ORAU Team **Dose Reconstruction Project for NIOSH** Pinellas Plant - Occupational Medical Dose	Document Number: ORAUT-TKBS-0029-3 Effective Date: 07/04/2006 Revision No.: 00 PC-1 Controlled Copy No.: _____ Page 1 of 23
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ACRONYMS AND ABBREVIATIONS

AAPM	American Association of Physicists in Medicine
AP	anterior posterior (x-ray view)
Al	aluminum (x-ray machine filtration)
cGy	centigray
cm	centimeter
DCF	dose conversion factor
DOE	U.S. Department of Energy
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
ESE	entrance skin exposure
ESEG	entrance skin exposure guideline
FDA	Federal Drug Administration
GEND	General Electric Nuclear Devices (Pinellas plant)
Gy	gray
HVL	Half Value Layer
ICRP	International Commission of Radiation Protection
IREP	Interactive RadioEpidemiological Program
KUB	Kidney, Ureter, Bladder
kVp	kilovolts peak or peak kilovoltage
LAT	lateral (x-ray view)
mA	milliampere
mAs	milliampere seconds
mGy	milligrey
mm	millimeter
mR	milliRoentgen
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
PA	posterior anterior (x-ray view)
PFG	photofluorographic
RMS	root mean square
SID	Source to Image Distance
SSD	Source to Skin Distance
TBD	Technical Basis Document
QA	Quality Assurance

3.0 INTRODUCTION AND OCCUPATIONAL MEDICAL DOSE

Diagnostic x-ray procedures were a contributor to the occupational radiation exposure of the Pinellas Plant. The Pinellas plant required pre-employment physical examinations as part of their occupational health and safety program. In general, the dose from these exposures was not measured, considered or included as part of the occupational exposure of the employee, although it is clearly related. Under the EEOICPA program, diagnostic medical x-rays administered in conjunction with routine or special physical examinations required for employment are recognized as a valid source of occupational exposure. These medical examinations typically included diagnostic Posterior Anterior (PA) and infrequently Lateral (LAT) chest x-rays.

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historic background information and guidance to assist in the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist the NIOSH staff in the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA defines a DOE facility as "any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the Department of Energy (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program)" [42 U.S.C. § 7384l(12)]. Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation[1]] guidelines established under subsection (c) …" [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work.

As noted above, the statute includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition contains an exclusion with respect to the Naval Nuclear Propulsion Program, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally derived radiation

[1] The U.S. Department of Labor is ultimately responsible under the EEOICPA for determining the POC.

exposures at the facility in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external dosimetry monitoring results are considered valid for use in dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived:

- Radiation from naturally occurring radon present in conventional structures
- Radiation from diagnostic X-rays received in the treatment of work-related injuries

3.1 EXAMINATION FREQUENCIES

Review of about 10% of the medical x-ray files for the Pinellas plant indicates that since the start-up of the plant to closure in 1997 PA chest x-rays were given up to an annual basis with infrequent LAT chest x-rays. The medical x-ray file contains information about the actual type of x-ray acquired, number of views, type of view and frequency. This information is recorded on the outside storage envelope of the x-ray films. The dose reconstructor should refer to the claimants' medical records for the most accurate information on the actual x-rays performed, number of views, type of view and frequency. Some of this information may not be recorded in the employee medical records. The policy for chest x-ray frequency may have been (no written policy has been located) every 5 years before age 40 and every 3 years > 40 years of age.

Other x-rays that were offered to employees included KUB, lumbar spine, cervical spine, hand, ankle, foot, sinuses, and wrist. As far as it is known, these x-rays were not given in conjunction with employment and are not included in doses under EEOICPA. From 1969 to 1974 abdominal and KUB x-rays may have been given along with the typical PA chest x-ray as indicated in some claimant medical records.

Table 3.1-1 indicates the distribution of medical x-rays performed in 1983. This information was used to determine shielding requirements for the medical x-ray facility to account for proposed facility changes in 1984. It is not known why so many hand x-rays were given. The vast majority of x-rays were chest x-rays, about 64%.

Table 3.1-1 Medical X-rays with Parameters Utilized at the Pinellas Plant in 1983

X-ray Type	Number	mR/mAs[a]	mAs	kVp[b]	Distance (meters)
Chest	480	2.00	20	90	1.83
Cervical	6	1.00	20	70	1.83
Lumbar	5	7.00	70	90	1
Lumbar	5	5.00	100	80	1
Shoulder	12	5.00	20	80	1
Skull	1	5.00	20	80	1
Skull	1	6.00	40	85	1
Sinus	15	4.50	80	75	1
Ribs	5	4.50	20	75	1
Dorsal Spine	5	4.00	200	70	1
KUB	12	4.00	100	70	1
Ankle	20	3.50	5	65	1
Foot	24	3.00	5	60	1
Wrist	30	3.00	7.5	60	1
Hand	120	2.50	2.5	55	1
Knee	5	2.50	10	55	1
Total	746				

a. mR/mAs – milliroentgen/milliampere seconds.
b. kVp – peak kilovoltage.
Source: "Medical Facility Shielding Document", 1984.

3.2 EQUIPMENT AND TECHNIQUES

3.2.1 Photofluorography (1957-1960)

Chest photofluorography, which resulted in much greater patient doses from a diagnostic procedure, was used sporadically until as late as the early 1960's. Photofluorography used a smaller film (4 x 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 the exposure to the film to determine the time of exposure.

After the review of about 10% of the medical x-rays located at the Atlanta national archives there was no evidence of the use of photofluorography at the Pinellas plant. However, there was at least one occasion where photofluorography was conducted as evidenced from one claimant's files. Unless otherwise indicated in the employee's medical x-ray file, the use of photofluorography should be assumed to ensure conservative dose reconstructions from the time-period of 1957 through 1960. In the case where it is apparent that photofluorographic (PFG) films were not taken (no 4 inch x 5 inch films or two images on a 4 inch x 10 inch film are present), then the pre-1972 PA chest x-ray organ dose values should be utilized.

Photofluorography differed from conventional radiography with film in that while kVp and milliampere (mA) settings could be manipulated by the technician, the exposure time was regulated by the amount of light generated in the photofluorographic unit, with a cutoff or maximum exposure time. An exposure of 15 mAs (150 mA for 0.1 second) was sufficient to produce a satisfactory image on 35 millimeter (mm) film (4 inch x 5 inch); larger film required greater exposures (Sante, 1954, p. 129).

