DOE Review Release 01/12/2017

Site Profile for the Kansas City Plant

ORAUT-TKBS-0031 Rev. 01
Effective Date: 01/06/2017
Supersedes: Revision 00 PC-1

Subject Expert(s): Jackson R. Ellis, Richard J. Traub

Document Owner Approval:	Signature on File Jackson R. Ellis, Document Owner	Approval Date:	12/21/2016
Concurrence:	Wade C. Morris Signature on File for John M. Byrne, Objective 1 Manager	Concurrence Date:	12/21/2016
Concurrence:	Scott R. Siebert Signature on File for Edward F. Maher, Objective 3 Manager	Concurrence Date:	12/21/2016
Concurrence:	Vickie S. Short Signature on File for Kate Kimpan, Project Director	Concurrence Date:	12/20/2016
Approval:	Signature on File James W. Neton, Associate Director for Science	Approval Date:	01/06/2017

FOR DOCUMENTS MARKED AS A TOTAL REWRITE, REVISION, OR PAGE CHANGE, REPLACE THE PRIOR REVISION AND DISCARD / DESTROY ALL COPIES OF THE PRIOR REVISION.

☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
05/31/2005	00	New document to establish the technical basis for the development of a radiation exposure profile for the Kansas City Plant. First approved issue. No training required. Initiated by Donald E. Bihl.
01/06/2006	00 PC-1	Approved page change revision. Incorporates changes for environmental ambient external and internal doses for unmonitored, non-radiological workers as a result of formal internal review and informal OCAS comments. Page change includes new content added to pages 7 and 22 (Sections 1.0 and 5.1.4). Removed definition of unmonitored worker on page 26 (Section 6.4.1). Minor revisions were made to pages 17, 18, 19, and 23 (Sections 4.0, 5.0, 5.1.2, 5.2 and 6.2.1). As a result of NIOSH formal review, incorporates Attachment A on pages 43–46, into Site Profile. This attachment describes technical basis of ambient environmental dose estimate for unmonitored workers. No sections were omitted. Retraining is not required. Initiated by Jack J. Fix. Approval: Document Owner: Signature on File 12/19/2005 Jack J. Fix, TBD Team Leader Signature on File 12/20/2005 Judson L. Kenoyer, Task 3 Manager Signature on File 12/28/2005 Kate Kimpan, Project Director Signature on File 01/06/2006 James W. Neton, Associate Director for Science
01/06/2017	01	Revision initiated to incorporate changes to include information from the SEC-0210 Petition Evaluation Report and updated medical X-ray organ dose determination using guidance in ORAUT-OTIB-0006. Affected all sections. Expanded on the Machining Area operations, ThO_2 powder sources, and to expand on Mg-Th operational periods. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Jackson R. Ellis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE **TITLE** **PAGE**

ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AMAD	activity median aerodynamic diameter
AP	anterior-posterior
AWE	Atomic Weapons Employer
Bq	becquerel
cGy	centigray
Ci	curie
cm	centimeter
cpm	counts per minute
d	day
D&D	decontamination and decommissioning
DCF	dose conversion factor
DOE	U.S. Department of Energy
DOELAP	DOE Laboratory Accreditation Program
DOL	U.S. Department of Labor
dpm	disintegrations per minute
DU	depleted uranium
DXT	density times thickness
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ENSD	entrance skin dose equivalent
EXSD	exit skin exposure
ft	foot
g	gram
gal	gallon
GE	General Electric Company
GM	geometric mean
GSD	geometric standard deviation
Hp(d)	personnel dose equivalent at depth *d* in tissue
hr	hour
HVL	half-value layer
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiological Units and Measurements
IMBA	Integrated Modules for Bioassay Analysis
in.	inch
IREP	Interactive RadioEpidemiological Program
KCP	Kansas City Plant
keV	kiloelectron-volt, 1,000 electron-volts
kVp	peak kilovoltage
LAT	lateral
lb	pound
LOD	limit of detection

m	meter
mA	milliampere
mCi	millicurie
MDL	minimum detectable level
Mg-Th	magnesium-thorium alloy
min	minute
mL	milliliter
mm	millimeter
mR	milliroentgen
mrem	millirem
n	neutron
NCRP	National Council on Radiological Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
NTA	nuclear track emulsion, type A
OCAS	Office (now Division) of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities
OSL	optical stimulated luminescence
PA	posterior-anterior
pCi	picocurie
PIC	pocket ionization chamber
R	roentgen
RADEC)	RAdiation DEtection Capability
ROT	rotational
RSD	remote skin dose
SEC	Special Exposure Cohort
SRDB Ref ID	Site Research Database Reference Identification (number)
TBD	technical basis document
TLD	thermoluminescent dosimeter
U.S.C.	United States Code
yr	year
µCi	microcurie
µg	microgram
µm	micrometer
§	section or sections

1.0 INTRODUCTION

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 historical background information and guidance to assist in the preparation of dose reconstructions at particular Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities or categories of DOE or AWE facilities. They will be revised in the event additional relevant information is obtained about the affected DOE or AWE facility(ies). These documents may be used to assist NIOSH staff in the evaluation of Special Exposure Cohort (SEC) petitions and the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used to refer to an area, building, or group of buildings that served a specific purpose at a DOE or AWE facility. It does not mean nor should it be equated to an "AWE facility" or a "DOE facility." The terms AWE and DOE facility are defined in sections 7384l(5) and (12) of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), respectively. An AWE facility means "a facility, owned by an atomic weapons employer, that is or was used to process or produce, for use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining or milling." 42 U.S.C. § 7384l(5). On the other hand, a DOE facility is defined 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 [DOE] (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program);" and with regard to which DOE has or had a proprietary interest, or "entered into a contract with an entity to provide management and operation, management and integration, environmental remediation services, construction, or maintenance services." 42 U.S.C. § 7384l(12). The Department of Energy (DOE) determines whether a site meets the statutory definition of an AWE facility and the Department of Labor (DOL) determines if a site is a DOE facility and, if it is, designates it as such.

Accordingly, a Part B claim for benefits must be based on an energy employee's eligible employment and occupational radiation exposure at a DOE or AWE facility during the facility's designated time period and location (i.e., covered employee). After DOL determines that a claim meets the eligibility requirements under EEOICPA, DOL transmits the claim to NIOSH for a dose reconstruction. EEOICPA provides, among other things, guidance on eligible employment and the types of radiation exposure to be included in an individual dose reconstruction. Under EEOICPA, eligible employment at a DOE facility includes individuals who are or were employed by DOE and its predecessor agencies, as well as their contractors and subcontractors at the facility. Unlike the abovementioned statutory provisions on DOE facility definitions that contain specific descriptions or exclusions on facility designation, the statutory provision governing types of exposure to be included in dose reconstructions for DOE covered employees only requires that such exposures be incurred in the performance of duty. As such, NIOSH broadly construes radiation exposures incurred in the performance of duty to include all radiation exposures received as a condition of employment at covered DOE facilities in its dose reconstructions for covered employees. For covered employees at DOE facilities, individual dose reconstructions may also include radiation exposures related to the Naval Nuclear Propulsion Program at DOE facilities, if applicable. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction.

