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12/15/2003	12/15/2003	00	First approved issue. Initiated by William E. Murray.

ACRONYMS AND ABBREVIATIONS

Al	Aluminum
cGy	centigray
DCF	Dose conversion factor
DOE	Department of Energy
eq.	Equivalent
ESE	Entrance skin exposure
GE	General Electric
Gy	gray
HVL	Half value layer
ICRP	International Commission on Radiological Protection
IREP	Interactive Radio-Epidemiological Program
keV	kiloelectronvolt
kVp	kilovolts peak
mA	milliampere
MeV	Megaelectronvolt
mGy	milligray
mm	millimeter
NCRP	National Council on Radiation Protection and Measurements
PA	Posterior/anterior
PFG	Photofluorographic
POC	Probability of causation
RMS	Root-mean-square
s	second
SID	Source-to-image distance
SSD	Source-to-skin distance
TBD	Technical Basis Document
TEC	Tennessee Eastman Corporation
Y-12	Y-12 National Security Complex

3.1 INTRODUCTION

The Y-12 Plant, now known as the Y-12 National Security Complex, required pre-placement and routine physical examinations as part of their occupational health and safety program. These medical examinations typically included diagnostic chest X-rays. The doses from these diagnostic X-ray procedures depended not only on the characteristics of the X-ray machine and the procedure used, but also on the frequency of the examination. This section is based primarily on information provided by the staff at the present Y-12 Medical X-ray Department (Wiley 2002).

For evaluating Probability of Causation (POC), the doses to be included in calculating the worker's dose are those from diagnostic X-rays that are required by the employer as a condition of employment, e.g., X-rays taken for pre-employment, pre-placement, or routine physical examinations. These X-rays are referred to in this Technical Basis Document (TBD) as occupational X-rays. Doses from diagnostic X-rays taken by either the employer or an off-site health care provider for on-the-job or off-the-job injuries or illnesses are not included in the worker's dose calculation for POC.

3.2 EXAMINATION FREQUENCIES

The frequency of exams differed significantly over the years. The frequency of chest X-rays is shown in Table 3-1 for different age groups and for specific groups of workers through the years based on information provided by Y-12 (Wiley 2002).

Table 3-1. Frequency of occupational posterior/anterior chest X-rays at Y-12 (Wiley 2002)[a].

Period	Frequency	Comment
1943 to July 17, 1988	Pre-placement	All employees
	Annually	All employees
	At termination	All employees
July 18, 1988 to June 30, 1993	Pre-placement	All employees
	Time of entry into hazardous job	Asbestos and beryllium workers and other jobs with potential pulmonary pathogens
	Annually	Active and previous asbestos and beryllium workers
	Every 10 years	Employees under 30 years old
	Every 5 years	Employees aged 30-45 years old
	Every 3 years	Employees over 45 years old
	At termination	All employees
July 1, 1993 – March 1998	Pre-placement	All employees
	Time of entry into hazardous job	Asbestos and beryllium workers and other jobs with potential pulmonary pathogens
	Annually	Active and previous asbestos and beryllium workers
	At termination	All employees
March 1998 – Present	Pre-placement	All employees
	Time of entry into hazardous job	Asbestos and beryllium workers and other jobs with potential pulmonary pathogens
	Annually	Active asbestos workers
	Every 3 years	Previous asbestos workers; active and previous beryllium workers
	At termination	All employees

a.) Workers in certain occupations may have received chest X-rays more frequently. This information may be in the claimant's file provided by DOE.

However, occupational X-rays may have occurred more frequently than on the schedule indicated in Table 3-1 at least in the early years. Wolf specified more frequent physical examinations (including X-

ray) for various occupational groups (Wolf 1945). A recommended procedure for post-employment, routine medical examinations specified more frequent X-rays for the following occupational groups:

- Food handlers and cafeteria workers – every 6-12 months
- Alpha (calutron) workers – twice per year
- Liquid phase workers exposed to uranium, phosgene, or carbon tetrachloride – three times per year.

However, no date was provided on this document. Information on employer-required medical X-rays may be available in the claimant's file.

3.3 EQUIPMENT AND TECHNIQUES

The medical practices used at Y-12 are assumed to have followed the adoption of standards of radiology practice during the 1930s and 1940s to minimize dose to the patient. However, there is the potential for significant dose from occupational medical X-ray examinations, depending on the type of equipment, the technique factors, the number of photofluorographic (PFG) examinations typical in the early years, and the number of radiographic examinations (Cardarelli et al. 2002).