Typical operating parameters reported for 1950's photofluorography were 24 mAs at 83 kVp at a target to film distance of 36 inches (Braestrup, 1958, p. 143), and 30 mAs at 90 kVp with a target to film distance of 40 inches and 2.4 mm added filtration. In the absence of data, a HVL of 2.5 mm should be assumed for dose determinations and is claimant favorable. Measurements at the Hanford site indicated that for a 60 mAs photofluorography exposure at 100 kVp, the entrance skin exposure (ESE) was 1.53 R, which is likely an upper limit value based on a large patient and is consistent with an ESE of about 600-700 mR for a 24-30 mAs exposure at somewhat lower kVp. The Hanford measured value of 1.53R ESE is an upper limit and hence an overstatement of the actual exposure from photofluorography to the average patient, and thus this 1.53R ESE value times two views or 3.00 R ESE as implied in the site wide TIB (Table 4.01 in ORAUT-OTIB-0006) should be used.

3.2.2 Pre-1972 (1961-1971)

The x-ray machine information and techniques utilized prior to 1972 are not available. The ESE was based upon the complex-wide x-ray Technical Basis Document (TBD) (ORAUT-OTIB-0006, rev02), guidance as presented in Table 3.2.2-1. Default dose values by procedure are presented in section 3.3.3. An entrance air kerma of 200 mR for PA and 500 mR for Lat x-rays was utilized in the organ dose calculations.

Table 3.2.2-1 Technique Factors Used for Each Type of X-ray Equipment

Machine	Assumed HVL (mm Al[a])	Image Size (inches)	ESE (cGy[b]) PA		View	Current[c] (mA)	Voltage[c] (kVp)	Exposure Time[c] (sec.)
			PA	LAT				
1957-1960 (PFG)	2.5	4 x 5	3.0	NA	Techniques unknown. No records were kept with regard to the technique factors used during this time period.			
Pre-1972 (1961-1971)	2.5	14 x 17	0.2	0.5	PA[d]	Unknown		
Post-1972 (1972 – 1997)	3.5	14 x 17	0.035	0.0875	PA	200	85	1/10

a. Al – aluminum.
b. cGy – centrigray (equal to approximately 1 rem).
c. Manual technique factors obtained from GEND "Medical Facility Shielding Document", 1984.
d. PA indicates a PA view, the average PA chest measures 26 centimeters (cm). The average Lat. chest measures 34 cm.

3.2.3 Post 1972 (1972-1997)

The x-ray machine information from 1972 to the present is available from the following surveys: a) one survey conducted by the Pinellas county health department in 1972, b) a number of surveys conducted by Pinellas health physics department from 1975-1984 and c) one survey conducted by the Food and Drug Administration (FDA) in 1992. The highest measured mR/mAs value measured as listed in Table 3.2.3-1 is 1.20 mR/mAs which if multiplied by 20 mAs for a PA chest x-ray yields about 24 mR. This value is utilized as the air kerma value. The entrance air kerma value (or ESE) is then calculated by estimating the air kerma at the skin of the patient. A summary description of the x-ray equipment used at the Pinellas plant is included in Table 3.2.3-2. A summary of the specific technique factors for these machines is presented in Table 3.2.2-1.

Table 3.2.3-1 Medical X-ray Equipment, Technique Factors, mR/mAs Measurements and HVL

Date	View	Current (mA)	Voltage (kVp)	Exposure time (sec.)	mR/mAs	HVL
1972[a]	PA	200	85	1/10	1.20	3.20
1/1975[b]	PA	200	85	1/10	0.84	3.60
2/1975[b]	PA	200	85	1/10	0.96	3.25
6/1975[b]	PA	200	85	1/10	1.06	2.90
1/1976[b]	PA	200	85	1/10	0.86	3.50
6/1977[b]	PA	200	85	1/10	0.90	3.20
9/1978[b]	PA	200	85	1/10	1.02	3.20
9/1979[b]	PA	200	85	1/10	0.96	3.20
8/1982[b]	PA	200	90	1/10	0.87	3.20
5/1983[b]	PA	200	80	1/10	0.76	NR
1/1984[b]	PA	200	85	1/10	0.88	3.00
3/9/1992[c]	PA	200	97	1/30	16.3 mR (using LuCal phantom)	

a. Source: PCDH, 1972.
b. "GEND Medical x-ray Surveys (Health Physics Department)", 1975-1984. Acquired from free in air Ion Chamber measurements.
c. FDA Medical x-ray survey, March 9, 1992 with a LuCal chest phantom, assuming a 23 cm PA chest size.

Table 3.2.3-2 Description of the X-ray Equipment Used at the Pinellas Plant

Technique	Time period	Equipment
Photofluorography (PFG)	1957-1960	No information available.
Pre-1972	1961-1971	No information available. Probably the GE DXE-225, 200 mA machine since this was the original and only unit.[a]
Post-1972	1972–1997	GE DXE-225, single phase, 2 pulse, 200 mA, 125 kVp, automated collimator, AFP 14XL automatic film processor

a. "Medical X-ray Unit (Survey)", 1/1963.

3.2.4 Medical X-ray Quality Control

The x-ray equipment that was used had been quality control checked for ESE by the Pinellas plant health physics group from at least 1975. Although all of the records for these Quality Assurance (QA) checks on the x-ray equipment could not be found, the records available indicate that the x-ray equipment was working within FDA guidelines. American Association of Physicists in Medicine (AAPM) Report Number 4, "Basic Quality Control in Diagnostic Radiology" (1978), was followed to ensure the Entrance Skin Exposure Guide (ESEG) was achieved. A diagnostic medical x-ray survey checking the ESEG for different projection limits was followed. The QA of the x-ray machine included

checks on the kVp, half value layer (HVL) determination for beam quality, exposure timing accuracy, beam collimation and alignment testing. Table 3.2-4-1 through Table 3.2.4-3 summarizes the parameters tested and the allowed tolerances.