NIOSH does not consider the following types of exposure as those incurred in the performance of duty as a condition of employment at a DOE facility. Therefore these exposures are not included in dose reconstructions for covered employees (NIOSH 2010):

- Background radiation, including radiation from naturally occurring radon present in conventional structures
- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

1.1 PURPOSE

This site profile provides information about the Kansas City Plant (KCP) in Kansas City, Missouri. This information may be used in dose reconstruction.

1.2 SCOPE

Section 2.0 describes KCP and its operations. Section 3.0 discusses occupational medical doses from X-ray examinations, and Section 4.0 discusses onsite environmental doses. Sections 5.0 and 6.0 describe internal and external dosimetry, respectively. Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 7.0.

2.0 SITE DESCRIPTION

The U.S. Navy built the first facilities at the site during World War II to assemble engines for fighter planes. Pratt-Whitney operated the site from early 1943 until September 2, 1945. In 1947, Westinghouse began leasing the facility, and the Fairfax Storage Company used part of the building as a warehouse for tires, raw rubber, sugar, and lumber.

In 1948, the Bendix Corporation subleased from Westinghouse the warehouse portion of the plant on the eastern side, because the AEC had entered into a contract with Bendix on November 5, 1948 for the performance by the Contractor of certain work involving management and operation of Government-owned facilities and the performance of work therein. Bendix began work for the AEC at the site in 1949 and continued to do so when the Navy terminated its lease with Westinghouse on June 30, 1961. Ownership of 122.05 acres of land, with improvements thereon at the Bannister Complex was transferred to ERDA, effective September 30, 1976.

Over the years, KCP shared the site with the Federal Aviation Administration, Defense Finance and Accounting Service, U.S. Marine Corps, General Services Administration, Internal Revenue Service, National Oceanic and Atmospheric Administration, and National Logistics Support Center. Table 2-1 summarizes the history of the facility, and Figure 2-1 shows the layout of the site.

DOE moved the operations at KCP to a new location, the Kansas City National Security Campus in downtown Kansas City, beginning January 2013 and continuing through July 2014. (HFMT 2016).

KCP was a major operational facility administered by Honeywell Federal Manufacturing and Technologies/Kansas City. KCP produced nonnuclear weapons components for the nuclear weapons program. The principal products included arming systems, fusing and firing systems, radars, power supplies, rubber, plastic and foam parts, and outer casings. KCP was the only DOE facility for manufacturing these components (DOE 1997).

The DOE Kansas City Office reported directly to DOE headquarters and had line management responsibility for manufacturing nonnuclear components. In recent years, DOE relocated additional project roles from the Mound Site, Pinellas Plant, and Rocky Flats Plant to KCP (Reis 1998).

2.1 FACILITIES

KCP consisted of 37 buildings with about 2.9 million ft^2. The Main Manufacturing Building, constructed in 1942, was the largest facility (about 2.7 million ft^2), and housed the key manufacturing operations. DOE controlled about 1.75 million ft^2 of this building (DOE 2013). The following buildings supported the Main Manufacturing Building: Polymer Building, High Power Laboratory, Mold Heating and Cooling Building, Plating Building, Technology Transfer Center, Special Processes Building, and Manufacturing Support Building.

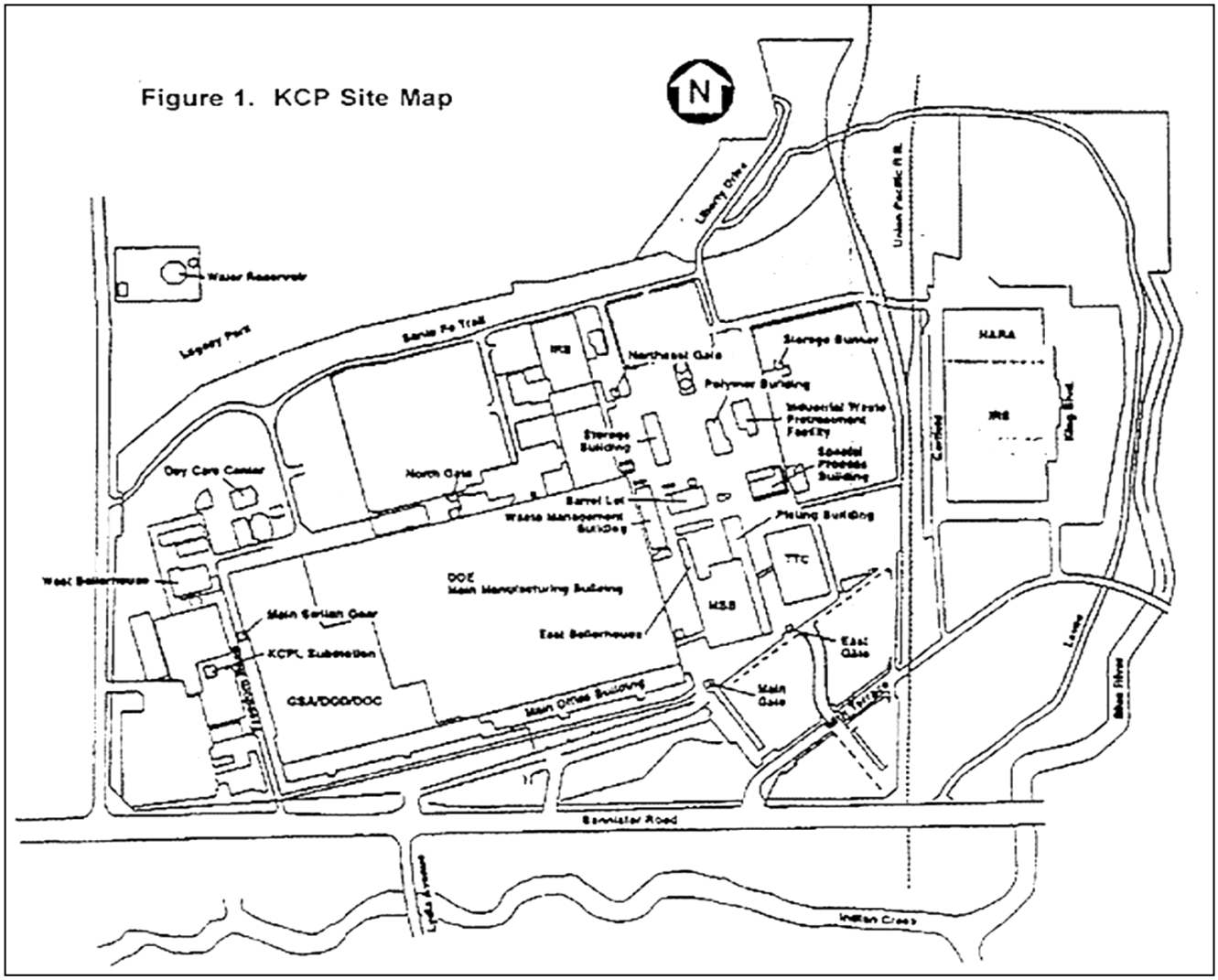

Figure 2-1. Site map (Reference).

Table 2-1. History of facility operations.