According to information provided by the Y-12 Medical X-Ray Department, pre-employment chest X-rays were always taken with a conventional medical diagnostic X-ray machine (Wiley 2002). They found no evidence of PFG chest X-rays in the employee medical X-ray folders and all chest X-rays in these folders were 14"x17" films. However, in reviewing the medical X-ray folders of workers from the 1940s, approximately 1400 4"x10" chest X-ray films were found in the medical X-ray folders of workers who were employed at Y-12 from 1943 to 1947. Originally these X-rays were thought to be copies of conventional X-rays that were taken elsewhere and sent to Y-12 when the person was hired there. In fact, these were PFG chest X-rays.

In February 1945, a General Electric (GE) stereoscopic photoroentgen unit is listed as an equipment item in the Y-12 Medical Department (Wolf 1945). Reexaminations and other chest films were done on conventional 14"x17' films. On October 12, 1945, the Tennessee Eastman Corporation (TEC) Medical Director sent a telegram to the GE X-Ray Corporation, requesting them to set up a Photoroentgen Unit 4x10 (Leggo 1945). In June 1946, TEC placed an order with the Oak Ridge Hospital for 6000 Eastman-Single Coated 4"x10" X-ray films for the period from August 1, 1946 to July 31, 1947 (Graham 1946). Thus, it is clear that pre-employment chest X-rays were taken with a PFG unit from 1943 to 1947, as evidenced by the 4"x10" films found in the medical records and the purchasing records mentioned above. All chest X-rays done since then are conventional 14"x17" X-rays.

No record has been located to determine what type of diagnostic X-ray machine was in use at Y-12 from 1948 until the GE-type machine mentioned above that was used in the early 1960s. This date may not be correct either. In a meeting with the X-ray technologist who provided the information for that report, the technologist said that more recent documentation indicated that the GE-type machine was installed in 1969, not in the early 1960s (Beck 2003). Thus, it is not possible at this time to state with certainty what X-ray machine was used from 1948 to 1968. From 1969 until January 1982, the X-ray machine in use was similar to a GE Model DXD-350. This machine was replaced with a GE Model DSX-650II in February 1982 (Wiley 2002).

A description of the X-ray equipment used at Y-12 is included in Table 3-2. The specific technique factors for these machines are shown in Table 3-3. Since no technique factors were identified by Y-12 for Types I and II equipment, organ doses, based on assumed technique factors, were developed on the basis of X-ray techniques contemporary with the time period (1943-1968), with due consideration given to claimant favorability.

Table 3-2. Description of the X-ray equipment used at Y-12.

Machine	Time period	Equipment
Type I	1943 to 1947	Photofluorographic unit at Oak Ridge Hospital or Y-12 Clinic
Type II	1948 to 1968	Unknown
Type III	1969 to January 1982	Similar to General Electric Model DXD-350 (exact model unknown)[a]
Type IV	February 1982 to present	General Electric DSX 650 II [a]

a.) From Wiley 2002

Table 3-3. Technique factors used for each type of X-ray equipment[b].

Machine	View	Current (milliampere [mA])	Voltage (kilovolts peak [kVp])	Exposure time (second [s])
Type I	X-rays were done at Oak Ridge Hospital or Y-12. Techniques are unknown. No records have been located.			
Type II	PA[a]	200	80	1/20
Type III	PA	200	80	1/20 [b]
Type IV	PA	200	110	Photo-timed [b]

a.) PA indicates a posterior/anterior view, the average PA chest measures 26 cm.
b.) From Wiley 2002

3.4 ORGAN DOSE CALCULATIONS

Most Y-12 employees received occupationally-related diagnostic X-rays annually for many years and at a lesser frequency in the later years. The frequency over time (1943-present) for various groups of workers is shown in Table 3-1. Only the PFG chests (from 1943-1947) and the posterior/anterior (PA) chest views from 1969 to the present are documented.

No actual X-ray output measurements are available. The X-ray technique factors provided may not be reliable, especially for the Type II equipment. Thus, default values for entrance kerma will be used in the calculation of organ dose conversion factors (DCFs) for use in dose reconstruction. Default values have been developed for the three of the most commonly used occupational medical diagnostic X-ray procedures: PA, lateral; and PFG chest films (Kathren et al., to be published). The default values are considered to be maxima developed from reviews of patient doses reported in the literature, machine characteristics, and knowledge of X-ray procedures used during the time periods indicated. Sufficient conservatism was included in the determination of the default values to ensure with near certainty (>99% confidence) that the actual exposures from the specified procedures would not exceed the default values, thus ensuring claimant favorability.