Table 3.2.4-1 Medical X-ray Quality Assurance Parameters[a]

kVp and mA Requirements	+/- 10 % combined deviation
Timing Requirements	t +/- 20 % for t > 10 milliseconds
Beam Alignment, Light and Radiation Field Congruence Requirements	Less than 2% of the source to image distance (SID) or 2 inches for PA chest.

a. "GEND Medical X-ray Surveys" (Health Physics Department), 1975-1984.

The limits for HVL are as follows:

Table 3.2.4-2 Half Value Layer Limits

Measured kVp	Minimum HVL (mm Al)	Measured kVp	Minimum HVL (mm Al)
50	1.3	110	3.0
60	1.3	120	3.2
70	1.5	130	3.5
80	2.3	140	3.8
90	2.5	150	4.1
100	2.7		

Source: AAPM, 1978.

The ESE guidelines are as follows:

Table 3.2.4-3 Entrance Skin Exposure Guidelines

Projection	ESEG (mR)
Chest (PA)	30
Skull (Lat)	300
Abdomen (AP)	750
Cervical Spine (AP)	250
Thoracic Spine (AP)	900
Full Spine (AP)	300
Lumbar-Sacral Spine (AP)	1000
Retrograde Pyelogram (AP)	900
Feet (D/P)	270

Source: AAPM, 1978.

3.2.5 Diagnostic X-ray Technique Generalizations 1957 to Date

For convenience and possible application to cases in which the standard Pinellas plant protocol was not followed, or for generic use, the effect of various technical factors has been tabulated below in Table 3.2.5-1.

Table 3.2.5-1 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	second	Linear
Filtration	mm Al	Intensity decreases by ~40% for each additional mm Al
Patient 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	+30 %	Assume all errors are positive, + 30% should be used
Re-takes	+5%	Assume all workers had re-takes equal to 5% average

Source: ORAUT-TKBS-0006-3 TBD 2003, p6.

Review of the available documentation pertaining to the occupational medical program at the Pinellas plant from 1957 to 1997 revealed that only one diagnostic medical radiographic procedure was administered in connection with pre-employment or regular post-employment medical examinations, PA 14" x 17" chest film and sometimes a LAT chest x-ray. Lumbar spine and abdominal/KUB x-rays may have been included as a part of the routine or periodic medical examination. Accordingly, doses from these four views were evaluated. Any other radiographic examinations of Pinellas plant employees that might have occurred were probably non-occupational in the sense that these were necessitated by illness or injury and hence not a part of the employee physical examination process. Thus, if there is no indication in the records that these other diagnostic radiographic examinations were administered as a part of the occupational medical program, then they should not be considered as part of the occupational dose.

3.3 ORGAN DOSE CALCULATIONS

International Commission of Radiation Protection (ICRP) Publication 34 (ICRP, 1982) provides tables of average absorbed dose (mGy) in selected organs for selected x-ray projections at 1 gray (Gy) entrance kerma (i.e., skin entrance air kerma without backscatter), for selected views (including PA), and for selected beam qualities (i.e., various HVLs). These tables provide the basic DCFs for converting skin entrance air kerma to organ dose.

The organ doses are found by multiplying the ICRP 34 organ dose conversion factors (DCFs) by the entrance air kerma values. The resulting organ doses for all years are in Tables 3A-1 through 3A-4. The doses are shown in units of dose equivalent or rem, assuming a quality factor of 1.0 for x-rays. Records will indicate the view and in most cases only one view was taken per medical examination.

X-ray organ dose estimates for occupational x-rays administered at the Pinellas plant are made for PFG chest exams (possibly used from 1957 through 1960), PA and lat chest exams performed on pre 1972 equipment (used from 1961 to 1971), and post 1972 equipment (used from 1972 to 1997). X-ray dose estimates are also made for lumbar spine and abdominal/KUB x-rays and presented in sections 3.6 and 3.7 respectively.

For the PA view, a standard SID of 72 inches (183 cm) was used. Additional information indicated that the x-ray machine was single phase (GE, 1980). QC checks of the machine indicated a 2.9 to 3.6 mm Al HVL as indicated in Table 3.2.3-1. A value of 3.5 mm Al HVL would be conservative for the post 1972 calculations. Attachment 3A contains organ doses for PA 14" x 17" chest films (Tables 3A-1 and 3A-2).

For the LAT view, 2.5 times the PA ESE value was used to estimate the LAT ESE value. Tables 3A-3 and 3A-4 in Attachment 3A list organ doses for LAT 14" x 17" chest films.

Default values of ESE have been developed for the three most commonly used occupational medical diagnostic x-ray procedures: PA chest radiography; LAT chest radiography; PFG chest films when actual measurement data or knowledge of technique factors is absent and minimal collimation is

assumed. The default values are considered to be maxima developed from review of patient doses as 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 that the actual exposures from the specified procedures would not exceed the default values. In determining these factors, it was assumed that a minimum of filtration was used along with low kilovoltage techniques, slow film speeds with standard development, and no additional collimation or use of cones.

The default values can then be used as described above in lieu of actual measurement data or entrance kerma (ESE) derived from technique factors. These default ESE values were used in conjunction with DCFs for poorly collimated beams as listed in the complex-wide x-ray TBD guidance document in Table 4.0-1 in ORAUT-OTIB-0006, rev 02, for years 1957-1960 (PFG), and 1961-1971. Post 1972 ESEs are based on actual measurements.

3.3.1 Photofluorography (1957-1960)

Organ doses for chest photofluorography are calculated in an analogous manner to organ doses calculated for conventional radiography using the ESE values. Table 4.0-1 provides DCFs for the ICRP organs based on a distance of 152 cm and beam quality of 2.5 mm Al HVL.

3.3.2 Pre-1972 (1961-1971)

Prior to about 1972, x-ray measurement data, techniques, or beam port information may not be available to estimate the collimation of the x-ray beam. Due to the reported variation in the literature and measurement data on the effects of collimation, it is conservative to assume minimal or no additional external collimation was used when measurement data, technique, or other information to describe the collimation are not available for x-ray procedures performed prior to 1972.

Without collimation, organs normally outside of the primary beam are exposed to the primary beam. This necessitates the use of DCFs from ICRP 34 other than those for a PA or LAT chest x-ray, since ICRP 34 DCFs are based on properly collimated beams. For poorly collimated beams used prior to 1972, the DCFs as listed in the complex-wide x-ray TBD guidance document in Table 4.0-1 were used. The ESE values for the pre-1972 x-ray machine that are used in the organ dose calculations are listed in Table 3.2.2-1. The calculation is analogous to the organ doses calculated for properly collimated beams as illustrated in section 3.3.3.

