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ACRONYMS AND ABBREVIATIONS

cm	centimeter
DF	dose conversion factor
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ESE	entrance skin exposure
Gy	gray
HVL	half value layer
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiological Units
IREP	Interactive RadioEpidemiological Program
kVp	Peak Kilovoltage, applied kilovoltage
Lat	lateral
mA	Milliampere
mAs	milliampere-second
mm	Millimeter
NCRP	National Council on Radiation Protection
NIOSH	National Institute for Occupational Safety and Health
PA	posterior-anterior
R	roentgen
RMS	root mean square
SID	source to image distance
SSD	source to skin distance

3.1 INTRODUCTION

Diagnostic X-ray procedures were an additional contributor to the occupational radiation exposure of Hanford workers. In general, the dose from these exposures was neither measured nor considered or included as part of the overall occupational exposure of the employee, although it clearly was occupationally related. With the passage of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), diagnostic medical X-rays administered in conjunction with routine or special physical examinations required for employment were recognized as a valid source of occupational exposure. Unlike occupational exposures incurred during normal work processes, individual diagnostic medical X-ray exposures were not monitored, necessitating reconstruction of the doses acquired in this manner. This report describes the technical aspects of dose reconstruction from medical X-rays administered prior to employment and periodically thereafter as a condition of employment.

3.2 TECHNICAL FACTORS AFFECTING DIAGNOSTIC X-RAY DOSE

A number of factors determine the dose to workers from a diagnostic X-ray procedure. For a more or less standard medical radiographic (i.e., diagnostic) unit with a tungsten target (anode) and focal spot of 1-2 mm, these include the basic machine settings used for the exposure~~,~~ which include the applied kilovoltage of the beam (kVp), beam current (mA), time of exposure, distance, waveform, amount and kind of filtration used, collimation or use of diaphragms, tube housing characteristics, type and speed of the film, development procedure, screens, grids, and the size of the worker. While this list of factors looks formidable, in the absence of direct measurements of the beam itself, which are rarely available, the dose to the worker can be estimated with a reasonable degree of accuracy with knowledge of only the three basic machine parameters (applied kilovoltage, current, and time) and assumptions about filtration, collimation, and waveform characteristics. The implications of these factors to worker dose are discussed below.

3.2.1 Applied Kilovoltage and Filtration

The energy of the X-ray beam is determined by the applied kilovoltage and the filtration, and is sometimes referred to as beam quality. X-rays, as produced in a typical medical X-ray tube, are bremsstrahlung and, as such, are a distribution or spectrum of energies ranging from zero to the applied kilovoltage, which refers to the potential between the anode and cathode of the tube. For a typical unfiltered X-ray spectrum, the average energy is about one-third of the peak energy, or applied kilovoltage. Hence, most of the X-rays produced are much lower in energy than the applied kilovoltage of the beam, and are attenuated by the torso or other portion of the body being radiographed and never reach the film. These X-rays are of little value in radiography but contribute significantly to worker dose.

To reduce the dose to the worker, filtration in the form of a specified thickness of absorbing material is added to the beam. This has the net effect of absorbing a large fraction of the lower energy X-rays that are of little or no value in making the radiograph while allowing most of the more energetic and radiographically useful X-ray photons to pass. In this manner, the dose to the worker is reduced significantly and radiographic quality might be enhanced. A filtered X-ray spectrum has a correspondingly higher average energy than before it was filtered, although the photon fluence rate is much reduced. Such a beam is said to have been hardened. A corollary to this filtration technique is to use a higher applied kilovoltage and to filter the beam relatively heavily to eliminate most of the low-energy radiographically useless photons from reaching the worker.

Beam energy is specified in terms of quality, or hardness, which in turn can be in terms of the half value layer (HVL) in aluminum. Unfortunately, this parameter is seldom available. Even if it is known, it is of limited value, in part because it does not specify the maximum energy of the beam or its true quality because, as the HVL measurement is made, the absorbers act as filters and the beam is further hardened. Thus, the first HVL is always smaller than the second, which in turn is smaller than the third, and so forth. What is commonly, although not always, available is the kVp of the machine and the external or added filtration. All X-ray tubes have so-called inherent filtration, which is the window or port of the tube. In medical diagnostic units, the window is thin, typically equivalent to 0.5 mm Al in attenuation and hence provides little beam hardening.

Although the benefits of filtration with respect to improved radiographic images were known and understood as early as March 1896, within months of the discovery of X-rays (Magie 1896), diagnostic radiographs were initially made with no added filtration. Recommendations, albeit not specific as to thickness, were made in 1937 by the International Committee for Radiological Units, which specified aluminum filters for X-rays of 20 to 120 kVp, which incorporated the diagnostic X-ray energy range (ICRU 1937). Typical external filtration in the 1940s ranged from none to 1 mm Al. This was in line with the 1936 recommendations of the U.S. Advisory Committee on X-Ray and Radium Protection, which later became the NCRP, which called for 0.5 mm of Al equivalent for radiographic installations, and 1mm Al for fluoroscopy (NBS1936). The NCRP recommended 1 mm Al filtration for radiography of thick parts of the body such as the chest in 1949 (NBS1949) and this thickness was used during World War II in 100 mA units in larger military hospitals, and hence presumably at Hanford as well (Olson, Trask and Dessen 1966). Recommended thicknesses were later increased; in 1955, the NCRP recommendation for diagnostic X-ray units called for 2-mm total Al filtration for new machines (NBS 1955). This increased again in 1968 to 2.5 mm for medical diagnostic units operating above 70 kVp (NCRP 1968). For operating machines, these recommended filter thicknesses might not have been used for some time after the date of the recommendation.

The relationship of beam intensity[1] to applied kVp and filtration is complex and to some extent machine-specific and hence is best determined empirically. However, in the absence of empirical data for a specific machine, adequate contemporary empirical and theoretical data exist upon which to determine machine output within a reasonable degree of uncertainty. Additional filtration reduces the entrance skin exposure[2] (ESE), generally in an exponential manner. For a typical single-phase, half-, full-, or self-rectified machine operating in the diagnostic range of 80 to 100 kVp, each additional millimeter of Al filtration will effect a reduction of about 40% in the ESE (Trout, Kelley, and Cathey 1952; Taylor 1957). Thus, the approximate intensity reduction afforded by any thickness of Al filtration can be determined by the following exponential equation:

$$I = I_o e^{-0.4t}$$

or

$$\ln (I/I_o) = -0.4\ t$$

1. As used herein, beam intensity refers to the output of the machine in terms of exposure in the special sense per mAs. Exposure in the special sense is referenced to ionization in air and, as such, is not a dose quantity.
2. Throughout this document, italics will be used to differentiate exposure in the special sense from exposure in the general sense. Thus exposure refers to exposure in the special sense. A brief discussion of exposure in both the general and special sense can be found in numerous publications, including NCRP Report 82 (1985) and ICRU Report 60 (1998). It is important to note that the definition and application of the quantity exposure and its concomitant unit the roentgen have undergone several important modifications over the years which have been documented throughout the literature.

where t is the thickness of Al in millimeters, and I and I_o are the beam intensities with and without the filter, respectively. In the absence of specific measurements or empirical data, this correction can be applied to determine the effect of filtration on beam intensity and is consistent with the guidance in Revision 1 to OCAS-IG-001, "External Dose Reconstruction Implementation Guideline" (August 2002).

Similarly, increasing the kVp will increase the beam intensity or exposure rate. This can be calculated using Kramer's rule, but such calculations are difficult, complex, and time-consuming, even with high-speed computers, and are at best approximations. However, many empirical studies of beam intensity as a function of kVp provide ample credible evidence to show that for a given amount of filtration, increasing the applied kVp will increase the beam intensity according to the 1.7 power of the applied kilovoltage (Handloser 1951; Trout, Kelley, and Cathey 1952; Kathren 1965; BRH 1970). In the absence of specific measurements or empirical data, this function can be applied to determine the effect of applied kilovoltage on beam intensity, and is fully consistent with the guidance in Revision 1 to OCAS-IG-001, "External Dose Reconstruction Implementation Guideline" (August 2002).

3.2.2 Current and Exposure Time

Diagnostic X-ray exposures are typically specified in terms of milliampere-seconds (mAs), the product of X-ray tube current and exposure time. Thus, all factors being equal (e.g., kVp, filtration, film, development and screen combination), radiation exposure is proportional to the number of mAs. The current in an X-ray tube refers to the number of electrons accelerated across the evacuated volume of the tube, flowing from the cathode to the anode. For a given applied kilovoltage, the number of X-ray photons produced, and hence the exposure, will, at least in theory, be directly proportional to the X-ray tube current; this is and has been true for most medical radiography units over their design tube current range. Data from beam measurements made with medical radiographic X-ray units at Hanford over the years are indicative of this linearity. Thus, in the absence of measurements or other data or information to the contrary, it is reasonable and consistent with long-standing radiographic practice (Sante 1946) to assume linearity of exposure with tube current for a given kVp and filtration.

Exposure time refers to the time that the beam was on or the machine was producing X-rays and is, for all practical purposes, linear with exposure. To avoid or minimize image blurring from the beating heart, exposure time for chest Radiography was minimized, and the current concomitantly and proportionately increased to obtain the desired exposure in terms of mAs. However, from a dose reconstruction standpoint, earlier medical radiographic units were equipped with mechanical timers whose accuracy was not as good as the electronic timers used on later apparatus. Gross bias errors in timer accuracy are unlikely in that these would result in over- or underexposure of the radiograph and so would be quickly detected and corrected. More subtle are small random errors, which might produce uncertainties of perhaps $\pm$20% in the exposure. However, measurement data, albeit limited, from the Hanford medical X-ray units give no indication or suggestion that the time or exposure parameters might be subject to error.