In determining the default factors in Table 3-4, it was assumed that minimum filtration was used, along with low kilovolt peak (kVp) techniques, slow film speeds with standard development procedures, and no additional collimation or use of cones. The default entrance kerma values for the three procedures are given in Table 3-4 below.

Table 3-4. Entrance kerma values for Y-12 chest X-rays.

Period	Entrance kerma (centigray [cGy])[a]	
	Posterior/anterior	Photofluorographic
Pre-1970	0.20	3.0
1970-1982	0.10	
1982-present	0.05	

a. From National Council on Radiation Protection and Measurements (NCRP) Report No. 102 (NCRP 1989).

A source-to-image distance (SID) of 72 inches (in) (183 centimeter [cm]) was standard for the time for the PA chest, and 42 in (106 cm) for the PFG chests. The X-ray machines used at Y-12 were most likely single-phase, and typically no air gap was used between the patient and the film. Before 1982, it is assumed that the X-ray equipment was operated at 80 kVp, had at least 1.5 millimeters (mm) aluminum (Al) total filtration (see Table 3.1 of National Council on Radiation Protection and Measurements [NCRP] [1989]), and that the half value layer (HVL) was approximately 2.5 mm Al equivalent [eq.] (see Table B.2 of NCRP [1989]). These were typical machine parameters for chest X-rays performed in this time period. After 1982, the X-ray equipment was operated at 110 kVp, had at least 2.5 mm Al total filtration, and that the HVL was approximately 3.5 mm Al eq. After 1982, the machine parameters were the same but the exposures were photo-timed (Wiley 2002). The default values for entrance kerma were also used for the PA chest X-rays after 1982 because the exposure time would not be known for a photo-timed (automatic) exposure.

The following formula was used to calculate the organ doses in Tables 3C-2, 3, 4, and 5.

Organ dose (rem) = Entrance kerma (cGy) x Organ DCF (mGy/Gy) x 1.0 E-3 (rem-Gy/cGy-mGy)

where, the entrance kerma is in centigray (cGy) and the organ DCF is in milligray (mGy)/gray (Gy). To obtain the organ dose in rem, the equation must be multiplied by 1.0 E-03 (rem-Gy/cGy-mGy).

The appropriate entrance kerma is selected from Table 3-4 and the DCFs are taken from the International Commission on Radiological Protection (ICRP) Report No. 34 (ICRP 1982).

Specific organ doses for the PA chest X-rays and PFG chest films calculated on the basis of the dose conversion factors found in ICRP (1982) are given in Tables 3C-2, 3, 4, and 5. Doses for organs not listed in ICRP (1982) but specified in the Interactive Radio-Epidemiological Program (IREP) code were determined by analogy with anatomical location as indicated in Table 3-5 below.

It is assumed that the X-ray beam was not collimated for X-rays taken before about 1965. Therefore, organs not normally in the primary beam for a PA chest were included in the primary beam by using ICRP (1982) organ dose conversion factors (DCFs) for procedures where those organs would normally be included in the primary beam or dose data from the literature was used. For example, assuming no collimation, the ovaries would be in the primary beam, and DCFs for the abdomen were used. Abdomen DCFs were used for ovaries, testes, uterus, and their analogues. The cervical spine DCF was used for the thyroid and its analogue.

Table 3-5. Analogues for Interactive Radio-Epidemiological Program (IREP) organs not included in ICRP (1982).

Anatomical location	ICRP 1982 reference organ	IREP organ analogues
Thorax	Lung	Thymus Esophagus Stomach Liver/gall bladder Bone surface Remainder organs
Abdomen	Ovaries	Urinary/bladder Colon/rectum Uterus
Head and neck	Thyroid	Eye/brain

ICRP (1982) provides tables of average absorbed dose in milligray (mGy) in selected organs for selected X-ray projections at 1 gray (Gy) entrance kerma (i.e., air kerma without backscatter), for selected views (including PA chest), and for selected beam qualities, (i.e., various HVLs). These tables provide the basic DCFs for converting air kerma to organ dose.