Year	Event
1943	Pratt-Whitney operated facility from early 1943 until September 2, 1945, to assemble engines for Navy fighter planes.
1947	Westinghouse began leasing facility, and Fairfax Storage Company used part of building as warehouse for tires, raw rubber, sugar, and lumber.
1948	KCP opens. AEC asks Bendix Corporation to manage facility and begin building nonnuclear components for nuclear weapons.
1982	Allied merger. Bendix merges with Allied Corporation.
1984	Allied-Signal merger. Allied merges with Signal companies to form Allied-Signal
1993	Site consolidation. KCP designated as consolidated site for all nonnuclear components for nuclear weapons.
1999	Honeywell merger. AlliedSignal merged with Honeywell.
2013	DOE moved the operations at KCP to the Kansas City National Security Campus.
2014	July 2014, DOE operations ceased.

These facilities supported the use of technologies for testing and evaluating engineering characteristics of materials and structures. Typical examinations included:

- Location of flaws, cracks, chemical contaminations, and internal features; measurement of thickness, density, internal dimensions, and percentage contamination;
- Sorting and identification of alloys;
- Evaluation of heat treatment conditions; and
- Image enhancement.

KCP used these methods to evaluate a variety of objects including welds and forgings, foams, plastics, adhesives, composites, ceramics, and coatings, electrical components, and mechanical assemblies.

Waste management operations at KCP consisted mainly of hazardous nonradiological waste storage in preparation for offsite treatment or disposal. Operations sometimes generated small quantities of low-level radioactive waste. Some waste is classified for national security reasons due to the nature of the generating process or constituents. KCP shipped classified hazardous wastes off site for sanitization and reclamation. There was onsite waste disposal in trenches that were cleaned up in later D&D efforts (see Section 5.2.9). Treatment operations were limited to industrial wastewater pretreatment and selective recycling.

2.2 PROCESS DESCRIPTIONS

In 1949, the Bendix Aviation Corporation began producing electrical and mechanical weapon components. This work consisted of metals machining, plastic machining and fabrication, plating, electronics and electrical assembly, and mechanical assembly. Much of this work involved materials and processes that can result in internal and external radiation exposure to workers. This work included operations with natural uranium, depleted uranium (DU), magnesium-thorium alloy (Mg-Th), thorium oxide powders, and tritium. In addition, cleanup activities and decontamination and decommissioning (D&D) activities had the potential to expose workers to radioactive materials.

2.2.1 Natural Uranium Operations

KCP workers inspected and assembled uranium components, machined uranium slugs, and handled uranium billets and ingots in the Main Manufacturing Building in the early 1950s. Starting in May 1950 and continuing to February 1955, workers in Department 3A inspected and assembled uranium components (Schiltz 1963, pp. 2–17).

In February 1951, KCP set up a machine shop in Department 49X. Its purpose was to produce 1,000 slugs per day to fuel production reactors at the Savannah River Site in South Carolina and Argonne National Laboratory near Chicago, Illinois. It consisted of a smooth finished concrete floor, steel panel walls, and an adjacent storeroom.

KCP received some of the 10-ft-long uranium rod stock for this work from the Lackawanna Test Site in New York. For the initial order, KCP produced 45,000 slugs. The plant had a plan to produce 5 tons of slugs per month.

The equipment for making slugs included an 8-in. Springfield bench lathe, a Fay Automatic lathe, a Schauer air collet machine, a power cut-off saw, and four Gisholt turret lathes. Two shifts operated with 14 machine operators, 3 inspectors, an accountability officer, and a packaging man (Mahaffey 1952; Author unknown 1951). Straightening of the 1.062-in.-diameter rods occurred before KCP received them. There, plant workers:

1. Sawed off the bar ends using a power hacksaw.

2. Placed the bars in the Gisholt turret lathes, turned them to 1-in. diameter, and cut them into 8.120-in. lengths.

3. Fed those rough slugs into the Fay Automatic lathe to turn them to the finished diameter of 0.997-in.

4. Cut a 30-degree cone chamfer.

5. Generated a 0.050-in. to 0.070-in. radius using the Schauer air collet machine and a mill file.

6. If any rework was necessary, it was performed on the 8-in. Springfield bench lathe (Mahaffey 1952).

Machining uranium rods into slugs continued in 1952. KCP received unstraightened rods Bethlehem Steel had rolled, then sent the slugs they made from those rods to Argonne National Laboratory and the Savannah River Site (Author unknown, 1951; Laing 1952). These uranium slug-machining operations ended at KCP in December 1952.

Also in 1952, KCP machined and handled natural uranium in the form of billets and ingots for AEC facilities at the Lake Ontario Ordinance Works in Youngstown, New York; Allegheny Ludlum in Watervliet, New York; and the Fernald site in Harrison, Ohio (Malone 1952a; Malone 1952b; Hobert 1953; Author unknown 1952).

2.2.2 Magnesium-Thorium Alloy Machining

KCP performed small-scale machining and fabrication of classified items with Mg-Th in the Main Manufacturing Building. The first report of Mg-Th machining at KCP was on August 23, 1961, in Department 20, and it continued there into 1962 as part of the RAdiation DEtection Capability (RADEC) weapons program (Foster 1961; Bendix 1958–2009, pp. 76–79).

The Mg-Th KCP first used was the alloy known as HK-31 from the Dow Chemical Company with a nominal 3% thorium content (Cayou 1958). In March 1963, KCP incorporated Dow's safety recommendations in *Magnesium-Thorium (3.5 % Max.), Suggested Care and Handling Methods* (Bendix 1963), then implemented controls for Department 20 machining.

Mg-Th operations were suspended beginning April 1, 1963, and did not begin again until after Health Services gave approval on August 28, 1970 (Foster 1970). Inventory information partially confirms the suspension of activities during this period. One data source with inventory information beginning in 1969 documents the presence of Mg-Th inventory starting in 1971 (Kolbay 2014). Another source, the Nuclear Materials Management and Safeguards System, corroborates the inventory information and documents the presence of Mg-Th beginning in 1971 (Smock 2014).

On August 28, 1970, KCP restarted operations in Department 20 and the Model Shop (also known as Department 851, later renamed Department 823) for the RADEC program (Foster 1970). During the second Mg-Th machining campaign (1970 to 1977), the Mg-Th was HM-21A, an alloy with less thorium (or 2% rather than 3%) (Tiehen 1987). This campaign involved machining work for U.S. Air Force Satellite Subsystems (Bendix 1974, p. 315). The equipment included a Van Norman mill, a CSIP Hydroptic 6A vertical-jig boring-machine, a Kearney & Trecker Milwaukee die mill, a Tape lathe, and a Heli-arc welder (Foster 1961).

2.2.3 Depleted Uranium Operations

KCP workers handled DU oxide beginning September 9, 1958, and continuing until 1971. They mixed the oxide with an encapsulate and machined and then inspected the product. This work occurred in the Machining Area, an area covering 12,000 ft^2 in the Main Manufacturing Building. The Machining Area was formerly Department 20.

The Machining Area was "cleaned and decommissioned" in the early 1970s after completion of DU production operations (Rockwell, 1987, pdf p. 106). However, there remained measurable levels of fixed radioactivity in sumps, floor drains, piping, floor expansion joints, and other surface areas. DOE remediated this area in phases and completed the final decontamination so that it met industrial standards by September 3, 1986.

In 1997, KCP began a new DU program to shape and size DU using an electrochemical process in an acid bath.

2.2.4 Thorium Oxide Powder Operations

KCP workers performed laboratory analysis and solution preparation work with thorium oxide (ThO_2) powder from July 23, 1958, through July 1959. Work included using ThO_2 sources and making thorium nitrate solutions.