Chest photofluorography, which resulted in much greater worker doses than a standard radiographic procedure, was used for a relatively short period at Hanford. Photofluorography used a smaller film (4 × 5 inches), a smaller source to skin distance (SSD) (42 inches), and both a higher kVp and typically a several-fold greater exposure in terms of mAs. Exposure was regulated by photometers, which utilized exposure to the film to determine the time of exposure.

3.2.3 Distance

X-ray beam intensity is a function of distance from the target, approximating the inverse square at large distances from the tube. Radiographic chest films were taken at a standard source to image distance (SID)[3] of 72 inches; the source refers to the focal spot of the tube and the image to the plane of the film. The distance to the worker, who was between the source and the film cassette, sometimes expressed in terms of the SSD, was somewhat smaller and, hence, the ESE to the worker was somewhat greater than the exposure at the plane of the film. In addition, patient attenuation would further reduce or attenuate the number of photons reaching the film. To compensate for the increased attenuation provided by a larger worker, X-ray technicians would sometimes increase the beam settings or, if the machine was so equipped, might use a high-speed Bucky diaphragm, probably with a somewhat higher kVp. Thus, it might be appropriate for an individual dose reconstruction to increase the ESE for a large or stout worker. Based on standard contemporary techniques (Picker 1941; Fuchs 1958; Cahoon 1961) for workers with a chest thickness of 25 to 27 cm, an increase of +50% from the ESE to the average worker should be sufficiently conservative; for still larger workers, a factor of 2 would be appropriate.

3.2.4 Collimation and Waveform Characteristics

Among other factors that could affect worker dose are collimation and waveform. X-ray waveforms are of three types: half wave rectified, which is almost never seen; full wave rectified, which is typical of medical radiographic units and characteristic of the units used at Hanford; and constant potential. A half wave rectified machine produces 60 half-sinusoidal shape pulses of X-rays per second, each with a duration of 1/120 of a second. A full wave rectified machine produces 120 half-sinusoidal pulses per second, each with a duration of 1/120 second. Thus, for a given setting of kVp and mA, the intensity of the beam from a half wave rectified machine is half that of the beam from the full wave rectified type. A constant potential machine produces a more or less steady (i.e., unpulsed) output of X-rays and has a somewhat greater beam intensity – approximately 10% – compared with a full wave rectified machine operating at the same kVp and mA. For Hanford, waveform is of no significance with respect to retrospective determination of worker exposure because actual output measurement data are available.

Collimation refers to the size of beam. The early philosophy was to use a fairly large aperture with limited collimation to ensure that the entire area of interest was included in the radiograph. Later, because of protection concerns, beams were collimated such that the smallest beam consistent with the area of interest was used, thereby limiting the area of the patient exposed and, in the case of chest radiography, minimizing dose to organs such as gonads, thyroid, and gastrointestinal tract. A practical check of collimation can be made by reference to the radiograph; a well-collimated beam will leave a small unexposed area or penumbra effect at the edges of the radiograph, while a poorly collimated beam will produce a radiograph that is exposed over all of its area. Available data, including direct beam measurements, indicate that X-ray beams used at Hanford were well collimated (Rising and Soldat 1959).

3.2.5 Screens, Grids, and Other Factors Potentially Affecting Worker Dose

A number of other factors affect the X-ray exposure required to obtain a proper radiograph and, hence, the dose to the worker. Knowledge of these factors is unnecessary for dose reconstruction purposes if beam measurements are available or if the primary machine characteristics of applied kilovoltage, time, and current are known along with the amount of primary beam filtration; however,

3. Also known as film-to-focus distance (FFD).

the factors can be used as additional confirmation of the applicability of the reconstructed dose. For completeness, this report makes brief mention of these factors, which are tube housing, type and speed of film, development procedure, screens, and grids.

X-ray tubes used for diagnostic radiography are typically enclosed in protective lead or shield tube housings with the primary beam brought out through a port or window in the side of the housing. Although some reduction of the dose to the worker is achieved, largely through elimination of scattered radiation and improved collimation, the primary purpose of this diagnostic tube housing is for the protection of the operator and unexposed X-ray film and nearby individuals other than the worker. This issue is moot, however, because virtually all X-ray tubes, and certainly those used at Hanford since its inception, had protective tube housings.

The amount of exposure needed for a suitable diagnostic radiograph is in some measure a function of film speed and development. Fine grain emulsions produce a superior radiographic image but require additional exposure in comparison to fast films. Underdevelopment of films also requires additional exposure to achieve satisfactory radiographic quality. Intensifying screens are used in the cassette to intensify the radiographic effect and thereby increase film speed and reduce worker dose. Grids, specifically the Potter-Bucky diaphragm (colloquially known as a Bucky) are sometimes utilized for thick section radiography, but rarely for chest radiography except with large workers. In any case, the above are all factored into the technique (i.e., kVp, mA) that is used and, except in rare instances and a virtually complete absence of other data, are not important in dose reconstruction.

3.3 DIAGNOSTIC X-RAY DOSES TO HANFORD WORKERS, 1943 TO DATE

For convenience and possible application to cases in which the standard Hanford protocol was not followed, or for generic use, Table 3-1 lists the effects of various technical factors.

Extensive review of the available documentation on the occupational medical program at Hanford from 1943 to the present revealed that only three diagnostic medical radiographic procedures were administered in connection with pre-employment or regular postemployment medical examinations:

1. Posterior-anterior (PA) 14” × 17” chest film
2. Lateral chest film
3. 4” × 5” chest photofluorographic film

Accordingly, only doses from these three techniques were evaluated. Other radiographic examinations of Hanford employees that might have occurred were nonoccupational in the sense that they were necessitated by illness or injury and were not part of the employee physical examination process. Thus, there is no indication in the records that other diagnostic radiographic examinations were administered as part of the occupational medical program, or that radiological treatment for shrinkage of lymphoid tissue was ever performed on Hanford workers.

A potential problem common to all procedures relates to the conversion of exposure represented by ESE to absorbed organ dose, and to changes in the definition of dose and the burgeoning of numerous dose quantities. Over the 50 or so years since the beginning of Hanford operations, the quantity known today as *exposure* has undergone several important conceptual changes, as has the application of the unit of exposure, the roentgen, which in itself is obsolete. Thus, there is much confusion about the definition of *exposure* and its associated unit, the roentgen. At one time, the roentgen was used to quantify the dose from electromagnetic radiation and, when this proved confusing and inexact, was defined as *exposure dose* to distinguish it from the term *absorbed dose*, which was applicable to any type of radiation.

Additional confusion was engendered by changes in the values of the conversion coefficients used to convert exposure to absorbed dose; at various times an exposure of 1 R would be equated to a soft tissue dose of 0.83, 0.877, or 0.93 rad. Thus, an exposure to air of 1 R would result in an absorbed dose of somewhat less than 1 rad (1 cGy = 10 mGy). Nonetheless, regulations applicable to Hanford and other DOE sites defined 1 R as exactly equal to a dose of 1 rad (10 mGy), thereby producing an overestimate in the reported dose or dose equivalent because dosimeters were typically calibrated against a field measured in R, which was numerically equated as absorbed dose in rad (Kathren and Petersen 1989). Further complicating the conversion of ESE in terms of exposure to absorbed dose is the contemporary trend to refer to X-ray intensity in terms of the quantity *kerma*, which is measured in the same units as absorbed dose. Typically, the numerical value of kerma is slightly lower than the corresponding value of absorbed dose. Thus, to ensure conservatism and compliance with National Institute for Occupational Safety and Health (NIOSH) guidance document OCAS-IG-001, and to avoid any risk dose underestimation, 1 R of exposure was taken to be equal to1 rad of absorbed dose and to 1 rad (10mGy) of kerma.

Conversion of exposure expressed as ESE was made in accordance with published conversion coefficients in Tables A2 through A9 of International Commission on Radiological Protection Publication 34 (ICRP 1982). These tables provide average absorbed organ doses for specific selected medical radiography procedures relative to an entrance air kerma without backscatter of 1 Gy for various beam qualities expressed in terms of HVL of aluminum. However, the tables do not include all organs identified in the Interactive RadioEpidemiological Program (IREP) code. For organs included in the IREP but not specifically identified in ICRP Publication 34, use of the dose conversion coefficient for the organ identified in ICRP Publication 34 that is anatomically the closest would seem to be a reasonable and simple first-order approach that generally would be claimant-favorable or neutral. Thus, the factor for lung would be applied to all other organs within the thoracic cavity (thymus, esophagus, and stomach). Because an appreciable fraction of the skeleton, in particular the trabecular bone, which has a large surface-to-volume ratio, and the sternum, which is a primary location of red marrow in the adult, lies within the trunk, the factor for lung would also be applied to the bone surfaces and bone marrow. For organs in the abdomen (i.e., liver, urinary bladder, colon and uterus) the dose conversion coefficient for ovary would be used. For the eye, the analogous organ is the thyroid.