3.5 UNCERTAINTY

Error, defined as deviation from the correct, true or conventionally accepted value of a quantity, and uncertainty, defined in terms of the potential range of a stated, measured, assumed or otherwise determined value of a quantity, provides an indication of the confidence of the dose estimates. Error implies knowledge of what the correct or actual value is, which is, of course, not known. Hence a more appropriate term is uncertainty, which is expressed in terms of a confidence level, e.g. 99%. This means that the correct or true value, although not actually known, has a 99% probability of falling within the range cited. The uncertainty includes both the precision, i.e., how reproducible the measurement is, and the accuracy, i.e., how close the measurement or estimate of dose comes to the actual or correct value.

In theory a large number of variables can introduce uncertainties or affect the X-ray machine output intensity and dose to the patient. In practice only four variables can be reasonably considered to have an impact on dose uncertainty. These are variations in (1) applied kVp, (2) beam current, (3) exposure time, and (4) distance from the patient to the source of the X-rays (source-to-skin distance [SSD]). Other variables, such as the use of screens and grids, reciprocity failure, film speed and development, would not affect the beam output intensity.

For a given set of machine settings and parameters, the X-ray output should theoretically be constant and unvarying. Although this is not always true in practice, the output is essentially constant unless focal spot loading occurs when the power rating of the machine is exceeded. This is unlikely because it would be difficult to achieve in practice and would damage the X-ray tube. However, even with the use of constant voltage transformers to control line voltages, slight variations may occur in line voltage input or other internal voltages, which could alter the kVp of the output beam. For a given kVp setting, the variation in kVp falls within ±5% of the machine setting (Seibert et al. 1991). The beam intensity is approximately proportional to the 1.7 power of the kilovoltage. This translates to an uncertainty of approximately ±8.7% for the output beam intensity in the 76-84 and 105-116 kVp ranges. For conservatism, this is rounded up to ±9%.

Similarly, slight variations in tube current are normal. As a tube ages or heats up from usage, the tube current may change and typically it will drop. Hence, with all other factors remaining constant, the beam output will be reduced in direct proportion to the change in tube current. Typically, the reduction in beam output from current variation is not more than a few per cent under normal operating conditions. Large decreases in beam output will be readily detected. This will result in performing maintenance on the machine to restore the output, or, as a temporary stopgap measure, increasing the current or kVp to provide the necessary beam output for proper radiography. For a given kVp setting, the beam output is a function of the tube current. A milli-ammeter on the machine measures the average tube current. This measurement is subject to uncertainties. In addition, there may be minor changes in output as the tube heats up from normal usage, but these variations are typically small. Hence the uncertainty in beam output attributable to current variation has been estimated at ±5%.

Another parameter that has potential to affect the dose, perhaps significantly, from a diagnostic radiograph relates to the exposure time. This can be readily understood by noting that a full-wave rectified machine produces 120 pulses per second of X-rays. For an exposure time of 1/20 of a second, only six pulses would result. A small error in the timer that resulted in a change of only ±1 pulse would correspondingly affect the output by ±17%. For an exposure time of 1/30 of a second, the change in output corresponding to a deviation of ±1 pulse is ±25%. Early mechanical timers were notoriously inaccurate, although timer accuracy improved significantly with the introduction of electronic timers. However, once again for conservatism, the uncertainty in the beam output attributable to timers will be assumed to have an upper limit of +25%.

The final factor that is likely to affect patient dose relates to distance from the source of the X-rays, which is a determinant of the entrance skin exposure (ESE). For a given individual, the source-to-skin distance (SSD) will be determined largely by the thickness of the patient and the accuracy in positioning the patient. For a typical patient, this variation in SSD is estimated at no more than a few centimeters, with an upper limit of perhaps 7.5 cm. Using the inverse square law, this indicates an uncertainty of ±10 % from this source.

Two approaches can be used to determine the combined uncertainty from the above four potential sources of uncertainty. The first, and most conservative in that it gives the greatest range, would be to assume that the uncertainties are additive. This would give an uncertainty range of up to 9%+5%+25%+10%=49%. However, a more reasonable approach would be to assume that the uncertainties are in fact random, and to compute the statistical root-mean-square (RMS) value. The RMS value is simply the square root of the sum of the squares, and computes as ±28.7%. Thus, for any individual ESE or derived organ dose, an uncertainty of ±30 % at the 99% confidence level may be assumed. For further conservatism, it may be appropriate to assume that errors are all positive, and only the + 30% should be used.