2.2.5 Tritium Work and Operations

KCP workers used luminescent paint made with organically-bound tritium to fill engraved "Hi-Lo" switch plates. This work occurred between 1963 and 1968.

KCP workers also worked with tritium in the manufacture of tritium monitors from 1959 through 1975. The tritium was in the form of tritiated water in calibration standards for monitors of tritium in air, water, and urine.

2.2.6 Nickel Plating

KCP used ^{63}Ni as a part of the manufacturing of tritium monitors. The workers plated the ^{63}Ni onto aluminum plates for use as a calibration standard for tritium- in- air and urine monitors.

2.2.7 Decontamination and Decommissioning

KCP contracted with Rockwell International Corporation to perform Decontamination and Decommissioning of the Main Manufacturing Building in 1984. This work occurred between 1984 and 1986 and consisted of cleaning waste burial trenches and the Machining Area where uranium work had occurred.

2.3 OCCUPATIONAL SAFETY PROGRAM

The plant maintained a formal procedures manual (BAC 1958); Procedure S-306 of this manual, dated November 24, 1958, defines health and safety measures for receiving, handling, and storing the radioactive materials. Sections in the procedure address area access control, physical requirements, protective apparel, personal hygiene, material handling, production area, scrap and waste disposal, and injuries. KCP revised this procedure in 1960 (Foster 1960) and in 1962 (Foster 1962).

In 1965, the plant evaluated 23 categories of workers for potential exposure to solvents, alcohols, etc., and to radiation. Table 2-2 summarizes the evaluations for those categories in which workers had the

potential for exposure to radiation (Schiltz 1966a). There was a routine program of measuring uranium in urine (and lead in blood) for selected workers on a permanent access list for specific work areas (Bendix undated). The security, medical, and safety departments used this list together. Those on the list had permission to work in areas of radioactive material handling (Nasca 2004a). This list is no longer in use.

Table 2-2. Categorization of workers in special physical examination program working with radiation (Schiltz 1966a).

Group	Description	Potential exposure sources[a]
I	Radiation workers, Departments 22, 34C, and 217-22	Uranium oxide and litharge (lead) powders with particle size ranging from nearly 0 to 20 microns; fumes from chlorinated hydrocarbon solvents.
IV	X-ray workers, Department 213C	X-ray radiation or gamma radiation from Cs-137 source (7 Ci); parts containing uranium dioxide.
VI	Radiation workers, Departments 267, 268, and 280	Electronic tubes with a very small amount of radioactive material; drums with radioactive waste material (uranium dioxide) from Departments 22 and 34C.
X	Electron beam welders, Departments 45, 585, 201, 851, and Maintenance	Electron beam welders, which operate much like X-ray machines.
XV	Personnel handling neutron sources	There is none of this work at the plant at present; however, the Test Laboratory could be working with neutron sources in near future.
XX	Personnel using microderm thickness gauge	A small amount of beta radiation.

a. Note that physicals normally include chest X-rays. Firemen and patrolmen received physicals every 2 yr and had exit physicals. Cafeteria workers received physicals every 3 yr but no exit physicals. All other groups received an initial physical, annual periodic physical, and exit physical.

2.4 RADIATION MONITORING PROGRAM

The KCP Safety Department had primary responsibility for industrial hygiene and health physics. Potential exposure from X-rays and isotopic beta, photon, and neutron radiation sources represented a significant concern, but the historical emphasis appears to have involved higher potential nonradiological exposures to solvents such as acetone, methyl ethyl ketone, trichloroethylene, alcohol, toluene, and xylene; solvent fumes; epoxy resins and amine catalysts; polyester resins and peroxide catalysts, silicones, polysulfides, polyurethane, and tolylene isocyanate catalysts; and to fumes from acid, base, and salt chemicals of a wide variety. The focus appears to have involved ongoing evaluations of industrial, chemical, and radiological workplace hazards. There are records of frequent reviews of ionizing radiation equipment to evaluate the adequacy of shielding and interlocks. The earliest survey of radiation-generating devices (RGDs) apparently occurred in 1953 through the contracted services of a certified radiological physicist to evaluate the 1-MeV and 250-keV industrial X-ray units (Hoecker 1953). There are records of contamination surveys of the workplace using forms that imply a routine evaluation (Baldwin 1966).

2.5 RADIATION SOURCES

KCP operations used radiation as one of the analytical tools to accurately manufacture, fabricate, and inspect nonnuclear components of nuclear weapons. Table 2-3 summarizes the types of radioactive sources at KCP during 1964 and 1987. Significant differences involve the extensive earlier use of radium sources and the presence of the 230-Ci ^{137}Cs instrument calibration source in 1987. The primary radiation sources at KCP have involved analytical laboratory technologies for the manufacturing and testing of electronic and mechanical devices. The plant examined fabricated materials, parts, and assemblies for internal flaws and defects to ensure compliance with engineering specifications and requirements.

Table 2-3. Radiation sources and predominant radiation types.

Nuclide	Use	1964[a]	1987[b]	Type	Major energies (keV)
C-14	Calibration source, beta scope, thickness gauges	Yes	Yes	Beta	45–156
Fe-55	Testing	No	Yes	Gamma	Bremsstrahlung to 230
Co-60	Calibration sources	Yes	No	Gamma	1,170, 1,330
Ni-63	Gas chromatograph	No	Yes	Beta	67
Sr-90	Calibration, thickness gauges	No	Yes	Beta	546
Tc-99	Calibrations	No	Yes	Beta	292
Tl-204	Beta scope, thickness gauges	No	Yes	Beta	766
Cd-109	Plating thickness gauge	No	Yes	Gamma	88
Ba-133	Neutron generator	No	Yes	Gamma	30–382
Cs-137	Calibration sources	Yes	Yes	Beta	514–1,176
Cs-137	Calibration sources	Yes	Yes	Gamma	662
Pm-147	Calibration sources, thickness gauges	No	Yes	Beta	70–256
Tl-204	Beta scope, thickness gauges	No	Yes	Beta	766
Radium	Calibration sources, thickness gauges	Yes	Yes	Alpha	4,600–4,780
Radium	Calibration sources, thickness gauges	Yes	Yes	Gamma	186–610
Uranium	Calibration sources	No	No	Alpha/gamma progeny radiations from Th-230, Ra-226, etc.	Alpha/gamma progeny radiations from Th-230, Ra-226, etc.
Pu-239	Calibration sources, boron analysis	Yes	Yes	Alpha	5,110–5,160
Pu-239	Calibration sources, boron analysis	Yes	Yes	Gamma	39–770

a. Source: Schiltz (1964).
b. Source: Author unknown (1987).

In addition to the sources in Table 2-3, thorium oxide ThO_2 powder was handled in the plant" (Schiltz 1963, p. 12). Inventories of radiological sources show use of some ThO_2 sources and that KCP made a thorium nitrate solution at a rate of 20 g/yr (Allied-Signal 1989–1990).

In addition to the radiation sources, radiographic inspections involved the use of numerous RGDs. Table 2-4 lists typical RGDs, and the following summarizes radiation-generating examinations:

- X-Ray Radiography. KCP used X-ray machines of different sizes and power to examine fabricated materials for structural defects such as voids or inclusions in weld or braze joints. This is also useful for failure analysis of electrical and mechanical assemblies.