Because, as discussed above, 1 R was taken to be 10 mGy of kerma, conversion could easily be made if the beam quality was known. Measured beam quality data were not found. However, the kVp and filtration were known, and an estimate of beam quality could be made from these data. Because for a given amount of filtration and exposure (mAs) absorbed organ dose increases as a function of HVL, for conservatism the upper limit on the likely beam quality was calculated and rounded up to match the closest value in the tables in ICRP Publication 34. For the period prior to January 28, 1983, beam quality expressed as HVL was conservatively estimated to be 2.5 mm Al; after January 28, 1983, the estimate was 4.0 mm Al. These values are somewhat greater than the 1.75 and approximately 3.5 mm Al values that would be derived from Table A16 of ICRP Publication 34 and, therefore, are claimant-favorable.

Tables 14 through16 list the frequency of various occupationally required X-ray procedures for preemployment, annual, transfer (on leaving and sometimes entry), and interval, culled from Hanford documents (Cantril 1946; Cleavinger 1978; Daly 1985; Fuqua 1981, Kirklin et al. 1969, Milroy 1988; Vails 1980). In the early years at the site, periodic X-ray examinations were relatively frequent and identified at-risk groups of workers received medical exams, including X-rays, at even more frequent intervals. For work with radiation hazards, interval exams in January 1944 were as close to 4 weeks as possible. By July 1945, the exam intervals were lengthened from 4 to 7 or 8 weeks. Other employees not working with radiation or other special hazards were examined every 3 to 6 months

(Cantril 1946). The frequency of medical radiographs was reduced to annually until 1959, and thereafter on a schedule dependent on age but no greater than annually.

3.3.1 Doses From 14" × 17" PA Chest Radiography

Table 3-2 summarizes salient data for the 14" × 17" PA chest radiography. As indicated in the tables, 14" × 17" PA chest radiography was the most widely used diagnostic procedure. The dates of measurement refer to the dates of an actual measurement of machine output for the procedure specified. There is a generally decreasing trend of ESE with time, which is wholly consistent with what has been the general experience nationally (Gray 1993). For conservatism in determining or reconstructing doses and in accordance with the guidance in OCAS-IG-001, the ESE should be assumed to have been constant from the time of the measurement until the time of the next measurement. Thus, referring to Table 3-2, radiographs taken from February 4, 1998, to the present would have an ESE of 11 mR; those taken prior to February 4, 1998, but on or after April 22, 1997, would have an ESE of 17 mR.

Certain aspects of the data require further explanation. The ESE for March 30, 1990, is characterized as "21 mR Assumed". In fact, the results from a survey performed by the State of Washington indicate that the measured worker exposure from the 14" × 17" PA chest radiography procedure was 11.7 mR. This value seemed inconsistent with the 21-mR value obtained by the State with the same machine and settings on November 11, 1993, and too small in comparison to the measurement of 35 mR obtained by the State on January 21, 1988. In fact, the ratio of ESE from the 1988 and 1993 measurements (35/21 = 1.67), was very close to the exposure in mAs (10/6.7 = 1.5) for this pair of measurements. Thus, for conservatism and in accordance with the guidance provided by OCAS-IG-001, 21 mR was assumed to be the proper value for the March 30, 1990, measurement.

Organ Dose Calculation Methods – Posterior/Anterior Chest Films:

The organ doses for PA chest films were calculated using the exposure expressed as ESE and in accordance with conversion coefficients in Tables A2 through A9 of ICRP Publication 34 (ICRP 1982). Table 3-2, "Summary of Beam Parameters for 14" × 17" PA Chest Radiography," provided the measured dose information for each period during which the PA chest films were given to Hanford workers. Because absorbed organ dose for PA chest radiographs will increase as a function of HVL, two HVL were calculated and used for dose determination. For the period prior to January 28, 1983, the estimated beam quality expressed as HVL was 2.5 mm Al; after January 28, 1983, 4.0 mm Al was used (see above for details).

Following are the methods used to calculate the dose in gray (Gy) from the Table 3-2 measured doses used in the dose determination for each period from 1943 to date. (**NOTE**: the PA ESE assumed for the period before 1946 were 120 mR based on experience and references from the early 1940s):

Before 2/1/1946	14" × 17" PA chest X-ray with 2.5-mm Al filter and an assumed ESE of 120 mR. Absorbed dose in Gy determined by 120 mR/100mGy per mR = 1.2 mGy and 1.2 mGy/1000mGy per 1 Gy = 0.0012 Gy. This value in Gy is used with Table 3-3 dose conversion factors (mGy per Gy air kerma for a beam quality for 2.5 mm Al HVL) to determine organ doses in Table 3-5 for the listed organs in ICRP Publication 34. Dose to ovaries and associated organs, and to the testes, were calculated from ratios determined from the dose factors given in ICRP 34 (1982) and measurements made by (Rising and Soldat 1959).

2/1/46 to 4/21/1959	14" × 17" PA chest X-ray with 2.5-mm Al filter and a measured ESE of 79 mR. Absorbed dose in Gy determined by 79 mR/100mGy per mR = 0.79 mGy and 0.79 mGy/1000mGy per 1 Gy = 0.00079 Gy. This value in Gy is used with Table 3-3 DFs (mGy per Gy air kerma for a beam quality for 2.5 mm Al HVL) To determine organ doses in Table 3.6 for the listed organs in ICRP Publication 34. Doses to the ovaries and testes are calculated from measurements (Rising & Soldat 1959)
4/12/59 to 1/28/1983	14" × 17" PA chest X-ray with 2.5-mm Al filter and a measured ESE of 40 mR. Absorbed dose in Gy determined by 40 mR/100mGy per mR = 0.40 mGy and 0.40 mGy/1000mGy per 1 Gy = 0.00040 Gy. This value in Gy is used with Table 3-3 DFs (mGy per Gy air kerma for a beam quality for 2.5 mm Al HVL) to determine organ doses in Table 3-7 for the listed organs in ICRP Publication 34. Doses to ovaries and testes are calculated from measurements (Rising & Soldat April 1959)
1/28/1983 to 3/30/1990	14" × 17" PA chest X-ray with 4.0-mm Al filter and a measured ESE of 35 mR. Absorbed dose in Gy determined by 35 mR/100mGy per mR = 0.35 mGy and 0.35 mGy/1000mGy per 1 Gy = 0.00035 Gy. This value in Gy is used with Table 3-4 DFs (mGy per Gy air kerma for a beam quality for 4.0 mm Al HVL) to determine organ doses in Table 3-8 for the listed organs in ICRP Publication 34.
3/30/1990 to 4/22/1997	14" × 17" PA chest X-ray with 4.0-mm Al filter and a measured ESE of 21 mR. Absorbed dose in Gy determined by 21 mR/100mGy per mR = 0.21 mGy and 0.21 mGy/1000mGy per 1 Gy = 0.00021 Gy. This value in Gy is used with Table 3-4 DFs (mGy per Gy air kerma for a beam quality for 4.0 mm Al HVL) to determine organ doses in Table 3-9 for the listed organs in ICRP Publication 34.
4/27/1997 to 2/4/1998	14" × 17" PA chest X-ray with 4.0-mm Al filter and a measured ESE of 17 mR. Absorbed dose in Gy determined by 17 mR/100mGy per mR = 0.17 mGy and 0.17 mGy/1000mGy per 1 Gy = 0.00017 Gy. This value in Gy is used with Table 3-4 DFs (mGy per Gy air kerma for a beam quality for 4.0 mm Al HVL) to determine organ doses in Table 3-10 for the listed organs in ICRP Publication 34.
42/4/1998 to Present	14" × 17" PA chest X-ray with 4.0-mm Al filter and a measured ESE of 11 mR. Dose in Gy determined by 11 mR/100mGy per mR = 0.11 mGy and 0.17 mGy/1000mGy per 1 Gy = 0.00011 Gy. This value in Gy is used with Table 3-4 DFs (mGy per Gy air kerma for a beam quality for 4.0 mm Al HVL) to determine organ doses in Table 3-11 for the listed organs in ICRP Publication 34.

3.3.2 Lateral 14" × 17" Chest Radiography

Table 3-16 summarizes period, frequency, applicability, ESE, and organ doses for the lateral 14" × 17" chest radiography. Although lateral 14" × 17" chest radiography might have been incorporated into the pre- and continuing employment physical examinations at Hanford, lateral chest exams were not a regularly scheduled or standard practice and occurred on an *ad hoc* basis. The dose from a lateral 14" × 17" chest radiograph is significantly greater than that from the more common 14" × 17" PA chest radiography procedure. All other factors notwithstanding, the ESE must of necessity be increased because of the greater body thickness presented laterally in comparison to PA. This means that the body will be closer to the X-ray tube, which will further increase the ESE. Few measurement data are available for lateral 14" × 17" chest radiography at Hanford. Data by Kirklin et al. (1969) indicate that the ESE from a lateral radiograph was 1.94 times the ESE from a PA chest radiograph, or approximately, twice the ESE from a PA chest radiograph. Depending on the degree of measurement

error, this value could be slightly greater or smaller. Because other measured data suggest that the ratio of ESE from lateral and PA chest radiographs could have been somewhat greater (Cardarelli et al. 2002; Stanford and Vance 1955), to ensure that dose from this source was not underestimated a moderately conservative factor of 2.5 was assumed for the ratio of ESE from lateral to PA chest radiography for organ dose calculations.