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GLOSSARY

Calutron - an electromagnetic apparatus for separating isotopes according to their masses.

Entrance kerma – see kerma

Entrance skin exposure (ESE) – the exposure at the point where the X-ray beam enters the skin.

Film speed – a measure of the sensitivity of the film to X-rays or light.

Filtration – material in the useful beam which usually absorbs preferentially the less penetrating radiation.

Focal spot – the apparent size of the radiation source region in a source assembly when viewed from the central axis of the useful radiation beam.

Gray (Gy) – the special name for the SI unit of absorbed dose, kerma, and specific energy imparted equal to one (1) joule per kilogram (J/kg). (1 Gy = 1 J/kg = 100 rad)

Grid – a series of lead strips used to improve the quality of radiographic images by removing scattered X-rays.

Half value layer (HVL) – thickness of a specified substance which, when introduced into the path of a given beam of radiation, reduces the kerma rate by one-half. (Usually specified in mm Al.)

Interactive RadioEpidemiological Program (IREP) – a computer software program that uses information on the dose-response relationship, and specific factors such as a claimant's radiation exposure, gender, age at diagnosis, and age at exposure to calculate the probability of causation for a given pattern and level of radiation exposure.

International Commission on Radiological Protection (ICRP) – an independent Registered Charity, established to advance for the public benefit the science of radiological protection, in particular by providing recommendations and guidance on all aspects of protection against ionising radiation.

Inverse square law – the relationship between the exposure rate from a point source of radiation and the distance from the source.

Kerma – the sum of the initial kinetic energies of all the charged ionizing particles liberated by uncharged ionizing particles per unit mass of a specified material.

Kiloelectronvolt (keV) – the energy equal to that acquired by a particle with one electron charge in passing through a potential difference of 1000 volts.

Milliammeter – an instrument for measuring electric current in milliamperes.

National Council on Radiation Protection and Measurements (NCRP) – a nongovernmental, public service organization that formulates and disseminates information, guidance and recommendations on radiation protection and measurements.

Organ dose – the dose to a given organ from an X-ray procedure.

Photofluorography – an obsolete radiographic technique in which the image produced on a fluorescent screen by X-rays was photographed.

Photon - a quantum of electromagnetic radiation.

Posterior/anterior (P/A) – an X-ray in which the X-ray beam passes from posterior to the anterior side of the patient.

Pre-placement X-ray – an X-ray, usually a chest X-ray, taken before a worker is hired or assigned to a specific job.

Probability of causation (POC) – the probability or likelihood that a cancer was caused by radiation exposure incurred by a covered employee in the performance of duty.

Pulmonary - relating to, functioning like, or associated with the lungs.

Root-mean-square - the square root of the arithmetic mean of the squares of a set of numbers.

Screens – a fluorescent material used in diagnostic radiology that absorbs the X-rays and converts it into light that exposes the X-ray film.

Source-to-image distance (SID) – the distance measured along the central ray from the center of the front of the surface of the source (focal spot) to the surface of the image detector.

Source-to-skin distance (SSD) – the distance measured along the central ray from the center of the front of the surface of the source (focal spot) to the surface of the irradiated object or the patient.

Technique factors – the variables, i.e., the peak voltage (kVp), current (mA), and time (s), that are used for taking an X-ray.

Termination X-ray – an X-ray, usually a chest X-ray that is taken when the employee is separated from the company.

Tube current – the current flowing through the filament or cathode in an X-ray tube.

Variable – a quantity that may assume any one of a set of values.

X-ray - electromagnetic radiation of the same nature as visible radiation but having an extremely short wavelength of less than 10^{-8} m; a photograph obtained by use of X rays.

X-ray tube – an evacuated electronic tube in which X-rays are generated when electrons are accelerated by an applied voltage and strike an anode or target.

ATTACHMENT 3C
OCCUPATIONAL MEDICAL DOSE

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3C.1 Y-12 MEDICAL X-RAY PROGRAM

Y-12 conducted pre-placement and annual physical examinations as part of their occupational health program. These examinations typically included a chest X-ray. In general, the frequency of the examinations over the years and by age of the worker is shown in Table 3C-1 (Wiley 2002). For some workers, and occupations, chest X-rays could be more frequent. For example, food handlers and cafeteria workers were examined every 6-12 months; alpha (calutron) workers were examined twice per year; and liquid phase workers exposed to uranium, phosgene or carbon tetrachloride underwent three examinations per year.