3.3.3 Post 1972 (1972-1997)

Based on the techniques in Table 3.2.2-1, the mAs for the types of equipment were calculated for each view:

Current (mA) × Exposure Time (sec) = Current for View (mAs) (3.3.3–1)
Example for post 1972 PA view: 200 mA × 1/10 second = 20 mAs

One method of calculating the air kerma is by using the machine parameters and appropriate conversions. The air kerma rate for 85 kVp was determined to be 0.165 cGy per 100 mAs (see Table B.3 of NCRP, 1989) and the air kerma was calculated after converting the rate to air kerma per mA.

Current for View (mAs) × Corrected Air Kerma Rate (cGy/mAs) = Air Kerma (cGy) (3.3.3–2)
Example for post 1972 PA view: 20 mAs × 0.00165 cGy/mAs = 0.033 cGy

Multiply by 0.6 to account for 3.5 mm Al versus 2.5 mm Al Table B.3 (NCRP, 1989) (3.3.3–3)
is based upon; 0.6 X 0.033 cGy = 0.020 cGy

This calculated air kerma is about equal to the measured 0.024 cGy air kerma as discussed in section 3.2.3.

The air kerma was corrected for the thickness of the chest (26 cm) and for distance between the chest and the plane of the film (5 cm) to obtain the air kerma at skin entrance.Air kerma at 183 cm x SID squared ÷ SSD squared = air kerma at skin entrance (3.3.3–4)
Example for post 1972 PA view: 0.024 cGy x $(183\ cm)^2 \div (152\ cm)^2$ = 0.035 cGy

Air kerma at skin entrance was multiplied by the DCFs in Table A.2 through A.8 of ICRP Publication 34 (ICRP, 1982) for PA chest and HVL of 3.5 mm Al equivalent.

Air Kerma (cGy) x Dose conversion factor = Dose for View (cGy) (3.3.3–5)

Example for post 1972 PA view, dose to thyroid:
0.035 cGy x 62 mGy/Gy x 1 Gy/100 cGy x 1 rad/10 mGy = 2.17E-3 rad

Specific organ doses to be attributed for PA chest x-rays calculated on the basis of the DCFs found in ICRP Publication 34 (ICRP, 1982) are given in Attachment A, Table 3A-1 and 3A-2. LAT DCFs are given in Attachment 3A, Table 3A-3 and 3A-4. For organs not listed in ICRP Publication 34 (ICRP, 1982) but specified in the Interactive RadioEpidemiological Program (IREP) code, doses were determined by analogy with anatomical location (Table 3.3.3-1). Thus IREP code organs in the thoracic cavity, but not mentioned in the ICRP Publication 34 (ICRP, 1982) were assigned the same dose as the lungs; doses to the organs in the head and neck were assigned the same dose as the thyroid. The head and neck organ dose estimates (i.e. eye/brain), should be somewhat greater than doses actually incurred, because of geometry considerations and at least in the case of the brain, because of attenuation by the bony cranium. To ensure conservatism in the view of the variations in organ dose described in ICRP Publication 34 (ICRP, 1982, p. 51), the doses for females (lungs), which are slightly higher than those for males, were used and the doses for males (bone marrow), which are slightly higher than those for females, were used. Table 3.3.3-1 lists the reference organ used to approximate the organ analogue doses prior to 1972 for PA and LAT chest and PFG.

Table 3.3.3-1 Analogues for IREP Organs not Included in ICRP 34

Anatomical Location	ICRP 34 Reference Organ	IREP Organ Analogues
Thorax	Lung	Thymus Esophagus Stomach Bone Surface Liver/Gall Bladder/Spleen Remainder organs
Abdomen	Ovaries	Urinary Bladder Colon/Rectum
Head and Neck	Thyroid	Eye/brain

Since at least 1972 beam collimation was checked and found adequate from annual surveys conducted from about 1972 though 1985 and verified by a FDA survey conducted in 1992. The Pinellas x-ray equipment was likely properly collimated since 1957 since the same x-ray machine and associated equipment was probably used from 1957-1997 and there is no evidence that the machine was altered significantly. However, some organs for Lumbar spine and abdominal/KUB x-rays will be

considered to be in the primary beam before 1974 and for PA and LAT chest prior to 1972. The testes dose for the AP lumbar spine x-rays will be approximated by the abdominal/KUB testes dose conversion factor multiplied by the appropriate lumbar spine ESE. The testes dose for the LAT lumbar spine x-rays will be approximated by the LAT pelvis testes dose conversion factor multiplied by the appropriate lumbar spine ESE. The lumbar spine and abdominal/KUB breast dose was estimated by using the dose conversion factors for the AP and LAT UGI all years. Table 3.3.3-2 lists the dose conversion factors as a function of view and x-ray machine technique factors.

Table 3.3.3-2 Dose conversion factors in mGy/1 Gy of entrance kerma as a function of view and x-ray machine technique factors

Examination Parameters											
Projection	View	SID (cm)	HVL (mm)	ESE (R)	Thyroid	Ovaries	Testes	Lungs	Female Breast	Uterus (embryo)	Active bone marrow
Lumbar Spine 1969-1997	AP	102	3.5	1.05	0.9	331	9	109	37 (AP UGI)	421	71
Lumbar Spine 1957-1968	AP	102	3.5	1.05	0.9	331	32 (ab/ KUB testes)	109	37(AP UGI)	421	71
Abdominal/ KUB 1975-1997	AP	102	3.5	.825	0.01	360	32	23	37 (AP UGI)	451	76
Abdominal/ KUB 1957-1974	AP	102	3.5	.825	0.01	360	125 (Pelvis testes)	23	37(AP UGI)	451	76
Chest Post 1972	PA	183	3.5	.035	62	3.2	0.01	610	91	3	146
Chest Pre 1972	PA	183	2.5	0.20	174	125	25	451	49	125	92
Lumbar Spine 1975-1997	LAT	102	3.5	2.62	0.01	87	1.8	22	17 (LAT UGI)	61	43
Lumbar Spine 1957-1974	LAT	102	3.5	2.62	0.01	87	7 (ab/ KUB testes)	22	17 (LAT UGI)	61	43
Abdominal/ KUB 1975-1997	LAT	102	3.5	2.06	0.01	107	7	6.3	17 (LAT UGI)	82	47
Abdominal/ KUB 1957-1974	LAT	102	3.5	2.06	0.01	107	45 (Pelvis testes)	6.3	17 (LAT UGI)	82	47
Chest Post 1972	LAT	183	3.5	.088	151	1.6	0.10	310	316	1.4	61
Chest Pre 1972	LAT	183	2.5	0.50	137	65	12.5	220	255	65	37

3.4 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% (i.e. 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.