Organ Dose Calculation Methods – Lateral Chest Radiography

The organ doses for lateral (Lat) chest radiography were calculated using the exposure expressed as ESE and were in accordance with conversion coefficients in Tables A2 through A9 of ICRP Publication 34 (ICRP 1982). Several of the references above support the use of a factor of 2.5 times the PA chest radiography dose for the lateral chest radiography dose. This factor was used to determine doses for lateral chest radiography for Hanford workers for 1943 to date. Because absorbed organ dose for lateral chest radiographs increases as a function of the HVL of the Al filter used, two HVLs were calculated and used for dose determination. For the period prior to January 28, 1983, the estimated beam quality being expressed as HVL was 2.5 mm Al; after January 28, 1983, the estimate was 4.0 mm Al.

Following are the methods used to calculate the dose in Gy from the Table 3-2 measured doses that are used in the dose determination for each period from 1943 to date. (**NOTE**: The lateral dose used for the period before 1946 is 2.5 times the 120-mR PA assumed ESE, or 300 mR for the lateral chest radiography dose):

Before 2/1/1946	14” × 17” Lat chest X-ray with 2.5-mm Al filter and an assumed ESE of 300 mR. Absorbed dose in Gy determined by 300 mR/100mGy per mR = 3.0 mGy and 3.0 mGy/1000mGy per 1 Gy = 0.003 Gy. This value in Gy is used with Table 3-3 DFs (mGy per Gy air kerma for a beam quality for 2.5 mm Al HVL) to determine organ doses in Table 3-5 for the listed organs in ICRP Publication 34. Dose to the ovaries and associated organs, and to the testes, were calculated from ratios determined from the dose factors given in ICRP 34 (1982) and measurements by (Rising and Soldat 1959).
2/1/46 to 4/21/1959	14” × 17” Lat chest X-ray with 2.5-mm Al filter and a measured ESE of 198 mR. Absorbed dose in Gy determined by 198 mR/100mGy per mR = 1.98 mGy and 1.98 mGy/1000mGy per 1 Gy = 0.00198 Gy. This value in Gy is used with Table 3-3 DFs (mGy per Gy air kerma for a beam quality for 2.5 mm Al HVL) to determine organ doses in Table 3-6 for the listed organs in ICRP Publication 34. Doses to Ovaries and testes are calculated from measurements (Rising & Soldat 1959).
4/12/59 to 1/28/1983	14” × 17” Lat chest X-ray with 2.5-mm Al filter and a measured ESE of 100 mR. Absorbed dose in Gy determined by 100 mR/100mGy per mR = 1.00 mGy and 1.00 mGy/1000mGy per 1 Gy = 0.0010 Gy. This value in Gy is used with Table 3-3 DFs (mGy per Gy air kerma for a beam quality for 2.5 mm Al HVL). to determine organ doses in Table 3-7 for the listed organs in ICRP Publication 34. Doses to ovaries and testes are calculated from measurements (Rising & Soldat 1959) .

1/28/1983 to 3/30/1990	14" × 17" PA chest X-ray with 4.0-mm Al filter and a measured ESE of 88 mR. Absorbed dose in Gy determined by 88 mR/100mGy per mR = 0.88 mGy and 0.88 mGy/1000mGy per 1 Gy = 0.00088 Gy. This value in Gy is used with Table 3-4 DFs (mGy per Gy air kerma for a beam quality for 4.0 mm Al HVL) to determine organ doses in Table 3-8 for the listed organs in ICRP Publication 34.
3/30/1990 to 4/22/1997	14" × 17" PA chest X-ray with 4.0-mm Al filter and a measured ESE of 53 mR. Absorbed dose in Gy determined by 53 mR/100mGy per mR = 0.53 mGy and 0.53 mGy/1000mGy per 1 Gy = 0.00053 Gy. This value in Gy is used with Table 3-4 DFs (mGy per Gy air kerma for a beam quality for 4.0 mm Al HVL) to determine doses for the listed organs in ICRP Publication 34.
4/27/1997 to 2/4/1998	14" × 17" PA chest X-ray with 4.0-mm Al filter and a measured ESE of 43 mR. Absorbed dose in Gray determined by 43 mR/100mGy per mR = 0.43 mGy and 0.43 mGy/1000mGy per 1 Gy = 0.00043 Gy. This value in Gy is used with Table 3-4 DFs (mGy per Gy air kerma for a beam quality for 4.0 mm Al HVL) to determine organ doses in Table 3-10 for the listed organs in ICRP Publication 34.
42/4/1998 to Present	14" × 17" PA chest X-ray with 4.0-mm Al filter and a measured ESE of 28 mR. Absorbed dose in Gy determined by 28 mR/100mGy per mR = 0.28 mGy and 0.28 mGy/1000mGy per 1 Gy = 0.00028 Gy. This value in Gy is used with Table 3-4 DFs (mGy per Gy air kerma for a beam quality for 4.0 mm Al HVL).to determine organ doses in Table 3-11 for the listed organs in ICRP Publication 34.

3.3.3 Chest Photofluorography

For a relatively short period beginning in March 1945, when fluoroscopic equipment was received at Hanford, 4" × 5" photofluorographic chest films were taken at the Site (Cantril 1946). The potential for high exposure from this procedure was recognized by Herbert Parker, who, citing studies done in 1943 and 1945, noted that the ESE was about 1 R but could be as much as 2.5 R (Parker 1947). The measured value for ESE of 1.51 R for 4" × 5" chest photofluoroscopy (Kirklin et al. 1969) is fully consistent with the value of 1.53 R observed by Parker and probably a reasonably accurate representation of the average worker dose. However, in keeping with the principle of claimant favorability, the higher ratio of 1.53 was used for dose calculations.

Organ Dose Calculation Methods – Chest Photofluorography

The organ doses for photofluorography chest radiography were determined using a measured ESE value of 1.53 R for 4" × 5"chest photofluorography (Kirklin et al.1969). Organ doses were calculated using the exposure expressed as ESE and were made in accordance with conversion coefficients in Tables A2 through A9 of ICRP Publication 34 (ICRP 1982). These tables list organ doses based on an SID of 183 cm for chest radiography. Photofluorography was accomplished with an SID of 40 inches or 102 cm. Given the geometric considerations regarding divergence of the beam as discussed in ICRP Publication 34 (pp. 23ff), this difference in distance would have a negligible effect on organ doses and, therefore, the values listed in Tables A2 to A9 are appropriate for chest photofluorography. Because absorbed organ dose for radiographs are a function of beam quality, an HVL of 2.5 mm Al was used for dose determination.

The following method was used to calculate the dose in Gy for the period from March 1945 to January 31, 1962, using the measured dose of 1.53 R.

March 1945 to 1/31/62	4" × 5" photofluorographic chest X-ray with 2.5-mm Al filter and a measured ESE of 1.53 R. Absorbed dose in Gy determined by 1530 mR/100 mGy per mR = 15.30 mGy and 15.30 mGy/1000 mGy per 1 Gy = 0.0153 Gy. This value in Gy is used with Table 3-12.DFs (mGy per Gy air kerma for a beam quality for 2.5 mm Al HVL) to determine organ doses in Table 3-13 for the listed organs in ICRP Publication 34. Doses to ovaries and testes are calculated from measurements (Rising & Soldat 1959).

3.4 UNCERTAINTY ANALYSIS FOR HANFORD RADIOGRAPHY DOSES

Error (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) provide 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. Therefore, the more appropriate factor is uncertainty, which is expressed in terms of a confidence level (e.g., 99% -- that the correct or true value, although not actually known, has a 99% probability of falling within the range cited) and includes both precision or reproducibility of the measurement and accuracy, or how close the measurement or estimate of dose comes to the actual or correct value.

In theory a large number of factors can introduce uncertainties or affect the X-ray machine output intensity and dose to the worker. However, because X-ray doses at Hanford were derived largely from actual beam intensity measurements, in practice only five factors can be reasonably considered to have an impact on dose uncertainty:

1. Measurement error
2. Variation in applied kilovoltage
3. Variation in beam current
4. Variation in exposure time
5. Distance from the worker to the source of the X-rays (SSD)

The influence of such other factors as use of screens, grids, reciprocity failure, film speed, and development, while potentially variable, would not affect the beam output intensity.

X-ray doses at Hanford were largely derived from actual measurement of X-ray machine output with R-meters or similar ionization chamber devices; if properly calibrated and used, these typically and historically have had an uncertainty of $\pm$ 2% for photon energies below 400 keV (Kathren and Larson 1969). Although more recent versions of these instruments might provide a somewhat smaller uncertainty, perhaps on the order of $\pm$ 1% (NBS 1985, 1988), for conservatism, the uncertainty range of $\pm$ 2% should be applied to measurements of X-ray intensity at Hanford.

Theoretically, for a given set of machine settings and parameters, X-ray output should be constant and unvarying. However, this is not true in practice, although output is essentially constant unless focal spot loading occurs, as might be the case when the power rating of the machine is exceeded. It is unlikely that power ratings were ever exceeded because such an event would be difficult to achieve in practice and could result in damage to the X-ray tube. However, even with the use of constant voltage transformers to control line voltages, slight variations might occur in line voltage input or other internal voltages, which in turn could alter the kVp of the output beam. In general, for a given kVp setting, variation in kVp falls within $\pm$ 5% of the machine setting (Seibert et al. 1991). As noted above, beam intensity is approximately proportional to the 1.7 power of the kilovoltage; this translates to an uncertainty of approximately ± 8.6% with respect to output beam intensity in the 80 to 100 kVp used for diagnostic radiographs at Hanford. For conservatism, this is rounded up to $\pm$ 9%.