Table 3C-1. Frequency of occupational posterior/anterior chest X-rays at Y-12 (Wiley 2002).[a]

Period	Frequency	Comment
1943 – Present	Pre-placement	All employees
	At termination	All employees
1943 – July 18,1988	Annually	All employees
July 18, 1988 – Present	Time of entry into hazardous job	Asbestos and beryllium workers and other jobs with potential pulmonary pathogens
July 18, 1988 – March 1998	Annually	Active and previous asbestos and beryllium workers
July 18, 1988 – June 30, 1993	Every 10 years	Employees under 30 years old
	Every 5 years	Employees aged 30-45 years old
	Every 3 years	Employees over 45 years old
March 1998 – Present	Annually	Active asbestos workers
	Every 3 years	Previous asbestos workers; active and previous beryllium workers

a.) Workers in certain occupations may have received chest X-rays more frequently. This information may be in the claimant's file provided by DOE.

3C.2 ORGAN DOSES FROM MEDICAL X-RAYS

X-ray organ doses for occupational X-rays at Y-12 are estimated for all years from 1943 to present. The schedule for these exams for all Y-12 employees over this time period is shown in Table 3C-1. The organ dose estimates are provided in Tables 3C-2, 3, and 4. The X-ray organ dose estimates were made for Type I equipment (used from 1943 to 1947), Type II equipment (used from 1948 to 1968), Type III equipment (used from 1969 to January 1982), and Type IV equipment (used from February 1982 to present) (Wiley 2002).

For organs outside the chest cavity, other ICRP (1982) organ dose conversion factors (DCFs) besides PA chest were used to ensure that the organ doses reflected their presence in the primary beam. For example, the dose to the ovaries for Type I equipment assumes they were in the primary beam, so the air kerma at the skin was multiplied by the DCF for ovaries in the abdomen.

3C.3 DOSE RECONSTRUCTOR INSTRUCTIONS

The information given below summarizes instructions given to the dose reconstructors in determining organ doses from occupational medical X-ray procedures. For the purpose of evaluating probability of causation (POC), X-ray doses are always considered acute, and are considered to be photons with energies in the range from 30 to 250 kiloelectronvolts (keV).

3C.3.1 Assignment of Organ Doses from X-ray Procedures: Maximizing Approach for Dose Reconstructions

Organ doses from X-ray procedures have been calculated and are presented in Tables 3C-2, 3, 4, and 5. The organ doses assigned for each X-ray procedure are the highest doses to any organ in the relevant group as listed in Tables 3C-2 to 5,. One annual X-ray procedure for each full or partial year of employment is assumed. However, if the dose reconstructor determines that more frequent procedures occurred or may have occurred, the annual organ doses can be raised accordingly. As mentioned above in 3C.1, the TEC specified more frequent examinations for certain occupations. The dose reconstructor should assume that food handlers and cafeteria workers, and alpha calutron workers received two (2) X-rays per year; liquid phase workers exposed to uranium, phosgene or carbon tetrachloride received three examinations per year. Since this was a TEC guideline, the higher frequency of X-ray examinations should be applied only during TEC's tenure at Y-12 (1943 to 1947).

The X-ray doses presented above are treated as a point estimate (constant) for the purpose of calculating probability of causation.

3C.3.2 Assignment of Organ Doses from X-ray Procedures: Best Estimate Approach for Dose Reconstructions

For the dose calculation, a normal distribution is applied with a standard deviation of 30%. The value of the standard deviation is equal to the mean value times 30%. Thus, the dose reconstructor should multiply the organ doses listed in Tables C-2, 3, 4, and 5 by 1.3. The dose reconstructor may use a frequency other than annual if the actual frequency is known and apply the guidance in 3C.3.1 above.

Table 3C-2. Organ doses (rem)[a] for a beam quality (HVL) of 2.5 mm Al and 80 kVp (Type I machine; 1943-1947).