Although in theory a large number of factors can introduce uncertainties or affect the x-ray machine output intensity and dose to the patient, in practice only four factors can be reasonably considered to have an impact on dose uncertainty. These are 1) variation in applied kilovoltage, 2) variation in beam current, 3) variation in exposure time, and 4) distance from the patient 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.

For a given set of machine settings and parameters, x-ray output should theoretically be constant and unvarying. However, this is not true in practice; although output is essentially constant unless focal spot loading occurs such as might be the case when the power rating of the machine is exceeded. It is unlikely that power ratings were ever exceeded since so doing would be difficult to achieve in practice and would result in damage to the x-ray tube. However, even with the use of so-called constant voltage transformers to control line voltages, slight variations may 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 ± 5% of the machine setting (Siebert et al., 1991). Since as noted above beam intensity is approximately proportional to the 1.7 power of the kilovoltage, this translates to an uncertainty of approximately $\pm$ 8.7% with respect to output beam intensity in the 70 to 90 kVp range used for diagnostic radiographs at the Pinellas plant. 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, tube current may change and typically will drop. Hence, all other factors remaining constant, beam intensity will be reduced, and 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 and result in maintenance on the machine to restore the output or, as a temporary stopgap measure, increase in the current or kVp to provide the necessary intensity for proper radiography. There is no evidence to suggest that these stopgap measures were ever necessary or applied at the Pinellas plant. For a given kVp setting, output of the beam is a function of the tube current, which in turn is measured by a milli-ammeter on the machine and measures average tube current. The measurement is subject to uncertainties, and in addition there may be minor changes in output as the tube heats up from normal usage. These variations are typically small, and hence 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 time of exposure. 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. Once again for conservatism, uncertainty in 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 ESE. For a given individual, the SSD will be determined largely by the thickness of the patient, and how accurate the positioning is. 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 Inverse Square, this indicates an uncertainty of ± 10% from this source.

There are two approaches to determination of 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, which 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 ± 28.8%. Thus, for any individual ESE or derived organ dose, an uncertainty of ± 30% may be assumed; for further conservatism it may be appropriate to assume that errors are all positive, and only the + 30% should be used (ORAUT-OTIB-0006, rev02).

3.5 DOSE RECONSTRUCTOR INSTRUCTIONS

The information below provides instructions for dose reconstructors in determining organ doses from occupational medical (x-ray) procedures. For the purpose of evaluating probability of causation, x-ray doses are always considered acute, and are photons with energy E=30-250 keV (NIOSH, 2002). Dose should be assigned based upon recorded individual x-ray examination medical histories. This may or may not be recorded in the medical file but can be found in the medical x-ray files recorded on the file envelope. The assigned doses in Tables 3A-1 through 3A-4 and the number of examinations is a point estimate. Uncertainty should be applied as a normal distribution with an uncertainty of 30%.

3.6 ORGAN DOSE EQUIVALENTS FOR LUMBAR SPINE EXAMINATIONS

Lumbar spine examinations have occurred throughout Pinellas plant operations. It does not appear to have been a frequent pre-employment or regular examination from the review of about 10% of the medical x-rays located at the Atlanta national archives and upon the review of a number of claimant medical records. In the interim, to be claimant favorable, any medical x-ray that cannot be directly connected to injury or illness should be considered occupational. There also seems to have been only one view taken, an AP view. However, the LAT organ doses have been calculated and presented in Table 3.6-1. As seen in Table 3.1-1 the frequency of lumbar spine x-rays was less than 2% in 1983. The best indication of lumbar spine x-ray frequency is the claimant medical x-ray file. The kerma value at the SID for the AP view is calculated from the measured 5.0 mR/mAs value multiplied by the 100 mAs technique factor as listed in Table 3.1-1. This amounts to 500 mR air kerma rate. Correcting for a distance of the body of 26 cm and cassette thickness of 5 cm and noting that the SID = 102 cm yields about a 1050 mR ESE. This also happens to be close to the guideline set in 1978 (see Table 3.2.4-3).

The HVL most likely was about 2.5 to 3.5 mm Al, but for conservatism we will use 3.5 mm. Utilizing the DCF for lumbar spine from Tables A2 through A9 from ICRP 34 (1982), Table 3.6-1 lists the dose equivalent in rem. See the last paragraph of section 3.3.3 and Table 3.3.3-2 for more information on the dose conversion factors used in the organ dose calculations. Note that the LAT view entrance kerma is approximated by multiplying the AP view entrance kerma by 2.5.

Table 3.6-1 Organ Dose Equivalents in Rem for Lumbar Spine Examinations[c]

Organ	**1957-1968 AP lumbar spine** HVL 3.5 mm AL ESE 1.05 rem	**1957-1968 LAT lumbar spine** HVL 3.5 mm AL ESE 2.625 rem	**1969-1997 AP lumbar spine** HVL 3.5 mm AL **ESE 1.05 rem**	**1969-1997 LAT lumbar spine** HVL 3.5 mm AL **ESE 2.625 rem**
Bone Marrow	7.46×10^{-2}	1.13×10^{-1}	7.46×10^{-2}	1.13×10^{-1}
Bone Surface	1.14×10^{-1}	5.78×10^{-2}	1.14×10^{-1}	5.78×10^{-2}
Breast (Female)[a]	3.89×10^{-2}	4.46×10^{-2}	3.89×10^{-2}	4.46×10^{-2}
Colon/Rectum	3.48×10^{-1}	2.28×10^{-1}	3.48×10^{-1}	2.28×10^{-1}
Esophagus	1.14×10^{-1}	5.78×10^{-2}	1.14×10^{-1}	5.78×10^{-2}
Eye/Brain	9.45×10^{-4}	2.62×10^{-5}	9.45×10^{-4}	2.63×10^{-5}
Liver/Gall Bladder/Spleen	1.14×10^{-1}	5.78×10^{-2}	1.14×10^{-1}	5.78×10^{-2}