Similarly slight variations in tube current are normal; as a tube ages, or heats up from use, current can change and typically will drop. With all other factors constant, beam intensity 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 percent under normal operating conditions; large decreases are readily detectable and result in maintenance on the machine to restore the output or, as a temporary measure, an increase in the current or kVp to provide the necessary intensity for proper radiography. There is no evidence to suggest that such temporary measures were ever necessary or applied at Hanford. For a given kVp setting, the output of the beam is a function of the tube current, which in turn is measured by a milliammeter, which measures average tube current. The measurement is subject to uncertainties; there might be minor changes in output as the tube heats from normal use. Because these variations are typically small, the estimated uncertainty in beam output attributable to current variation is ± 5%.

Another parameter that has potential to affect the dose from a diagnostic radiograph, perhaps significantly, relates to the time of exposure. A full wave rectified machine produces 120 pulses per second of X-rays. In 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; accuracy improved significantly with the introduction of electronic timers. Other than measurements of reproducibility made in the late 1980s and beyond by the State of Washington, there are no data on which to base an evaluation of the accuracy and precision of the timers on Hanford X-ray machines. The measurements made by the State suggest that the timers, and indeed the entire X-ray output, were fairly constant. However, for conservatism, the assumed uncertainty in beam output attributable to timers has an upper limit of ± 25%.

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

There are two approaches to determine the combined uncertainty from the five potential sources of dose uncertainty listed above. The first, and most conservative in that it gives the greatest range, would be to assume that the uncertainties are additive, which would give an uncertainty range of 2 + 9 +5 + 25 + 10 = + 51%. 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 ± 28.9%. Rounding this up to ± 30% would seem to provide an adequate and suitably conservative indication of uncertainty. Thus, for an individual ESE or derived organ dose, an uncertainty of ± 30% can be assumed; for further conservatism it might be appropriate to assume that errors are all positive, and only + 30% should be used.

Table 3-1. Relationship of beam intensity and various technical factors.

Parameter	Units	Relationship with Intensity
Applied voltage	kVp	Intensity proportional to 1.7 power of kVp
Tube current	mA	Linear
Exposure time	s	Linear
Filtration	mm Al	Intensity decreases by ~40% for each additional mm Al
Worker Size (chest thickness)	25-27 mm > 27 mm	Dose increased by factor of 1.5 Dose increased by factor of 2
Distance	d	Approximately inverse square relations ($1/d^2$)
Uncertainty	$\pm$ 30 %	Assume all errors are positive, + 30% should be used

Table 3-2. Summary of beam parameters for 14" × 17 " PA chest radiography.

Date Measured	10/18/1999	2/04/98	4/22/1997	11/11/1993	3/30/1990	1/21/1988	1/20/1988	1/28/1983	4/12/1959	2/1/1946	Before 2/46
Procedure	Chest PA 14"×17"	Chest PA 14"×17"	Chest PA 14"×17"	Chest PA 14"×17"	Chest PA 14"×17"	Chest PA 14"×17"	Chest PA 14"×17"	Chest PA 14"×17"	Chest PA 14"×17"	Chest PA 14"×17"	Chest PA 14"×17"
Machine type	XMA - 360	XMA - 360	CONXI Type 12	CONX Type 12	CONX Type 12	CONX Type 12	CONX Type 12	G.E. DXR 750	Unknown	Unknown	Unknown
Machine settings kVp:	110	110	110	110	110	110	110	100	80	80	Unknown
mA	300	300	300	200	200	200	100	200	300	500	Unknown
Exposure time	1/60 sec	1/60 sec	1/30 sec	1/30 sec	1/30 sec	1/20 sec	1/10 sec	1/20 sec	1/30 sec	1/20 sec	Unknown
mAs	5	5	10	6.7	6.7	10	10	10	10	25	Unknown
Added filter	2.7 mm	2.7 mm	2.5 mm	2.5 mm	2.5 mm	2.5 mm	2.5 mm	2.5 mm	1.5 mm	1.5 mm	1.5 mm
Filtration used for calcs.	4.0 mm	4.0 mm	4.0 mm	4.0 mm	4.0 mm	4.0 mm	4.0 mm	2.5 mm	2.5 mm	2.5 mm	2.5 mm
Source to skin distance	72"	72"	72 "	72 "	72 "	72 "	72 "	72 "	72 "	72 "	72 "
Entrance skin exposure	11 mR	11 mR	17 mR	21mR	21 mR (Assumed)	35 mR	35 mR	35 mR	40 mR	79 mR	120 mR
mR/mAs	2.2	2.2	1.7	3.3	3.3	3.5	3.5	3.5	4	3.2	Unknown
Date range		2/98 to date	4/97 to 2/98		3/90 to 4/97			1/83 to 3/90	4/59 to 1/83	2/46 to 4/59	
Reference	Washington State Dept. of Health Measurement	Washington State Dept. of Health Measurement	Washington State Dept. of Health Measurement	Washington State Dept. of Health Measurement	Measured at 11.7 mR by State. The 1993 value used as it was higher for same settings& machine.	Washington State Dept. Of Health Measurement	Washington State Dept. of Health Measurement	Kathren to Heid memorandum Dated 1/28/83	Rising & Soldat letter to Norwood dated 4/30/59	Mancuso et al. Dated 1966	Based on experience & references of early 1940s x-ray dose. Assumed for Hanford.

Table.3- 3. Average absorbed chest X-ray dose (mGy) for selected organs for 1 Gy entrance kerma (air kerma without backscatter) for a beam quality of 2.5 mm aluminum (HVL).[a]

Organ	View	Source-image distance(cm)	Image receptor size (cm)	Dose conversion factor (mGy per Gy air kerma) (beam quality 2.5 mm aluminum HVL)
Thyroid	PA	183	35.6 × 43.2	32
	Lat.	183	35.6 × 43.2	115
Ovaries	PA	183	35.6 × 43.2	1
	Lat.	183	35.6 × 43.2	0.6
Testes	PA	183	35.6 × 43.2	0.01
	Lat.	183	35.6 × 43.2	0.1
Lungs (male)	PA	183	35.6 × 43.2	419
	Lat.	183	35.6 × 43.2	193
Lungs (female)	PA	183	35.6 × 43.2	451
	Lat.	183	35.6 × 43.2	220
Breast	PA	183	35.6 × 43.2	49
	Lat.	183	35.6 × 43.2	255
Uterus	PA	183	35.6 × 43.2	1.3
	Lat.	183	35.6 × 43.2	0.6
Bone marrow (male)	PA	183	35.6 × 43.2	92
	Lat.	183	35.6 × 43.2	37
Bone marrow (female)	PA	183	35.6 × 43.2	86
	Lat.	183	35.6 × 43.2	29
Total body (male)	PA	183	35.6 × 43.2	131
	Lat. [(b)]	183	35.6 × 43.2	64
Total body (female)	PA	183	35.6 × 43.2	118
	Lat.	183	35.6 × 43.2	60

a. Dose conversion factors from Tables A.2 through A.9 (ICRP 1982).
b. The values for lateral x-rays in Table A9 of ICRP (1982) for the 2.5-mm Al HVL beam quality appear to be switched. All other values show a higher total body dose for male relative to female. The female-male dose factors for 2.5-mm Al HVL were changed to agree with the factors listed for other HVLs.

Table 3-4. Average absorbed chest X-ray dose (mGy) for selected organs for 1 Gy entrance kerma (air kerma without backscatter) for a beam quality of 4.0 mm aluminum (HVL).[a]

Organ	View	Source-image distance (cm)	Image receptor size (cm)	Dose conversion factor (mGy per Gy air kerma) (beam quality 4.0 mm of aluminum HVL)
Thyroid	PA	183	35.6 × 43.2	78
	Lat.	183	35.6 × 43.2	164
Ovaries	PA	183	35.6 × 43.2	5.2
	Lat.	183	35.6 × 43.2	2.5
Testes	PA	183	35.6 × 43.2	0.01
	Lat.	183	35.6 × 43.2	0.1
Lungs (male)	PA	183	35.6 × 43.2	628
	Lat.	183	35.6 × 43.2	313
Lungs (female)	PA	183	35.6 × 43.2	674
	Lat.	183	35.6 × 43.2	351
Breast	PA	183	35.6 × 43.2	116
	Lat.	183	35.6 × 43.2	343
Uterus	PA	183	35.6 × 43.2	5.2
	Lat.	183	35.6 × 43.2	2.1
Bone marrow (male)	PA	183	35.6 × 43.2	178
	Lat.	183	35.6 × 43.2	76
Bone marrow (female)	PA	183	35.6 × 43.2	172
	Lat.	183	35.6 × 43.2	59
Total body (male)	PA	183	35.6 × 43.2	192
	Lat.	183	35.6 × 43.2	106
Total body (female)	PA	183	35.6 × 43.2	178
	Lat.	183	35.6 × 43.2	99

a. Dose conversion Factors from Tables A.2 through A.9 (ICRP 1982).

Table 3-5. Organ dose estimates for Hanford chest radiographs before 2/1/1946.