- Neutron Radiography. This is similar to X-ray radiography except it uses neutrons rather than X-rays. The primary advantage of neutron radiography is that high-density materials such as iron, lead, and uranium are nearly transparent to neutrons, while low-density materials such as organic compounds are highly absorptive to neutrons. This technique is particularly well suited to examining foams, encapsulants, or seals through relatively thick metal cases.

- Gauging. The plant used beta and X-ray techniques in a variety of applications to measure the thickness of materials. The backscatter of beta radiation can determine the thicknesses of platings and coatings.

KCP operations involved numerous analytical capabilities. Those involving ionizing radiation included nuclear magnetic resonance spectrometry, electron probe microanalysis, and scanning electron microscopy. Radiation protection surveys of equipment installations appear to have been an integral component of the safety program. For example, workplace surveys during 1960 and 1964 contain

detailed evaluations of the installations, normal operating conditions, routine survey instrumentation, enclosures, safety features, and electrical safeguards (Bendix 1960–1964; Bendix 1964–1965).

Table 2-4. Typical RGDs (HFMT 2004).

Devices	Energy (keV)	Types	Typical use	Period of use
Industrial X-ray units	50 to 2,000 (X-ray)	Rooms & cabinets	Radiography of parts	1950s–2004
DXT device[a]	12 to 200 (X-ray)	Cabinets	Density thickness	1960s–1980s
DXT device	Cs-137 (1 Ci)	Cabinets	Density thickness	1960s–1980s
Electron beam welders	35 to 150 (X-ray)	Cabinets	Welding small parts	1960s–2004
Electron microscopes	30 to 200 (X-ray)	Cabinets	Analysis	1960s–2004
Electron beam vacuum deposition systems	10 (X-ray)	Cabinets	Plating metals	1960s–2004
Neutron generators	14.7 MeV (neutron)	Open & cabinets	Generate microsecond pulsed radiation	1960s–2004
Neutron source	Pu-239/Be (73 mCi)	Cabinets	Boron-10 analysis	1966–2004
Neutron source	Pu-239/Be (10 mCi)	N/A	N/A	Received May 11, 1964
Neutron source	Ra/Be (20.48 mg)	N/A	Sandia workers	January 1955
Neutron source	Ra/Be (10 mg)	N/A	N/A	Received July 20, 1962
Gamma camera	Co-60 (19 Ci)	Exposure room	Test electronic products	1950s–1960s
Febetron accelerator	2,300 (X-ray) pulser	Cabinets	Irradiation of electronic components	1970s–1980s
Cesium irradiators	Cs-137 (230 Ci)	Exposure room	Calibration of radiation detection instruments	1950s–1980s
Medical X-ray	125 (X-ray)	Exposure room	X-rays of workers	Late 1950s–1990s
Electro curtain	175 (X-ray)	Cabinet	Radiation curing of adhesives	1980s–1990s

a. DXT = density times thickness.

Table 2-5. Radiation detection equipment list.[a]

Description	Detection Range	Number
Victoreen Low Range Beta-Gamma Survey Meter, Model #592B	0–1,000 mR/hr	2
Gas Proportional Alpha Survey Meters, Eberline Model #PAC-3G	0–100,000 cpm	4
Beta/Gamma Survey Meter, Nuclear Chicago Corporation, Model 2586	0–25, 0–250, and 0–2,500 mR/hr	1
Low-Range Beta-Gamma Survey Meters, Victoreen Model #389C	0–20 mR/hr	4
Fast-Slow Neutron Survey Meter, Nuclear Chicago Model #2715	$10–10^4$ n/cm^2	2
Air Proportional Alpha Survey Meter, Eberline Instrument Corp., Model #PAC-1A	0–100,000 cpm	1
Tritium Monitors, Atomic Accessories, Model #TSM91	0–100,000 mCi/cm^3 of air of tritium	2
Gamma Survey Meters, Victoreen Model 61720	0–500 R/hr	2
High Range Gamma Survey Meters, Eberline Instrument Corp., Model Gadora 1-B	0–5,000 R/hr	2
Victoreen Condenser R-Meter Model #570 with assortment of probes for energy and dose	Not applicable	2

Description	Detection Range	Number
Victoreen Model 510 Roentgen rate meter with assortment of probes	Not applicable	1
Gamma Radiation Monitor, Eberline Instrument Corp., Model RM-2	0–0.2 mR/hr	1
Beta-Gamma Count Rate Meters, Victoreen Model 743	0–60,000 cpm	2
Eberline Alpha Gas Proportional Floor Monitors, Model FM-2G	0–100,000 cpm	2
Pocket ionization dosimeters, charge readers, and approximately 170 dosimeters	0-100 R	Not known
Tritium Monitor, Atomic Accessories Corp., Model #TSM-91-C, BKC #29549	Not applicable	1
Alpha, Beta, Gamma Proportional Counter, Nuclear Measurements, Model PC3, Serial No. 275, BKC #14346	Not applicable	1
Proportional Counter Converter, Nuclear Measurements Corp., Model #PCC12A, Serial No. 145, BKC #17098	Not applicable	1
Cutie Pie Survey Meter, Model 2510, Nuclear Chicago	0–25,00 mR/hr	1

a. Source: Schiltz (1966b)

2.6 RADIATION DETECTION INSTRUMENTATION

The Industrial Hygiene Department appears to have had extensive radiation detection instrument capabilities. Table 2-5 lists the equipment from a memorandum that was apparently first written on May 19, 1964, and updated in August 1965 and March 1966 (Schiltz 1966b).

2.7 RADIOLOGICAL RECORDS

KCP has developed and maintained a radiological records database that contains records for all monitored worker exposures at KCP for all years of record.

The database contains exposure data for about 4,400 workers. General trends in the recorded dose are:

- Positive deep, shallow, and extremity doses first occurred in 1950.
- Positive neutron doses first occurred in 1966.
- Before about 1959, the recorded deep and shallow doses were essentially equal.
- Recorded extremity dose was higher in 1951 and 1952 than in any other year.
- Relatively high shallow dose (in comparison with deep dose) occurred from 1959 to 1964 and during 1973.
- Recorded neutron dose is typically equal to recorded deep dose and to recorded shallow dose. The shallow dose is typically equal to the deep dose.
- There are comparatively few records with positive neutron dose.
- The only years with recorded positive uranium bioassay results are 1959 to 1971.

It appears KCP recorded some doses in nearly all occupational categories. The records of higher doses and information from Nasca (2004b) indicate KCP assigned some doses to workers even though investigations at the time of measurement showed unexplainable causes. Given the information available, dose reconstructors should treat these doses as actual.

A KCP health physicist provided a spreadsheet with internal and external dosimetry data for 1950 through 2003 (Nasca 2004d). It includes 14,759 lines; each linecontains between one and five individual external dose records. Each individual record is the sum of the individual monitoring results throughout a given year. The spreadsheet does not contain names or social security numbers, but KCP transferred the complete database with this information to NIOSH on February 9, 2012 (HFMT 2012).

