**3.936E-08** (3.59E-8 - 4.09E-8)	***3.59E-08***	***4.75E-08***
> 20.0 Mev	**2.985E-08** (2.67E-8 - 4.33E-8)	**2.977E-08** (2.66E-8 - 4.33E-8)	**3.023E-08** (2.75E-8 - 4.11E-8)	n/a	***2.66E-08***	***4.33E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.091** (0.596-1.169)	**1.086** (0.585-1.163)	**0.830** (0.441-0.904)	**0.610** (0.322-0.663)	***0.322***	***1.169***
10 - 100 keV	**0.989** (0.860-1.169)	**0.986** (0.857-1.163)	**0.816** (0.727-0.913)	**0.714** (0.663-0.753)	***0.663***	***1.169***
0.1 - 2.0 Mev	**0.879** (0.817-0.987)	**0.876** (0.815-0.987)	**0.801** (0.710-0.917)	**0.738** (0.661-0.855)	***0.661***	***0.987***
2.0 - 20.0 Mev	**0.982** (0.722-1.127)	**0.981** (0.722-1.127)	**0.925** (0.685-1.067)	**0.840** (0.665-0.966)	***0.665***	***1.127***
> 20.0 Mev	**0.961** (0.722-1.328)	**0.958** (0.722-1.330)	**0.980** (0.674-1.370)	n/a	***0.674***	***1.370***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**0.955** (0.592-1.096)	**0.957** (0.585-1.090)	**0.729** (0.437-0.847)	**0.538** (0.313-0.621)	***0.313***	***1.096***
10 - 100 keV	**0.986** (0.836-1.117)	**0.982** (0.832-1.117)	**0.814** (0.706-0.887)	**0.714** (0.621-0.765)	***0.621***	***1.117***
0.1 - 2.0 Mev	**0.853** (0.773-0.938)	**0.850** (0.770-0.938)	**0.776** (0.674-0.871)	**0.713** (0.625-0.812)	***0.625***	***0.938***
2.0 - 20.0 Mev	**0.918** (0.722-1.052)	**0.917** (0.722-1.050)	**0.863** (0.685-1.003)	**0.794** (0.665-0.922)	***0.665***	***1.052***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Stomach

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**2.162E-09** (6.15E-10 - 2.45E-9)	**9.786E-10** (2.50E-10 - 1.12E-9)	**9.915E-10** (2.95E-10 - 1.13E-9)	**7.128E-10** (2.25E-10 - 8.16E-10)	***2.25E-10***	***2.45E-09***
10 - 100 keV	**4.904E-09** (2.45E-9 - 6.93E-9)	**2.302E-09** (1.12E-9 - 3.18E-9)	**2.401E-09** (1.13E-9 - 3.42E-9)	**1.771E-09** (8.16E-10 - 2.58E-9)	***8.16E-10***	***6.93E-09***
0.1 - 2.0 Mev	**3.238E-08** (6.93E-9 - 4.58E-8)	**8.968E-09** (3.18E-9 - 1.53E-8)	**1.387E-08** (3.42E-9 - 2.13E-8)	**1.008E-08** (2.58E-9 - 1.63E-8)	***2.58E-09***	***4.58E-08***
2.0 - 20.0 Mev	**5.432E-08** (4.58E-8 - 5.58E-8)	**3.416E-08** (1.53E-8 - 3.96E-8)	**3.537E-08** (2.13E-8 - 3.95E-8)	**2.935E-08** (1.63E-8 - 3.35E-8)	***1.53E-08***	***5.58E-08***
> 20.0 Mev	**4.531E-08** (4.09E-8 - 5.30E-8)	**5.196E-08** (3.96E-8 - 6.32E-8)	**4.673E-08** (3.95E-8 - 5.81E-8)	n/a	***3.95E-08***	***6.32E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**2.567** (0.889-2.679)	**1.161** (0.356-1.209)	**1.176** (0.406-1.216)	**0.844** (0.316-0.872)	***0.316***	***2.679***
10 - 100 keV	**1.244** (0.787-2.332)	**0.579** (0.361-1.066)	**0.593** (0.388-1.079)	**0.441** (0.293-0.777)	***0.293***	***2.332***
0.1 - 2.0 Mev	**0.858** (0.675-1.090)	**0.236** (0.171-0.364)	**0.365** (0.277-0.508)	**0.266** (0.192-0.388)	***0.171***	***1.090***
2.0 - 20.0 Mev	**1.160** (0.883-1.387)	**0.721** (0.364-0.830)	**0.748** (0.508-0.849)	**0.618** (0.388-0.694)	***0.364***	***1.387***
> 20.0 Mev	**1.458** (0.883-1.726)	**1.752** (0.660-2.526)	**1.570** (0.659-2.324)	n/a	***0.659***	***2.526***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**2.244** (0.751-2.295)	**1.016** (0.305-1.033)	**1.028** (0.360-1.042)	**0.738** (0.275-0.750)	***0.275***	***2.295***
10 - 100 keV	**1.221** (0.765-2.186)	**0.571** (0.351-1.000)	**0.584** (0.377-1.011)	**0.437** (0.285-0.729)	***0.285***	***2.186***
0.1 - 2.0 Mev	**0.824** (0.639-1.036)	**0.226** (0.166-0.351)	**0.351** (0.263-0.483)	**0.256** (0.185-0.369)	***0.166***	***1.036***
2.0 - 20.0 Mev	**1.099** (0.883-1.312)	**0.682** (0.346-0.760)	**0.707** (0.483-0.782)	**0.584** (0.369-0.641)	***0.346***	***1.312***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