Organ	View	Organ dose (mGy)	Organ dose (rem)
Thyroid	PA	3.84E-02	3.84E-03
	Lat.	3.45E-01	3.45E-02
Ovaries [(a)]	PA	2.60E-02	2.60E-03
	Lat.	2.93E-02	2.93E-03
Testes [(a)]	PA	7.47E-04	7.47E-05
	Lat.	1.31E-04	1.31E-05
Lungs (male)	PA	5.03E-01	5.03E-02
	Lat.	5.79E-01	5.79E-02
Lungs (female)	PA	5.41E-01	5.41E-02
	Lat.	6.60E-01	6.60E-02
Breast	PA	5.88E-02	5.88E-03
	Lat.	7.65E-01	7.65E-02
Uterus	PA	1.56E-03	1.56E-04
	Lat.	1.80E-03	1.80E-04
Bone marrow (male)	PA	1.10E-01	1.10E-02
	Lat.	1.11E-01	1.11E-02
Bone marrow (female)	PA	1.03E-01	1.03E-02
	Lat.	8.70E-02	8.70E-03
Total body (male)	PA	1.57E-01	1.57E-02
	Lat.	1.92E-01	1.92E-02
Total body (female)	PA	1.42E-01	1.42E-02
	Lat.	1.80E-01	1.80E-02

a. Doses were calculated from measurements (Rising and Soldat 1959).

Table 3-6. Organ dose estimates for Hanford chest radiographs from 2/1/46 to 4/12/59

Organ	View	Organ Dose (mGy)	Organ Dose (rem)
Thyroid	PA	2.53E-02	2.53E-03
	Lat.	2.28E-01	2.28E-02
Ovaries [(a)]	PA	1,71E-02	1.71E-03
	Lat.	1.95E-02	1.95E-03
Testes [(a)]	PA	5.79E-04	5.79E-05
	Lat.	6.63E-04	6.63E-05
Lungs (male)	PA	3.31E-01	3.31E-02
	Lat.	3.82E-01	3.82E-02
Lungs (female)	PA	3.56E-01	3.56E-02
	Lat.	4.36E-01	4.36E-02
Breast	PA	3.87E-02	3.87E-03
	Lat.	5.05E-01	5.05E-02
Uterus	PA	1.03E-03	1.03E-04
	Lat.	1.19E-03	1.19E-04
Bone marrow (male)	PA	7.27E-02	7.27E-03
	Lat.	7.33E-02	7.33E-03
Bone marrow (female)	PA	6.79E-02	6.79E-03
	Lat.	5.74E-02	5.74E-03
Total body (male)	PA	1.03E-01	1.03E-02
	Lat.	1.27E-01	1.27E-02
Total body (female)	PA	9.32E-02	9.32E-03
	Lat.	1.19E-01	1.19E-02

a. Doses were calculated from measurements (Rising and Soldat 1959).

Table 3-7. Organ dose estimates for Hanford chest radiographs from 4/12/59 to 1/28/83.

Organ	View	Organ dose (mGy)	Organ dose (rem)
Thyroid	PA	1.28E-02	1.28E-03
	Lat.	1.15E-01	1.15E-02
Ovaries [(a)]	PA	8.67E-03	8.67E-04
	Lat.	1.31E-02	1.31E-03
Testes [(a)]	PA	2.93E-04	2.93E-05
	Lat.	4.42E-04	4.42E-05
Lungs (male)	PA	1.68E-01	1.68E-02
	Lat.	1.93E-01	1.93E-02
Lungs (female)	PA	1.80E-01	1.80E-02
	Lat.	2.20E-01	2.20E-02
Breast	PA	1.96E-02	1.96E-03
	Lat.	2.55E-01	2.55E-02
Uterus	PA	5.20E-04	5.20E-05
	Lat.	6.00E-04	6.00E-05
Bone marrow (male)	PA	3.68E-02	3.68E-03
	Lat.	3.70E-02	3.70E-03
Bone marrow (female)	PA	3.44E-02	3.44E-03
	Lat.	2.90E-02	2.90E-03
Total body (male)	PA	5.24E-02	5.24E-03
	Lat.	6.40E-02	6.40E-03
Total body (female)	PA	4.72E-02	4.72E-03
	Lat.	6.00E-02	6.00E-03

a. Doses were calculated from measurements (Rising and Soldat 1959).

Table 3-8. Organ dose estimates for Hanford chest radiographs from 1/28/83 to 3/30/90.

Organ	View	Organ dose (mGy)	Organ dose (rem)
Thyroid	PA	2.73E-02	2.73E-03
	Lat.	1.44E-01	1.44E-02
Ovaries	PA	1.82E-03	1.82E-04
	Lat.	2.20E-03	2.20E-04
Testes	PA	3.50E-06	3.50E-07
	Lat.	8.80E-05	8.80E-06
Lungs (male)	PA	2.20E-01	2.20E-02
	Lat.	2.75E-01	2.75E-02
Lungs (female)	PA	2.36E-01	2.36E-02
	Lat.	3.09E-01	3.09E-02
Breast	PA	4.06E-02	4.06E-03
	Lat.	3.02E-01	3.02E-02
Uterus	PA	1.82E-03	1.82E-04
	Lat.	1.85E-03	1.85E-04
Bone Marrow (male)	PA	6.23E-02	6.23E-03
	Lat.	6.69E-02	6.69E-03
Bone Marrow (female)	PA	6.02E-02	6.02E-03
	Lat.	5.19E-02	5.19E-03
Total Body (male)	PA	6.72E-02	6.72E-03
	Lat.	9.33E-02	9.33E-03
Total Body (female)	PA	6.23E-02	6.23E-03
	Lat.	8.71E-02	8.71E-03

Table 3-9. Organ dose estimates for Hanford chest radiographs from 3/30/90 to 4/22/97.

Organ	View	Organ dose (mGy)	Organ dose (rem)
Thyroid	PA	1.64E-02	1.64E-03
	Lat.	8.69E-02	8.69E-03
Ovaries	PA	1.09E-03	1.09E-04
	Lat.	1.33E-03	1.33E-04
Testes	PA	2.10E-06	2.10E-07
	Lat.	5.30E-05	5.30E-06
Lungs (male)	PA	1.32E-01	1.32E-02
	Lat.	1.66E-01	1.66E-02
Lungs (female)	PA	1.42E-01	1.42E-02
	Lat.	1.86E-01	1.86E-02
Breast	PA	2.44E-02	2.44E-03
	Lat.	1.82E-01	1.82E-02
Uterus	PA	1.09E-03	1.09E-04
	Lat.	1.11E-03	1.11E-04
Bone marrow (male)	PA	3.74E-02	3.74E-03
	Lat.	4.03E-02	4.03E-03
Bone marrow (female)	PA	3.61E-02	3.61E-03
	Lat.	3.13E-02	3.13E-03
Total body (male)	PA	4.03E-02	4.03E-03
	Lat.	5.62E-02	5.62E-03
Total body (female)	PA	3.74E-02	3.74E-03
	Lat.	5.25E-02	5.25E-03

Table 3-10. Organ dose estimates for Hanford chest radiographs from 4/22/97 to 2/4/98.

Organ	View	Organ dose (mGy)	Organ dose (rem)
Thyroid	PA	1.33E-02	1.33E-03
	Lat.	7.05E-02	7.05E-03
Ovaries	PA	8.84E-04	8.84E-05
	Lat.	1.08E-03	1.08E-04
Testes	PA	1.70E-06	1.70E-07
	Lat.	4.30E-05	4.30E-06
Lungs (male)	PA	1.07E-01	1.07E-02
	Lat.	1.35E-01	1.35E-02
Lungs (female)	PA	1.15E-01	1.15E-02
	Lat.	1.51E-01	1.51E-02
Breast	PA	1.97E-02	1.97E-03
	Lat.	1.47E-01	1.47E-02
Uterus	PA	8.84E-04	8.84E-05
	Lat.	9.03E-04	9.03E-05
Bone marrow (male)	PA	3.03E-02	3.03E-03
	Lat.	3.27E-02	3.27E-03
Bone marrow (female)	PA	2.92E-02	2.92E-03
	Lat.	2.54E-02	2.54E-03
Total body (male)	PA	3.26E-02	3.26E-03
	Lat.	4.56E-02	4.56E-03
Total body (female)	PA	3.03E-02	3.03E-03
	Lat.	4.26E-02	4.26E-03

Table 3-11. Organ dose estimates for Hanford chest radiographs from 2/4/98 to present.

Organ	View	Organ dose (mGy)	Organ dose (rem)
Thyroid	PA	8.58E-03	8.58E-04
	Lat.	4.59E-02	4.59E-03
Ovaries	PA	5.72E-04	5.72E-05
	Lat.	7.00E-04	7.00E-05
Testes	PA	1.10E-06	1.10E-07
	Lat.	2.80E-05	2.80E-06
Lungs (male)	PA	6.91E-02	6.91E-03
	Lat.	8.76E-02	8.76E-03
Lungs (female)	PA	7.41E-02	7.41E-03
	Lat.	9.83E-02	9.83E-03
Breast	PA	1.28E-02	1.28E-03
	Lat.	9.60E-02	9.60E-03
Uterus	PA	5.72E-04	5.72E-05
	Lat.	5.88E-04	5.88E-05
Bone marrow (male)	PA	1.96E-02	1.96E-03
	Lat.	2.13E-02	2.13E-03
Bone marrow (female)	PA	1.89E-02	1.89E-03
	Lat.	1.65E-02	1.65E-03
Total body (male)	PA	2.11E-02	2.11E-03
	Lat.	2.97E-02	2.97E-03
Total body (female)	PA	1.96E-02	1.96E-03
	Lat.	2.77E-02	2.77E-03

Table 3-12. Average absorbed dose from chest photofluorography (mGy) for selected organs for 1 Gy entrance kerma (air kerma without backscatter) for a beam quality of 2.5 mm aluminum (HVL).[a]

Organ	View	Source-Image Distance(cm)	Image Receptor Size (cm)	Dose conversion factor (mGy per Gy air kerma) (beam quality 2.5 mm aluminum HVL)
Thyroid	Photo	102	10.2 × 12.7	32
Ovaries	Photo	102	10.2 × 12.7	1
Testes	Photo	102	10.2 × 12.7	0.01
Lungs (male)	Photo	102	10.2 × 12.7	419
Lungs (female)	Photo	102	10.2 × 12.7	451
Breast	Photo	102	10.2 × 12.7	49
Uterus	Photo	102	10.2 × 12.7	1.3
Bone marrow (male)	Photo	102	10.2 × 12.7	92
Bone marrow (female)	Photo	102	10.2 × 12.7	86
Total body (male)	Photo	102	10.2 × 12.7	131
Total body (female)	Photo	102	10.2 × 12.7	118

a. Dose conversion Factors from Tables A.2 through A.9, ICRP Publication 34 (1982).