The previous revision of this document contained a coworker model based on the spreadsheet data. The KCP SEC petition evaluation report uses the coworker model to bound some doses (NIOSH 2014). NIOSH performed a validation and verification (V&V; Darnell et al. 2015) of the complete database. The V&V showed accurate transfer of data from raw exposure records into a database and that the information is sufficiently accurate. As a result, dose reconstructors may use recorded doses from the KCP database to supplement the hard-copy original dosimeter processing information from DOE. In many cases the original records are difficult to read.

3.0 OCCUPATIONAL MEDICAL DOSE

As part of the requirements for employment at KCP starting in 1949, employees received preemployment, periodic, and/or termination physical examinations (Todd 2004a). These physical examinations might have included radiographic examinations of the chest to screen for disease. Because these were a job requirement, OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* (NIOSH 2007) requires the X-ray doses to be included as occupational radiation dose. This section discusses medical X-rays for screening that KCP required as a condition of employment. However, it does not include diagnostic and therapeutic exposures for diagnosis or treatment of disease or work-related injuries. The EEOICPA excludes those X-rays from dose reconstruction.

The following sections describe the estimation of absorbed dose from X-ray exposures for KCP workers. Section 3.1 describes the X-ray screening examination frequency at KCP from historical documents and claim file records. Section 3.2 provides information on equipment and techniques, including assumptions from a lack of protocol, measurement, or records data. Section 3.3 provides organ dose estimates by calendar year and type of X-ray. Section 3.4 documents uncertainty of dose estimates.

3.1 EXAMINATION FREQUENCY

All workers, including fire, patrol, radiation, and cafeteria workers, received a chest X-ray during the preemployment examination and annually thereafter until the mid-1980s (Todd 2004b, Todd 2004c, Brendlinger 1974, Stowers 1951a). The preemployment chest X-ray was discontinued in the mid-1980s. Several sources mention that the chest X-ray was a single posterior-anterior (PA) projection (Bendix 1976; Brendlinger 1974; Jacobson 1988; Todd 2004b). This is evident from the claim file records; lateral (LAT) chest X-rays are rare. Beginning in 1993 chest X-rays were taken every 5 years, or more frequently if worker history or physical circumstances indicated the need. In 1997, medical X-ray services were outsourced, presumably off site (Todd 2004c). A review of X-rays from the 1950s and 1960s (Todd 2004c) found no evidence that KCP used photofluorography. Table 3-1 summarizes the frequency of chest X-rays.

Dose reconstructors should assume annual PA chest X-rays through 1996. X-rays after 1996 do not qualify for dose reconstruction (ORAUT 2016a). Assign dose from the records (through 1996) in the claim file or according to the frequency in Table 3-1 if records are not available. Do not assign dose from photofluorography unless the claim file contains a record of it.

Other X-rays (lumbar spine, thoracic, etc.) are likely to be nonoccupational in the sense that they were associated with illness or injury and were not part of a screening process. There is no indication in the records that other radiographic examinations routinely occurred for screening.

Table 3-1. Frequency of occupational X-ray screening.

Period	Workers	X-ray projections	Frequency
1949–1985	All workers	PA chest[a]	Preemployment, annual, and termination
1986–1992	All workers	PA chest	Annual and termination[a]
1993–1996	All workers	PA chest	Every 5 years[b]
1997–present	Outsourced, presumably off site[b]	Outsourced, presumably off site[b]	Outsourced, presumably off site[b]

a. Todd 2004b.
b. Todd 2004c, p. 3.

3.2 EQUIPMENT AND TECHNIQUES

1949 to 1961
The earliest mention of X-ray equipment at KCP is from 1958 and is a memorandum about a survey of the medical X-ray equipment (Pettie 1958) following National Bureau of Standards Report 60 (NBS 1955). However, there is not enough technical information in this memo to use for dosimetric purposes.

Survey results from 1961 (Staggs and Schiltz 1961; Schiltz 1961), indicate the X-ray machine was from General Electric Company (GE) with 2.0-mm Al equivalent total filtration and includes the model, serial, and presumably the property number. The form states that there was no "cone" or beam limitation. There are no recorded primary beam measurements, but the form gives the technique for a PA chest X-ray as 76 kVp, 100 mA, and 0.1 s. The half-value layer (HVL) is 2.0 mm Al for 2.0-mm Al equivalent total filtration at 76 kVp (NCRP 1997).

Using this information, the methods in ORAUT-OTIB-0006 (ORAUT 2011a), and average air kerma rates from National Council on Radiation Protection and Measurements (NCRP) Report 102, the incident air kerma at the source-to-skin distance (SSD) is 2.29×10^{-2} cGy (NCRP 1997). This value includes a correction made for the 2.0-mm Al total filtration in this machine but using the tabulated values in Report 102, which are for 2.5 mm Al total filtration. While it is not certain this X-ray equipment was the original equipment from 1949 or 1950, the analysis assumed so.

The organ doses for this period (Table 3-2) are based on an incident air kerma of 2.29×10^{-2} cGy for a PA chest X-ray, poor collimation, and an HVL of 2.0 mm Al at 75 kVp.

1962 to 1970
Survey results from 1962 appear to be from a different GE machine because there are different model, serial, and property numbers (Meunier, Stewart, and Shiltz 1962). The reported total filtration is 2.5 mm Al equivalent, and there is mention of a "cone" for beam restriction. A 1964 survey has a rectangular diagram of the X-ray field, so this machine had an adjustable collimator to restrict the beam (Harrison, Meunier, and Schiltz 1964).

The staff made ionization chamber measurements in the primary beam of this machine with pencil ionization chambers taped to the wall with the X-ray tube 72 in. away, as it would be for a PA chest X-ray. The technique factors for the ionization chambers were 75 kVp, 100 mA, and 0.5 s (Harrison, Meunier, and Schiltz 1964), while the chest X-rays were exposed at 0.1 s. Several ionization chamber measurements were made at 4, 8, 12, and 16 in. from the center of the beam. By assuming that the measurement at 4 in. from the center would be about 70% of the center value, this analysis estimated the center measurement as 37 mR. This exposure measurement converts to an incident air kerma of 9.14×10^{-3}cGy at the SSD and after scaling to the exposure time for chest X-rays.

The organ doses for this period (Table 3-2) are based on an incident air kerma of 9.14×10^{-3} cGy for a PA chest X-ray, poor collimation, and an HVL of 2.5 mm Al at 75 kVp.

1971 to 1981
Several radiation surveys from this period seem to indicate still another GE machine because of different model and serial numbers (Meunier 1977, p. 4; DeCloud 1981a; Meunier and DeCloud 1980). A survey of a machine in 1984 mentions KCP installed the machine in 1971 (DeCloud 1984). The staff made ionization chamber measurements in the primary beam of this machine with pencil ionization chambers taped to the wall cassette holder to determine the average radiation exposure for a PA chest X-ray. The measurements, using both maximum and minimum chest technique factors, were averaged. The reported results range from 13 to 14 mR, which are presumably the actual readings of the ionization chamber at 72 in. from the X-ray tube.

Converting the 14-mR ionization chamber measurement to an incident air kerma using the equations in ORAUT-OTIB-0006 (ORAUT 2011a) results in an incident air kerma of 1.71×10^{-2} cGy. The filtration or HVL is not mentioned, so the analysis assumed the HVL is 2.5 mm Al for the PA chest technique factors. A further assumption for this period is proper collimation. Table 3-2 lists the organ doses.