Organ	Organ dose from photofluorographic chest X-ray (rem)
Entrance air kerma	3.00E+00[b]
Thyroid [c]	5.22E-01
Eye/brain	9.60E-02
Ovaries [e]	2.5 E-02
Liver/gall bladder	1.35E+00
Urinary bladder [e]	2.5 E-02
Colon/rectum [e]	2.5 E-02
Testes [e]	5.0 E-03
Lungs (male)	1.26E+00
Lungs (female)	1.35E+00
Thymus	1.35E+00
Esophagus	1.35E+00
Stomach	1.35E+00
Bone surface	1.35E+00
Remainder	1.35E+00
Breast	1.47E-01
Uterus [e]	2.5 E-02
Bone marrow (male)	2.76E-01
Bone marrow (female)	2.58E-01
Skin [d]	4.05E+00

a. For organs listed in ICRP 34 (1982) and proximal organs for input to IREP.
b. Kathren et al., to be published.
c. The DCF for the AP cervical spine was used, corrected by a 20% depth dose factor (NCRP (1989), Table B-8).
d. Skin dose is entrance skin kerma, multiplied by a backscatter factor of 1.35 from NCRP 102, Table B-8.
e. Modified from Webster.

Table 3C-3. Organ doses (rem) [a] for a beam quality (HVL) of 2.5 mm Al and 80 kVp (Type II machine; 1948-1968) assuming no collimation.

Organ	Organ dose from posterior/anterior chest X-ray (rem)
Entrance air kerma	2.00E-01[b]
Thyroid [c]	3.48E-02
Eye/brain	6.40E-03
Ovaries [e]	2.50E-02
Liver/gall bladder	9.02E-02
Urinary bladder [e]	2.50E-02
Colon/rectum [e]	2.50E-02
Testes [e]	5.00E-03
Lungs (male)	8.38E-02
Lungs (female)	9.02E-02
Thymus	9.02E-02
Esophagus	9.02E-02
Stomach	9.02E-02
Bone surface	9.02E-02
Remainder	9.02E-02
Breast	9.80E-03
Uterus [e]	2.50E-02
Bone marrow (male)	1.84E-02
Bone marrow (female)	1.72E-02
Skin [d]	2.70E-01

a. For organs listed in ICRP (1982) and proximal organs for input to IREP.
b. Kathren et al., to be published.
c. The DCF for the AP cervical spine was used, corrected by a 20% depth dose factor (NCRP (1989), Table B-8).
d. Skin dose is entrance skin kerma, multiplied by a backscatter factor of 1.35 from NCRP (1989), Table B-8.
e. Modified from Webster.

Table 3C-4. Organ doses (rem)[a] for a beam quality (HVL) of 2.5 mm Al and 80 kVp (1969-January 1982).

Organ	Organ dose from Posterior/anterior chest X-ray (rem)
Entrance air kerma	1.00E-01[b]
Thyroid	3.20E-03
Eye/brain	3.20E-03
Ovaries	1.00E-04
Liver/gall bladder	4.51E-02
Urinary bladder	1.00E-04
Colon/rectum	1.00E-04
Testes	1.00E-06
Lungs (male)	4.19E-02
Lungs (female)	4.51E-02
Thymus	4.51E-02
Esophagus	4.51E-02
Stomach	4.51E-02
Bone surface	4.51E-02
Remainder	4.51E-02
Breast	4.90E-03
Uterus	1.30E-04
Bone marrow (male)	9.20E-03
Bone marrow (female)	8.60E-03
Skin [c]	1.35E-01

a. For organs listed in ICRP (1982) and proximal organs for input to IREP.
b. Kathren et al., to be published.
c. Skin dose is entrance skin kerma, multiplied by a backscatter factor of 1.35 from NCRP (1989), Table B-8.

Table 3C-5. Organ doses (rem)[a] for a beam quality (HVL) of 3.5 mm Al and 110 kVp (January 1982-present).

Organ	Organ dose from posterior/anterior chest X-ray (rem)
Entrance air kerma	5.00E-02[b]
Thyroid	3.10E-03
Eye/brain	3.10E-03
Ovaries	1.60E-04
Liver/gall bladder	3.05E-02
Urinary bladder	1.60E-04
Colon/rectum	1.60E-04
Testes	5.00E-07
Lungs (male)	2.83E-02
Lungs (female)	3.05E-02
Thymus	3.05E-02
Esophagus	3.05E-02
Stomach	3.05E-02
Bone surface	3.05E-02
Remainder	3.05E-02
Breast	4.55E-03
Uterus	1.50E-04
Bone marrow (male)	7.30E-03
Bone marrow (female)	7.05E-03
Skin [c]	7.00E-02

a. For organs listed in ICRP (1982) and proximal organs for input to IREP.
b. Kathren et al., to be published.
c. Skin dose is entrance skin kerma, multiplied by a backscatter factor of 1.4 from NCRP (1989), Table B-8.