Table 3-13. Organ dose estimates for Hanford photofluorography March 1945 to 1/31/1962.

Organ	View	Organ dose (mGy)	Organ dose (rem)
Thyroid	Photo	4.90E-01	4.90E-02
Ovaries [(a)]	Photo	6.85E-02	6.85E-03
Testes [(a)]	Photo	4.80E-03	4.80E-04
Lungs (male)	Photo	6.41E+00	6.41E-01
Lungs (female)	Photo	6.90E+00	6.90E-01
Breast	Photo	7.50E-01	7.50E-02
Uterus	Photo	1.99E-02	1.99E-03
Bone marrow (male)	Photo	1.41E+00	1.41E-01
Bone marrow (female)	Photo	1.32E+00	1.32E-01
Total body (male)	Photo	2.00E+00	2.00E-01
Total body (female)	Photo	1.81E+00	1.81E-01

a. Ovaries and associated organ doses and testes doses for Before 2/1/1946 – 1/28/83 were calculated based on measurements (Rising and Soldat 1959).

Table 3-14. Summary of parameters and organ doses for Hanford 14" × 17" PA chest radiography.

Time period	Frequency	Applicability	PA Chest mR ESE[a]	Organ doses (rem) from 14" × 17" PA chest radiography								
				Thyroid [d]	Ovaries [d]	Testes [d]	Lungs [d]	Breast [d]	Uterus (Embryo) [d]	Bone marrow [d]	WB [d]	Remainder
Before 2/1/1946	Entrance Exit Annual	All	120	3.84E-03	2.60E-03 [e]	7.47E-05 [e]	Male 5.03E-02 Female 5.41E-02	5.88E-03	1.56E-04	Male 1.10E-02 Female 1.03E-02	Male 1.57E-02 Female 1.42E-02	Male 1.57E-02 Female 1.42E-02
2/1/46 to 4/12/1959	Entrance Exit Annual	All	79	2.53E-03	1.71E-03	5.79E-05	Male 3.31E-02 Female 3.56E-02	3.87E-03	1.03E-04	Male 7.27E-03 Female 6.79E-03	Male 1.03E-02 Female 9.32E-03	Male 1.03E-02 Female 9.32E-03
4/12/59 to 1/28/1983	Entrance(c) Exit Annual[b]	Over 50 years old	40	1.28E-03	8.67E-04	2.93E-05	Male 1.68E-02 Female 1.80E-02	1.96E-03	5.20E-05	Male 3.68E-03 Female 3.44E-03	Male 5.24E-03 Female 4.72E-03	Male 5.24E-03 Female 4.72E-03
	Biennial[b]	40-49 years old										
	Every 3rd year[b]	Under 40 years old										
1/28/83 to 3/30/1990	Biennial	Over 50 years old	35	2.73E-03	1.82E-04	3.50E-07	Male 2.20E-02 Female 2.36E-02	4.06E-03	1.82E-04	Male 6.23E-03 Female 6.02E-03	Male 6.72E-03 Female 6.23E-03	Male 6.72E-03 Female 6.23E-03
	Every 3rd year	40-49 years old										
	Every 5th year	Under 40 years old										
3/30/90 to 4/22/97	Every 5th year	All	21	1.64E-03	1.09E-04	2.10E-07	Male 1.32E-02 Female 1.42E-02	2.44E-03	1.09E-04	Male 3.74E-03 Female 3.61E-03	Male 4.03E-03 Female 3.74E-03	Male 4.03E-03 Female 3.74E-03
4/22/97 to 2/4/98	Every 5th year	All	17	1.33E-03	8.84E-05	1.70E-07	Male 1.07E-02 Female 1.15E-02	1.97E-03	8.84E-05	Male 3.03E-03 Female 2.92E-03	Male 3.26E-03 Female 3.03E-03	Male 3.26E-03 Female 3.03E-03
2/4/98 to present	Every 5th year	All	11	8.58E-04	5.72E-05	1.10E-07	Male 6.91E-03 Female 7.41E-03	1.28E-03	5.72E-05	Male 1.96E-03 Female 1.89E-03	Male 2.11E-03 Female 1.96E-03	Male 2.11E-03 Female 1.96E-03

a. Entrance skin exposure in mR.
b. Beginning January 4, 1982, protocol was biennial after age 45, and every 5 years for all others (Fuqua 1981).
c. Entrance and exit X-rays were provided from 1941 to mid 1990 (Vail 1990). These X-rays were not required after 1990 unless personnel were in a job class that required an X-ray or clinical needs were indicated.
d. Organs identified in ICRP (1982) for dose determination from ESE associated with chest radiography.
e. Ovaries and associated organ doses and testes doses from before 2/1/1946 – 1/28/83 were calculated based on measurements doses (Rising and Soldat 1959).

Table 3-14. (Continued) Summary of dose for IREP organs not listed in ICRP 34 (1982).

Time period	Frequency	Applicability	PA Chest mR ESE[a]	Organ doses (rem) from 14" × 17" PA chest radiography									
				Thymus	Esophagus	Stomach	Bone surface	Liver/gall bladder	Urinary/ bladder	Colon & rectum		Eye & brain	Skin [d]
Before 2/1/46	Entrance Exit Annual	All	120	Male 5.03E-02 Female 5.41E-02	Male 5.03E-02 Female 5.41E-02	Male 5.03E-02 Female 5.41E-02	Male 5.03E-02 Female 5.41E-02	2.60E-03	2.60E-03	2.60E-03	-	3.84E-03	1.62E-01
2/1/46 to 4/12/59	Entrance Exit Annual	All	79	Male 3.31E-02 Female 3.56E-02	Male 3.31E-02 Female 3.56E-02	Male 3.31E-02 Female 3.56E-02	Male 3.31E-02 Female 3.56E-02	1.71E-03	1.71E-03	1.71E-03	-	2.53E-03	1.07E-01
4/12/59 to 1/28/83	Entrance(c) Exit Annual[b]	Over 50 years old									-		
	Biennial[b]	40-49 years old		Male 1.68E-02	Male 1.68E-02	Male 1.68E-02	Male 1.68E-02	8.67E-04	8.67E-04	8.67E-04	-		
	Every 3rd year[b]	Under 39 years old	40	Female 1.80E-02	Female 1.80E-02	Female 1.80E-02	Female 1.80E-02				-	1.28E-03	5.40E-02
1/28/83 to 3/30/90	Biennial	Over 50 years old									-		
	Every 3rd year	40-49 years old		Male 2.20E-02	Male 2.20E-02	Male 2.20E-02	Male 2.20E-02				-		
	Every 5th year	Under 39 years old	35	Female 2.36E-02	Female 2.36E-02	Female 2.36E-02	Female 2.36E-02	1.82E-04	1.82E-04	1.82E-04	-	2.73E-03	4.90E-02
3/30/90 to 4/22/97	Every 5th year	All	21	Male 1.32E-02 Female 1.42E-02	Male 1.32E-02 Female 1.42E-02	Male 1.32E-02 Female 1.42E-02	Male 1.32E-02 Female 1.42E-02	1.09E-04	1.09E-04	1.09E-04	- -	1.64E-03	2.94E-02
4/22/97 to 2/4/98	Every 5th year	All	17	Male 1.07E-02 Female 1.15E-02	Male 1.07E-02 Female 1.15E-02	Male 1.07E-02 Female 1.15E-02	Male 1.07E-02 Female 1.15E-02	8.84E-05	8.84E-05	8.84E-05	- -	1.33E-03	2.38E-02
2/4/98 to Present	Every 5th year	All	11	Male 6.91E-03 Female 7.41E-03	Male 6.91E-03 Female 7.41E-03	Male 6.91E-03 Female 7.41E-03	Male 6.91E-03 Female 7.41E-03	5.72E-05	5.72E-05	5.72E-05	- -	8.58E-04	1.54E-02

a. Entrance skin exposure in mR.
b. Beginning January 4, 1982, protocol was biennial after age 45, and every 5 years for all others (Fuqua 1981).
c. Entrance and exit X-rays were provided from 1941 to mid 1990 (Vail 1990). These X-rays were not required after 1990 unless personnel were in a job class that required an X-ray or clinical needs were indicated.
d. Skin dose was determined by multiplying the ESE by the backscatter factors of 1.35 and 1.4 (for HVLs of 2.4 and 4.0 mm Al respectively) from ICRP (1985), Table B-8.