1982 to 1996
The same type of ionization chamber measurements continued in this period. There is no evidence to date of a new machine during this period. However, the ionization chamber measurement increased to 43 to 49 mR rather than the 14 mR in the previous period (Bendix Corporation ca. 1981; DeCloud 1982, 1983). The cause of this appears to be that KCP added a grid at this time to improve the chest X-ray images, which would explain the increase in the ionization chamber measurement. There is one handwritten notation in the survey results for 1982 that mentions adding a grid (Bendix Corporation ca. 1981).

The Food and Drug Administration (FDA) performed a survey in 1984 and measured the entrance skin exposure at 18 mR with a standard phantom (Patterson 1984, p. 3). This is lower than the above measurements, so the analysis assumed there was no grid. The inspector noted that the machine was manufactured before 1974 and did not have a phototimer or a positive beam-limiting device (automatic collimator). These factors indicate this machine was the same as in the previous period. Another document mentions that par speed (i.e., medium) film and screens (Jacobson 1988, p. 7). Which persons might have been X-rayed with a grid is unknown, and because the use of a grid to produce chest X-rays would have been good practice during the 1980s, the higher measured values in the previous paragraph were used to determine the organ doses.

Converting the 49-mR ionization chamber measurement to an incident air kerma using the equations in ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-Ray Procedures* (ORAUT 2011a), results in an incident air kerma of 5.99×10^{-2} cGy. FDA measured the HVL at 2.5 mm Al for 90 kVp (Patterson 1984, p. 2). A further assumption for this period is proper collimation. Table 3-2 lists the organ doses.

KCP outsourced X-rays starting in 1997, presumably to an offsite facility (Todd 2004c). While it is unlikely that the same X-ray machine has been in service since 1971 when the latest known GE machine was installed, the available records do not indicate otherwise. Therefore, the analysis assumed organ doses are valid through 1996 when X-rays were outsourced.

3.3 ORGAN DOSE ESTIMATES

The analysis determined organ dose equivalents using the methods in ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-Ray Procedures* (ORAUT 2011a), the above incident air kerma values, and dose conversion factors (DCFs) from International Commission on Radiological Protection (ICRP) Publication 34 (ICRP 1982). The dose equivalents incorporate assumptions of poor beam collimation for chest X-rays before 1971 and proper collimation starting in 1971.

Table 3-2 lists organ dose equivalents for PA chest X-rays for each period, and Table 3-3 lists skin dose equivalents.

The tissue at risk for chronic lymphocytic leukemia is the B-lymphocytes. The analysis used the method in ORAUT-OTIB-0082, *Dose Reconstruction Method for Chronic Lymphocytic Leukemia* (ORAUT 2012a), site-specific information, and ICRP Publication 34 DCFs (ICRP 1982) to determine the dose equivalent to the B-lymphocytes. Table 3-4 provides dose distributions and statistical parameters for input into the Interactive RadioEpidemiological Program (IREP).

Table 3-2. Organ dose equivalents for PA chest X-rays (rem).

Organ	1949–1961	1962–1970	1971–1981	1982–1996
Thyroid	3.45E–03	1.59E–03	5.47E–04	1.92E–03
Eye/brain	4.80E–04	2.92E–04	5.47E–04	1.92E–03
Ovaries	2.63E–03	1.54E–03	1.71E–05	5.99E–05
Liver/gall bladder/spleen/pancreas	8.12E–03	4.12E–03	7.71E–03	2.70E–02
Urinary bladder/prostate	2.63E–03	1.54E–03	1.71E–05	5.99E–05
Colon/rectum	2.63E–03	1.54E–03	1.71E–05	5.99E–05
Testes	1.30E–04	8.32E–05	1.71E–07	5.99E–07
Lungs male	7.66E–03	3.83E–03	7.17E–03	2.51E–02
Lungs female	8.12E–03	4.12E–03	7.71E–03	2.70E–02
Thymus	8.12E–03	4.12E–03	7.71E–03	2.70E–02
Esophagus	8.12E–03	4.12E–03	7.71E–03	2.70E–02
Stomach	8.12E–03	4.12E–03	7.71E–03	2.70E–02
Bone surfaces	8.12E–03	4.12E–03	7.71E–03	2.70E–02
Remainder	8.12E–03	4.12E–03	7.71E–03	2.70E–02
Breast	7.32E–04	4.48E–04	8.38E–04	2.93E–03
Uterus	2.36E–03	1.36E–03	2.22E–05	7.78E–05
Bone marrow male	1.58E–03	8.41E–04	1.57E–03	5.51E–03
Bone marrow female	1.44E–03	7.86E–04	1.47E–03	5.15E–03
Skin[a]	3.02E–02	1.23E–02	2.31E–02	8.08E–02

a. Entrance skin dose equivalent (ENSD) is determined by multiplying the incident air kerma by the backscatter factors of 1.32 and 1.35 for HVLs of 2.0 and 2.5 mm Al, respectively, from NCRP Report 102 (NCRP 1997, Table B-8). See Table 3-3 for skin doses.

Table 3-3. Skin dose guidance and skin dose equivalents (rem) for PA chest X-rays.[a,b]

Area of skin	PA chest guidance ≤1970	PA chest 1949–1961	PA chest 1962–1970	PA chest guidance >1970	PA chest 1971–1981	PA chest 1982–1996
Right front shoulder	EXSD	6.E–04	3.E–04	EXSD	5.E–04	1.8E–03
Right back shoulder	ENSD	3.02E–02	1.23E–02	ENSD	2.31E–02	8.08E–02
Left front shoulder	EXSD	6.E–04	3.E–04	EXSD	5.E–04	1.8E–03
Left back shoulder	ENSD	3.02E–02	1.23E–02	ENSD	2.31E–02	8.08E–02
Right upper arm to elbow	ENSD	3.02E–02	1.23E–02	10% ENSD	2.3E–03	8.1E–03
Left upper arm to elbow	ENSD	3.02E–02	1.23E–02	10% ENSD	2.3E–03	8.1E–03
Left hand	ENSD	3.02E–02	1.23E–02	10% ENSD	2.3E–03	8.1E–03
Right hand	ENSD	3.02E–02	1.23E–02	10% ENSD	2.3E–03	8.1E–03
Left elbow, forearm, wrist	ENSD	3.02E–02	1.23E–02	10% ENSD	2.3E–03	8.1E–03
Right elbow, forearm, wrist	ENSD	3.02E–02	1.23E–02	10% ENSD	2.3E–03	8.1E–03
Right side of head including ear and temple	10% ENSD	3.0E–03	1.2E–03	10% ENSD	2.3E–03	8.1E–03
Left side of head including ear and temple	10% ENSD	3.0E–03	1.2E–03	10% ENSD	2.3E–03	8.1E–03
Front left thigh	RSD (0.52 m)	7.E–04	4.E–06	RSD (0.52 m)	7.E–06	2.E–05