Organ	**1957-1968 AP lumbar spine** HVL 3.5 mm AL ESE 1.05 rem	**1957-1968 LAT lumbar spine** HVL 3.5 mm AL ESE 2.625 rem	**1969-1997 AP lumbar spine** HVL 3.5 mm AL **ESE 1.05 rem**	**1969-1997 LAT lumbar spine** HVL 3.5 mm AL **ESE 2.625 rem**
Lungs	1.14×10^{-1}	5.78×10^{-2}	1.14×10^{-1}	5.78×10^{-2}
Ovaries	3.48×10^{-1}	2.28×10^{-1}	3.48×10^{-1}	2.28×10^{-1}
Remainder	1.14×10^{-1}	5.78×10^{-2}	1.14×10^{-1}	5.78×10^{-2}
Skin	1.47×10^{0}	3.68×10^{0}	1.47×10^{0}	3.68×10^{0}
Stomach	1.14×10^{-1}	5.78×10^{-2}	1.14×10^{-1}	5.78×10^{-2}
Testes[b]	3.36×10^{-2}	1.84×10^{-2}	9.45×10^{-3}	4.73×10^{-3}
Thymus	1.14×10^{-1}	5.78×10^{-2}	1.14×10^{-1}	5.78×10^{-2}
Thyroid	9.45×10^{-4}	2.62×10^{-5}	9.45×10^{-4}	2.63×10^{-5}
Total Body	1.44×10^{-1}	1.55×10^{-1}	1.44×10^{-1}	1.55×10^{-1}
Urinary/Bladder	3.48×10^{-1}	2.28×10^{-1}	3.48×10^{-1}	2.28×10^{-1}
Uterus	4.42×10^{-1}	1.60×10^{-1}	4.42×10^{-1}	1.60×10^{-1}

a. ICRP 34 (1982) does not provide dose conversion factors for the lumbar spine view for the breast. The lumbar spine breast dose was estimated by using the dose conversion factors for the AP and LAT UGI
b. The testes dose was estimated using the abdominal/KUB AP and LAT dose conversion factors for the minimal collimation column (1957-1968).
c. Use a correction uncertainty factor of 1.3 to maximize the dose calculation.

3.7 ORGAN DOSE EQUIVALENTS FOR ABDOMINAL AND KUB EXAMINATIONS

There may have been abdominal or Kidney, Ureters, Bladder (KUB) x-rays performed as part of the routine or periodic physicals given at the Pinellas site. This may be indicated in the claim documents usually from 1969 through 1974. In the interim, to be claimant favorable, any medical x-ray that cannot be directly connected to injury or illness should be considered occupational.

The kerma value at the SID for the abdominal/KUB x-ray is calculated from the measured 4.0 mR/mAs value multiplied by the 100 mAs technique factor as listed in Table 3.1-1. This amounts to 400 mR air kerma rate. Correcting for a distance of the body of 26 cm and cassette thickness of 5 cm and noting that the SID = 102 cm yields 825 mR ESE. This also happens to be close to the guideline set in 1978 (see Table 3.2.4-3).

The HVL most likely was about 3.0 to 3.5 mm Al, but for conservatism we will use 3.5 mm. Utilizing the DCF for abdominal x-rays which include KUB views from Tables A2 through A9 from ICRP 34 (1982), Table 3.7-1 lists the dose equivalent in rem. See the last paragraph of section 3.3.3 and Table 3.3.3-2 for more information on the dose conversion factors used in the organ dose calculations. Note that the LAT view entrance kerma is approximated by multiplying the AP entrance kerma view by 2.5.

Table 3.7-1 Organ Dose Equivalents in Rem for Abdominal and KUB Examinations[c]

Organ	**1957-1974 AP Abdominal/KUB** HVL 3.5 mm AL ESE 0.825 rem	**1957-1974 LAT Abdominal/KUB** HVL 3.5 mm AL ESE 2.063 rem	**1975-1997 AP Abdominal/KUB** HVL 3.5 mm AL **ESE 0.825 rem**	**1975-1997 LAT Abdominal/KUB** HVL 3.5 mm AL **ESE 2.063 rem**
Bone Marrow	6.27×10^{-2}	9.69×10^{-2}	6.27×10^{-2}	9.69×10^{-2}
Bone Surface	1.90×10^{-2}	1.30×10^{-2}	1.90×10^{-2}	1.30×10^{-2}
Breast (Female)[a]	3.05×10^{-2}	3.51×10^{-2}	3.05×10^{-2}	3.51×10^{-2}
Colon/Rectum	2.97×10^{-1}	2.21×10^{-1}	2.97×10^{-1}	2.21×10^{-1}

Esophagus	1.90×10^{-2}	1.30×10^{-2}	1.90×10^{-2}	1.30×10^{-2}
Eye/Brain	8.25×10^{-6}	2.06×10^{-5}	8.25×10^{-6}	2.06×10^{-5}
Liver/Gall Bladder/Spleen	1.90×10^{-2}	1.30×10^{-2}	1.90×10^{-2}	1.30×10^{-2}
Lungs	1.90×10^{-2}	1.30×10^{-2}	1.90×10^{-2}	1.30×10^{-2}
Ovaries	2.97×10^{-1}	2.21×10^{-1}	2.97×10^{-1}	2.21×10^{-1}
Remainder	1.90×10^{-2}	1.30×10^{-2}	1.90×10^{-2}	1.30×10^{-2}
Skin	1.16×10^{0}	2.89×10^{0}	1.16×10^{0}	2.89×10^{0}
Stomach	1.90×10^{-2}	1.30×10^{-2}	1.90×10^{-2}	1.30×10^{-2}
Testes[b]	1.03×10^{-1}	9.28×10^{-2}	2.64×10^{-2}	1.44×10^{-2}
Thymus	1.90×10^{-2}	1.30×10^{-2}	1.90×10^{-2}	1.30×10^{-2}
Thyroid	8.25×10^{-6}	2.06×10^{-5}	8.25×10^{-6}	2.06×10^{-5}
Total Body	1.14×10^{-1}	1.28×10^{-1}	1.14×10^{-1}	1.28×10^{-1}
Urinary/Bladder	2.97×10^{-1}	2.21×10^{-1}	2.97×10^{-1}	2.21×10^{-1}
Uterus	3.72×10^{-1}	1.69×10^{-1}	3.72×10^{-1}	1.69×10^{-1}

a. ICRP 34 (1982) does not provide dose conversion factors for the abdominal/KUB view for the breast. The abdominal/KUB breast dose was estimated by using the dose conversion factors for the AP and LAT UGI.
b. The testes dose was estimated using the AP and LAT pelvis dose for the minimal collimation column (1957-1974).
c. Use a correction uncertainty factor of 1.3 to maximize the dose calculation.