Table 3-15. Summary of parameters and organ doses for Hanford lateral chest radiography.

Time period	Frequency	Applicability	Lateral chest mR ESE[a]	Organ doses (rem) from lateral chest X-ray								
				Thyroid [d]	Ovaries [d]	Testes [d]	Lungs [d]	Breast [d]	Uterus (Embryo) [d]	Bone marrow [d]	WB [d]	Remainder
Before 2/1/1946	Annual	All	300	3.45E-02	– 2.93E-03 [e]	– 1.31E-05 [e]	Male 5.79E-02 Female 6.60E-02	7.65E-02	1.80E-04	Male 1.11E-02 Female 8.70E-03	Male 1.92E-02 Female 1.80E-02	Male 1.92E-02 Female 1.80E-02
2/1/46 to 4/12/59	Annual	All	198	2.28E-02	1.95E-03 – –	6.63E-05 – –	Male 3.82E-02 Female 4.36E-02	5.05E-02	1.19E-04	Male 7.33E-03 Female 5.74E-03	Male 1.27E-02 Female 1.19E-02	Male 1.27E-02 Female 1.19E-02
4/12/59 to 1/28/83	Annual	Over 50 years old			– – –	– – –						
	Biennial	40-49 years old					Male 1.93E-02 Female 2.20E-02	2.55E-02	6.00E-05	Male 3.70E-03 Female 2.90E-03	Male 6.40E-03 Female 6.00E-03	Male 6.40E-03 Female 6.00E-03
	Every 3rd year	Under 40 years old	100	1.15E-02	1.31E-03	4.42E-05						
1/28/83 to 3/30/90	Biennial	Over 50 years old										
	Every 3rd year	40-49 years old					Male 2.75E-02 Female 3.09E-02	3.02E-02	1.85E-04	Male 6.69E-03 Female 5.19E-03	Male 9.33E-03 Female 8.71E-03	Male 9.33E-03 Female 8.71E-03
	Every 5th year	Under 40 years old	88	1.44E-02	2.20E-04	8.80E-06						
3/30/90 to 4/22/97	Every 5th year	All	53	8.69E-03	1.33E-04	5.30E-06	Male 1.66E-02 Female 1.86E-02	1.82E-02	1.11E-04	Male 4.03E-03 Female 3.13E-03	Male 5.62E-03 Female 5.25E-03	Male 5.62E-03 Female 5.25E-03
4/22/97 to 2/4/1998	As required	All	43	7.05E-03	1.08E-04	4.30E-06	Male 1.35E-02 Female 1.51E-02	1.47E-02	9.03E-05	Male 3.27E-03 Female 2.54E-03	Male 4.56E-03 Female 4.26E-03	Male 4.56E-03 Female 4.26E-03
2/4/98 to present	As Required	All	28	4.59E-03	7.00E-05	2.80E-06	Male 8.76E-03 Female 9.83E-03	9.60E-03	5.88E-05	Male 2.13E-03 Female 1.65E-03	Male 2.97E-03 Female 2.77E-03	Male 2.97E-03 Female 2.77E-03

a. Entrance skin exposure in mR.
b. Beginning January 4, 1982, protocol was biennial after age 45, and every 5 years for all others (Fuqua 1981).
c. Entrance and exit X-rays were provided from 1941 to mid 1990 (Vail 1990). These X-rays were not required after 1990 unless personnel were in a job class that required an X-ray or clinical needs were indicated.
d. Organs identified in ICRP (1982) for dose determination from ESE associated with chest radiography.
e. Ovaries and associated organ doses and Testes doses from before 2/1/1946 – 1/28/83 were calculated based on measurements (Rising and Soldat1959).

Table 3-15. (Continued) Summary of dose for IREP organs not listed in ICRP 34 (1982).

Time period	Frequency	Applicability	Lateral chest mR ESE[a]	Organ doses (rem) from lateral chest X-ray									
				Thymus	Esophagus	Stomach	Bone surface	Liver/Gall bladder	Urinary/ bladder	Colon & rectum		Eye & brain	Skin [b]
Before 2/1/1946	Annual	All	300	Male 0.0579 Female 6.60E-02	Male 0.0579 Female 6.60E-02	Male 0.0579 Female 6.60E-02	Male 0.0579 Female 6.60E-02	2.93E-03	2.93E-03	2.93E-03		3.45E-02	4.05E-01
2/1/46 to 4/12/59	Annual	All	198	Male 3.82E-02 Female 4.36E-02	Male 3.82E-02 Female 4.36E-02	Male 3.82E-02 Female 4.36E-02	Male 3.82E-02 Female 4.36E-02	1.95E-03 -	1.95E-03 -	1.95E-03 -		2.28E-02	2.67E-01
4/12/59 to 1/28/83	Annual	Over 50 years old						1.31E-03	1.31E-03	1.31E-03			
	Biennial	40-49 years old		Male 1.93E-02 Female 2.20E-02	Male 1.93E-02 Female 2.20E-02	Male 1.93E-02 Female 2.20E-02	Male 1.93E-02 Female 2.20E-02	- -	- -	- -			
	Every	Under 39						-	-	-			
	3rd year	years old	100									1.15E-02	1.35E-01
1/28/83 to 3/30/90	Biennial	Over 50 years old											
	Every 3rd year	40-49 years old		Male 2.75E-02 Female 3.09E-02	Male 2.75E-02 Female 3.09E-02	Male 2.75E-02 Female 3.09E-02	Male 2.75E-02 Female 3.09E-02						
	Every 5th year	Under 39 years old	88					2.20E-04	2.20E-04	2.20E-04		1.44E-02	1.23E-01
3/30/90 to 4/22/97	Every 5th year	All	53	Male 1.66E-02 Female 1.86E-02	Male 1.66E-02 Female 1.86E-02	Male 1.66E-02 Female 1.86E-02	Male 1.66E-02 Female 1.86E-02	1.33E-04	1.33E-04	1.33E-04		8.69E-03	7.42E-02
4/22/97 to 2/4/1998	As required	All	43	Male 1.35E-02 Female 1.51E-02	Male 1.35E-02 Female 1.51E-02	Male 1.35E-02 Female 1.51E-02	Male 1.35E-02 Female 1.51E-02	1.08E-04	1.08E-04	1.08E-04		7.05E-03	6.02E-02
2/4/98 to present	As Required	All	28	Male 8.76E-03 Female 9.83E-03	Male 8.76E-03 Female 9.83E-03	Male 8.76E-03 Female 9.83E-03	Male 8.76E-03 Female 9.83E-03	7.00E-05	7.00E-05	7.00E-05		4.59E-03	3.92E-02

a. Entrance skin exposure in mR.
b. Skin dose was determined by multiplying the ESE by the backscatter factors of 1.35 and 1.4 (for HVLs of 2.5 and 4.0 mm Al, respectively) from NCRP (1985), Table B-8.

Table 3-16 Summary of parameters and organ doses for Hanford 4" × 5" chest photofluorography.

Time period	Frequency	Applicability	Photofluoro-graphic chest ESE[a]	Organ doses (rem) from photofluorographic chest X-ray								
				Thyroid [c]	Ovaries [c]	Testes [c]	Lungs [c]	Breast [d]	Uterus (Embryo) [d]	Bone marrow [d]	WB [d]	Remainder
March 1945 to 1/31/62	Annual & Periodic[b]	All	1530 mR	4.90E-02	6.85E-03 [d]	4.80E-04 [d]	Male 6.41E-01 Female 6.90E-01	7.50E-02	1.99E-03	Male 1.41E-01 Female 1.32E-01	Male 2.00E-01 Female 1.81E-01	Male 2.00E-01 Female 1.81E-01

a. Entrance skin exposure in mR.
b. After March 1945 until June 1, 1957, some classes of workers received photofluorographic exams every 4 to 6 weeks, some received stereoscopic exams, requiring two exams for better resolution. Some were on a 6-month schedule if they did not work around radioactive material.
c. Organs identified in ICRP (1982) for dose determination from ESE associates with chest radiography.
d. Ovaries and associated organ doses and testes doses from before 2/1/1946 – 1/28/83 were calculated based on measurements (Rising and Soldat 1959).

Table 3-16.(Continued) Summary of dose for IREP organs not listed in ICRP 34 (1982).

Time period	Frequency	Applicability	Photofluoro-graphic chest ESE[a]	Organ doses (rem) from photofluorographic chest X-ray									
				Thymus	Esophagus	Stomach	Bone surface	Liver/gall bladder	Urinary/ bladder	Colon & rectum		Eye & brain	Skin [c]
March 1945 to 1/31/62	Annual & Periodic[b]	All	1530 mR	Male 6.41E-01 Female 6.90E-01	Male 6.41E-01 Female 6.90E-01	Male 6.41E-01 Female 6.90E-01	Male 6.41E-01 Female 6.90E-01	6.85E-03	6.85E-03	6.85E-03		4.90E-02	2.07E+00

a. Entrance skin exposure in mR.
b. After March 1945 until June 1, 1957, some classes of workers received photofluorographic exams every 4 to 6 weeks, some received stereoscopic exams, requiring two exams for better resolution. Some were on a 6-month schedule if they did not work around radioactive material.
c. Skin dose was determined by multiplying ESE by the backscatter factor of 1.35 for an HVL of 2.5 mm Al, from NCRP (1985), Table B-8.

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