Organ: Thyroid

Neutron Exposures

Fluence (ϕ) to Organ Dose Equivalent (H_T) (cSv cm^2)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.526E-09** (7.05E-10 - 1.80E-9)	**5.344E-10** (1.45E-10 - 6.07E-10)	**8.223E-10** (3.70E-10 - 9.62E-10)	**5.675E-10** (2.95E-10 - 6.58E-10)	***1.45E-10***	***1.80E-09***
10 - 100 keV	**4.581E-09** (1.80E-9 - 7.51E-9)	**1.037E-09** (6.07E-10 - 1.62E-9)	**2.402E-09** (9.62E-10 - 3.77E-9)	**1.707E-09** (6.58E-10 - 2.55E-9)	***6.07E-10***	***7.51E-09***
0.1 - 2.0 Mev	**4.256E-08** (7.51E-9 - 5.57E-8)	**5.291E-09** (1.62E-9 - 9.83E-9)	**2.195E-08** (3.77E-9 - 3.24E-8)	**1.219E-08** (2.55E-9 - 1.82E-8)	***1.62E-09***	***5.57E-08***
2.0 - 20.0 Mev	**5.520E-08** (5.18E-8 - 5.72E-8)	**2.543E-08** (9.83E-9 - 3.14E-8)	**4.384E-08** (3.24E-8 - 4.59E-8)	**3.257E-08** (1.82E-8 - 4.07E-8)	***9.83E-09***	***5.72E-08***
> 20.0 Mev	**3.787E-08** (3.18E-8 - 5.18E-8)	**5.471E-08** (3.14E-8 - 6.72E-8)	**4.625E-08** (4.56E-8 - 4.66E-8)	n/a	***3.14E-08***	***6.72E-08***

Ambient Dose Equivalent (H(10)) to Organ Dose Equivalent (H_T) (cSv/cSv)*

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.803** (0.919-1.882)	**0.623** (0.193-0.660)	**0.964** (0.425-1.010)	**0.674** (0.298-0.694)	***0.193***	***1.882***
10 - 100 keV	**1.079** (0.853-1.717)	**0.311** (0.184-0.578)	**0.579** (0.428-0.916)	**0.398** (0.290-0.627)	***0.184***	***1.717***
0.1 - 2.0 Mev	**1.125** (0.848-1.325)	**0.144** (0.092-0.234)	**0.567** (0.400-0.772)	**0.320** (0.248-0.434)	***0.092***	***1.325***
2.0 - 20.0 Mev	**1.186** (0.864-1.418)	**0.533** (0.234-0.611)	**0.934** (0.765-1.081)	**0.682** (0.434-0.729)	***0.234***	***1.418***
> 20.0 Mev	**1.199** (0.864-1.351)	**1.864** (0.524-2.688)	**1.515** (0.765-1.881)	n/a	***0.524***	***2.688***

Deep Dose Equivalent $H_{p,slab}(10)$ to Organ Dose Equivalent (H_T) (cSv/cSv)

Neutron Energy	DCF_{AP}	DCF_{PA}	DCF_{ROT}	DCF_{ISO}	DCF_{Min}	DCF_{Max}
<10 keV	**1.579** (0.861-1.610)	**0.554** (0.177-0.568)	**0.856** (0.395-0.863)	**0.588** (0.303-0.595)	***0.177***	***1.610***
10 - 100 keV	**1.066** (0.829-1.610)	**0.302** (0.179-0.542)	**0.571** (0.416-0.859)	**0.391** (0.281-0.587)	***0.179***	***1.610***
0.1 - 2.0 Mev	**1.086** (0.805-1.259)	**0.132** (0.089-0.222)	**0.552** (0.378-0.734)	**0.309** (0.235-0.412)	***0.089***	***1.259***
2.0 - 20.0 Mev	**1.123** (0.864-1.355)	**0.504** (0.222-0.561)	**0.881** (0.734-1.013)	**0.644** (0.412-0.692)	***0.222***	***1.355***
> 20.0 Mev	n/a	n/a	n/a	n/a	***n/a***	***n/a***

APPENDIX B - IREP-EXCEL INPUT FORMAT

PERSONAL INFORMATION								
Claimant Name	Claim #	Claimant SSN	DOL Claim Center	Gender	Birth Year	Year of Diagnosis	Cancer Model	Should alt model be run?
John Q. Doe	000001-DE	123-45-6789	Denver CO	Male	1942	2002	Oral Cavity and Pharynx	No

CLAIMANT CANCER DIAGNOSES						
	Primary Cancer #1	Primary Cancer #2	Primary Cancer #3	Secondary Cancer #1	Secondary Cancer #2	Secondary Cancer #3
Cancer Type	N/A	N/A	N/A	N/A	N/A	N/A
Date of Daignosis	N/A	N/A	N/A	N/A	N/A	N/A

EXPOSURE INFORMATION							
Number of exposures							
1							
Exposure #	Exposure Year	Exposure Rate	Radiation Type	Dose Distribution Type	Parameter 1	Parameter 2	Parameter 3
1	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
2	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
3	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
4	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
5	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
6	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
7	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
8	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
9	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
10	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
11	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
12	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
13	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
14	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
15	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
16	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
17	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
18	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
19	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
20	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
21	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
22	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
23	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
24	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
25	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
26	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
27	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
28	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
29	1982	chronic	electrons	Lognormal	2.000	2.000	0.000
30	1982	chronic	electrons	Lognormal	2.000	2.000	0.000