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GLOSSARY

absorbed dose
The energy imparted per unit mass by ionizing radiation to matter at a specified point. The SI unit of absorbed dose is joule per kilogram (J/kg). The special name for this unit is gray (Gy). The previously used unit of absorbed dose, rad is being replaced by the gray. 1 rad = 0.01 Gy. 1 Gy = 100 rad.

ampere
Electric current unit. One ampere is equal to one coulomb per second.

dose equivalent
The product of the absorbed dose in tissue, quality factor and all other necessary modifying factors at the location of interest. The SI unit for dose equivalent is the sievert. The historical unit for the dose equivalent is the rem. The ICRP defines dose equivalent as equivalent dose.

entrance kerma (or entrance skin kerma or ESE)
Refers to kerma without backscatter.

exposure
A measure of the quantity of x or gamma radiation based upon its ability to ionize air through which it passes. The SI unit for exposure is coulomb per kilogram. The historical unit for exposure is Roentgen (R).

film
A medium used to record an image.

filtration
Material in the useful beam that usually absorbs preferentially the less penetrating radiation.

gray (Gy)
The special name for the SI unit of absorbed dose, Kerma, and specific energy imparted equal to one joule per kilogram. One gray equals to one joule per kilogram.

half-value layer (HVL)
Thickness of a specified substance which, when introduced in the path of a given beam of radiation, reduces the Kerma rate by one-half.

kerma
The sum of the initial kinetic energies of charged ionizing particles liberated by uncharged ionizing particles per unit mass of a specified material. Kerma is measured in the same units as absorbed dose. The SI unit of kerma is joule per kilogram and the special name is gray (Gy). Kerma can be quoted for any specified material at a point in free space, at the skin entrance or in an absorbing medium.

milligray (mGy)
1 mGy = 10 rad

phantom
An object used to simulate the absorption and scatter characteristics of the patient's body for radiation measurement purposes.

radiography

The production of images on film by the action of x-rays transmitted through the patient.

rad

Historical unit for absorbed dose. One rad equals 100 ergs per gram. The word derives from *radiation absorbed dose*.

roentgen

The previously used special unit of exposure. An exposure of one roentgen will produce 2.58×10^{-4} coulomb of ions of either sign per kilogram in air.

rem

Historical unit of dose equivalent. The word derives from *roentgen equivalent (in) man*.

sievert (Sv)

The special name for the SI unit of dose equivalent. One sievert equals one joule per kilogram. One sievert is equal to 100 rem.

source to image distance (SID)

The distance measured along the central ray from the center of the front of the surface of the source (x-ray 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 surface of the source (x-ray focal spot) to the surface of the irradiated object or patient.

technique factors

Refer to x-ray machine settings used in am examination procedure. The factors include such terms as kilovolt peak, milliampere, and exposure time.

voltage

Electrical potential energy per unit charge. The SI unit volt (V). One volt is equal to a joule per coulomb.

Attachment 3A

Table 3A-1 Dose Equivalents for Organs Identified in ICRP 34 (1982) for PA Views[f]

Time Period	Frequency[g]	Organ dose Equivalents per PA Chest (rem)							
		Air Kerma at Skin Entrance[a]	Thyroid[d]	Ovaries[d]	Testes[d]	Lungs[d]	Breast[d]	Uterus[d] (Embryo)	Bone Marrow[d]
1957-1960 (PFG)[b]	Annual	3.000 2.5 mm HVL	5.20×10^{-1}	2.50×10^{-2}	5.00×10^{-3}	1.35×10^{0} (1.26×10^{0})[e]	1.47×10^{-1}	2.50×10^{-2}	2.76×10^{-1} (2.58×10^{-1})
1961-1971 (Pre-1972)[c]	Annual	0.200 minimal collimation	3.48×10^{-2}	2.50×10^{-2}	5.00×10^{-3}	9.02×10^{-2} (8.38×10^{-2})[e]	9.80×10^{-3}	2.50×10^{-2}	1.84×10^{-2} (1.45×10^{-2})
1972-1997 (Post-1972)	Annual	0.035 3.5 mm HVL	2.17×10^{-3}	1.12×10^{-4}	3.50×10^{-7}	2.14×10^{-2} (1.98×10^{-2})[e]	3.19×10^{-3}	1.05×10^{-4}	5.11×10^{-3} (4.94×10^{-3})

a. Air kerma at entrance skin in rem = ESE (R) x 0.00873 Gy/R ~ ESE (R) x 0.01 Gy/R.
b. PFG chest entrance kerma (uncollimated) (2.5 mm Al HVL) (ORAUT-OTIB-0006, Table 4.0-1).
c. Pre-1970 chest 99% confidence entrance kerma (uncollimated) (2.5 mm Al HVL) (ORAUT-OTIB-0006, Table 4.0-1).
d. Organs identified in ICRP 34 (1982) for dose determination from entrance air kerma associated with chest radiography.
e. Male lung organ dose and female bone marrow organ dose is given in parenthesis. The dose in the parenthesis is less conservative than the dose outside of the parenthesis.
f. Use a correction uncertainty factor of 1.3 to maximize the dose calculation.
g. Use claim medical files for frequency information, if available.

Table 3A-2 Dose Equivalent for IREP Organs not Included in ICRP 34 (1982) for PA Views[e]

Time Period	Freq.[f]	Organ dose Equivalents per PA Chest (rem)										
		Air Kerma at Skin Entrance	Thymus	Esoph-agus	Stomach	Bone Surface	Liver/Gall Bladder/ Spleen	Urinary Bladder	Colon/ Rectum	Eye/Brain	Skin[c]	Remain-der
1957-1960 (PFG)[a]	Annual	3.000 2.5 mm HVL	1.35×10^{0} (1.26×10^{0})[d]	1.35×10^{0} (1.26×10^{0})[d]	1.35×10^{0} (1.26×10^{0})[d]	1.35×10^{0} (1.26×10^{0})[d]	1.35×10^{0} (1.26×10^{0})[d]	2.50×10^{-2}	2.50×10^{-2}	9.60×10^{-2}	4.05×10^{0}	1.35×10^{0} (1.26×10^{0})[d]
1961-1971 (Pre-1972)[b]	Annual	0.200 minimal collimation	9.02×10^{-2} (8.38×10^{-2})[d]	9.02×10^{-2} (8.38×10^{-2})[d]	9.02×10^{-2} (8.38×10^{-2})[d]	9.02×10^{-2} (8.38×10^{-2})[d]	9.02×10^{-2} (8.38×10^{-2})[d]	2.50×10^{-2}	2.50×10^{-2}	6.40×10^{-3}	2.70×10^{-1}	9.02×10^{-2} (8.38×10^{-2})[d
1972-1997 (Post-1972)	Annual	0.035 3.5 mm HVL	2.14×10^{-2} (1.98×10^{-2})[d]	2.14×10^{-2} (1.98×10^{-2})[d]	2.14×10^{-2} (1.98×10^{-2})[d]	2.14×10^{-2} 1.98×10^{-2})[d]	2.14×10^{-2} (1.98×10^{-2})[d]	1.12×10^{-4}	1.12×10^{-4}	2.17×10^{-3}	4.90×10^{-2}	2.14×10^{-2} (1.98×10^{-2})[d]

a. PFG chest entrance kerma (uncollimated) (2.5 mm Al HVL) (ORAUT-OTIB-0006, Table 4.0-1).
b. Pre-1970 chest 99% confidence entrance kerma (uncollimated) (2.5 mm Al HVL) (ORAUT-OTIB-0006, Table 4.0-1).
c. Entrance skin dose is ESE calculated from air kerma, multiplied by a backscatter factor of 1.4 from NCRP, 1989, Table B-8.
d. Male organ dose is given in parenthesis. The dose in parenthesis is less conservative than the dose outside of the parenthesis.
e. Use a correction uncertainty factor of 1.3 to maximize the dose calculation.
f. Use claim medical files for frequency information, if available.

Table 3A-3 Dose Equivalents for Organs Identified in ICRP 34 (1982) Beam Quality for LAT Views[e]

Time Period	Frequency[f]	Organ Dose Equivalents per LAT Chest (rem)							
		Air Kerma at Skin Entrance[a]	Thyroid[c]	Ovaries[c]	Testes[c]	Lungs[c]	Breast[c]	Uterus[c] (Embryo)	Bone Marrow[c]
1961-1971 (Pre-1972)[b]	Annual	0.500 uncollimated	6.85×10^{-2}	1.30×10^{-2}	2.50×10^{-3}	1.10×10^{-1} (9.65×10^{-2})[d]	1.28×10^{-1}	1.30×10^{-2}	1.85×10^{-2} (1.45×10^{-2})
1972-1997 (Post-1972)	Annual	0.0875 3.5 mm HVL	1.32×10^{-2}	1.40×10^{-4}	8.75×10^{-6}	2.71×10^{-2} (2.42×10^{-2})[d]	2.77×10^{-2}	1.23×10^{-4}	5.34×10^{-3} (4.20×10^{-3})

a. Air kerma at entrance skin in rem = ESE (R) x 0.00873 Gy/R ~ ESE (R) x 0.01 Gy/R.
b. Pre-1970 chest entrance kerma (uncollimated) (2.5 mm Al HVL) (ORAUT-OTIB-0006, Table 4.0-1).
c. Organs identified in ICRP 34 (1982) for dose determination from entrance air kerma associated with chest radiography.
d. Male lung organ dose and female bone marrow organ dose is given in parenthesis. The dose in the parenthesis is less conservative than the dose outside of the parenthesis..

e. Use a correction uncertainty factor of 1.3 to maximize the dose calculation.
f. Use claim medical files for frequency information, if available.

Table 3A-4 Dose Equivalent for IREP Organs not Included in ICRP 34 (1982) for LAT Views[d]

Time Period	Freq.[e]	Organ Dose Equivalents per LAT Chest (rem)										
		Air Kerma at Skin Entrance	Thymus	Esoph-agus	Stomach	Bone Surface	Liver/Gall Bladder/ Spleen	Urinary/ Bladder	Colon/ Rectum	Eye/ Brain	Skin [b]	Remain-der
1961-1971 (Pre-1972)[a]	Annual	0.500 uncollim-ated	1.10×10^{-1} (9.65×10^{-2})[c]	1.10×10^{-1} (9.65×10^{-2})[c]	1.10×10^{-1} (9.65×10^{-2})[c]	1.10×10^{-1} (9.65×10^{-2})[c]	1.10×10^{-1} (9.65×10^{-2})[c]	1.30×10^{-2}	1.30×10^{-2}	6.85×10^{-2}	6.75×10^{-1}	1.10×10^{-1} (9.65×10^{-2})[c]
1972-1997 (Post-1972)	Annual	0.0875 3.5 mm HVL	2.71×10^{-2} (2.42×10^{-2})[c]	2.71×10^{-2} (2.42×10^{-2})[c]	2.71×10^{-2} (2.42×10^{-2})[c]	2.71×10^{-2} (2.42×10^{-2})[c]	2.71×10^{-2} (2.42×10^{-2})[c]	1.40×10^{-4}	1.40×10^{-4}	1.32×10^{-2}	1.23×10^{-1}	2.71×10^{-2} (2.42×10^{-2})[c]

a. Pre-1970 chest entrance kerma (uncollimated) (2.5 mm Al HVL) (ORAUT-OTIB-0006, Table 4.0-1).
b. Entrance skin dose is ESE calculated from air kerma, multiplied by a backscatter factor of 1.4 from NCRP, 1989, Table B-8
c. Male organ dose is given in parenthesis. This dose is less conservative than the female dose.
d. Use a correction uncertainty factor of 1.3 to maximize the dose calculation.
e. Use claim medical files for frequency information, if available.