Area of skin	PA chest guidance ≤1970	PA chest 1949–1961	PA chest 1962–1970	PA chest guidance >1970	PA chest 1971–1981	PA chest 1982–1996
Back left thigh	RSD (0.52 m)	7.E–04	4.E–06	RSD (0.52 m)	7.E–06	2.E–05
Front right thigh	RSD (0.52 m)	7.E–04	4.E–06	RSD (0.52 m)	7.E–06	2.E–05
Back right thigh	RSD (0.52 m)	7.E–04	4.E–06	RSD (0.52 m)	7.E–06	2.E–05
Left knee and below	RSD (0.86 m)	3.E–04	1.E–06	RSD (0.86 m)	2.E–06	8.E–06
Right knee and below	RSD (0.86 m)	3.E–04	1.E–06	RSD (0.86 m)	2.E–06	8.E–06
Left side of face	Eye/Brain	5.E–04	3.E–04	Eye/Brain	5.E–04	1.9E–03
Right side of face	Eye/Brain	5.E–04	3.E–04	Eye/Brain	5.E–04	1.9E–03
Left side of neck	ENSD	3.02E–02	1.23E–02	10% ENSD	2.3E–03	8.1E–03
Right side of neck	ENSD	3.02E–02	1.23E–02	10% ENSD	2.3E–03	8.1E–03
Back of head	10% ENSD	3.0E–03	1.2E–03	10% ENSD	2.3E–03	8.1E–03
Front of neck	Eye/Brain	5.E–04	3.E–04	Thyroid	5.E–04	1.9E–03
Back of neck	ENSD	3.02E–02	1.23E–02	10% ENSD	2.3E–03	8.1E–03
Front torso: base of neck to end of sternum	EXSD	6.E–04	3.E–04	EXSD	5.E–04	1.8E–03
Front torso: end of sternum to lowest rib	EXSD	6.E–04	3.E–04	EXSD	5.E–04	1.8E–03
Front torso: lowest rib to iliac crest	EXSD	6.E–04	3.E–04	10% EXSD	5.E–05	2.E–04
Front torso: iliac crest to pubis	10% EXSD	6.E–05	3.E–05	10% EXSD	5.E–05	2.E–04
Back torso: base of neck to mid–back	ENSD	3.02E–02	1.23E–02	ENSD	2.31E–02	8.08E–02
Back torso: mid–back to lowest rib	ENSD	3.02E–02	1.23E–02	ENSD	2.31E–02	8.08E–02
Back torso: lowest rib to iliac crest	ENSD	3.02E–02	1.23E–02	10% ENSD	2.3E–03	8.1E–03
Back torso: buttocks (Iliac crest and below)	10% ENSD	3.0E-03	1.2E-03	10% ENSD	2.3E-03	8.1E-03
Right torso: base of neck to end of sternum	ENSD	3.02E-02	1.23E-02	ENSD	2.31E-02	8.08E-02
Right torso: end of sternum to lowest rib	ENSD	3.02E-02	1.23E-02	ENSD	2.31E–02	8.08E–02
Right torso: lowest rib to iliac crest	ENSD	3.02E–02	1.23E–02	10% ENSD	2.3E–03	8.1E–03
Right torso: iliac crest to pubis (right hip)	10% ENSD	3.0E–03	1.2E–03	10% ENSD	2.3E–03	8.1E–03
Left torso: base of neck to end of sternum	ENSD	3.02E–02	1.23E–02	ENSD	2.31E–02	8.08E–02
Left torso: end of sternum to lowest rib	ENSD	3.02E–02	1.23E–02	ENSD	2.31E–02	8.08E–02
Left torso: lowest rib to iliac crest	ENSD	3.02E–02	1.23E–02	10% ENSD	2.3E–03	8.1E–03
Left torso: iliac crest to pubis (left hip)	10% ENSD	3.0E–03	1.2E–03	10% ENSD	2.3E–03	8.1E–03

a. ENSD = entrance skin exposure; EXSD = exit skin exposure; RSD = remote skin dose.
b. Values less than 0.1 mrem shown to one significant digit.

Table 3-4. IREP dose distributions and statistical parameters for the dose to the B-lymphocytes.

Projection and period	IREP distribution	Parameter 1	Parameter 2	Parameter 3
PA chest 1949–1961	Weibull3	2.822290	0.004820	6.90976E-06
PA chest 1962–1970	Weibull3	2.929763	0.002503	9.79606E-06
PA chest 1971–1981	Weibull3	2.067236	0.003250	-1.38818E-07
PA chest 1982–1996	Weibull3	2.054835	0.011383	1.11014E-05

3.4 UNCERTAINTY

ORAUT-OTIB-0006 lists these five major sources of uncertainty in X-ray output intensity and their effects on dose to the worker (ORAUT 2011a):

- X-ray beam measurement error (±2%),
- Variation in peak kilovoltage (±9%),
- Variation in X-ray beam current (±5%),
- Variation in exposure time (±25%), and
- Variation in source-to-skin distance as a result of worker size (±10%).

The 10% uncertainty in output intensity as a result of worker size derives from an inverse square correction of output intensity changes from differences of standard chest thickness of ±7.5 cm.

Uncertainties are usually random; therefore, the analysis calculated the combined statistical uncertainty as the square root of the sum of the squares of all the uncertainties, which is ±28.9%. Rounding this to ±30% provides an adequate and suitably conservative indication of uncertainty. Therefore, a total combined standard uncertainty of ±30% applies to a derived dose equivalent to an individual organ other than the B-lymphocytes. Dose reconstructors should, therefore, input the organ dose equivalent as the mean of a normal distribution with a standard uncertainty of ±30%.

4.0 OCCUPATIONAL ENVIRONMENTAL DOSE

4.1 EXTERNAL AMBIENT DOSE

KCP prepared a site safety assessment in 1995 (Allied-Signal 1995) that concluded that plant operations had produced no undue hazard to the general public and no significant effect on the environment. It appears that there were minimal, if any, historical radiological effects. Staff routinely monitored air and water effluents to assess compliance with relevant criteria. KCP routinely handled hazardous chemicals, but there was limited handling of radioactive materials. Therefore, significant occupational environmental exposure from releases were unlikely. The plant did generate low-level radioactive waste including equipment radiation sources, tritium exit signs, irradiated components, gap tubes, smoke detectors, and small amounts of cleanup materials and personal protective equipment. Mixed wastes (hazardous and radioactive) consisted of encapsulated electronic assemblies and spent solvents for cleaning and decontaminating radioactive materials (primarily defective sources).

There was no significant offsite environmental exposure to the public. Therefore, the analysis calculated that the variability in ambient exposure of background control personnel dosimeters at 2-sigma (25 mrem per year) is favorable to unmonitored workers (Attachment A). For a best estimate of external ambient dose, dose reconstructors should assign 25 mrem per year using the organ DCFs for isotropic exposure geometry in accordance with ORAUT-PROC-0060*, Occupational Onsite Ambient Dose Reconstruction for DOE Sites* (ORAUT 2006b).

4.2 INTERNAL ENVIRONMENTAL DOSE

The primary and apparently only substance present in large quantities with a potential for significant environmental release was DU from 1958 through 1970. As described in Attachment A, the recommended approach to assign an internal environmental dose to unmonitored nonradiological workers is to assume an annual intake fraction of 0.01 times the GM annual measured air concentrations in Table 5-3 (i.e., multiply annual concentrations in Table 5-3 by 6.58×10^{10} to convert to picocuries per day). The 0.01 estimate of the decrease in concentration is favorable to claimants based on dispersion between inside and outside air concentrations.

For the period after 1970, there are no workplace air sampling data available for analysis. There is a potential for unknown small releases or residual contamination, such as the known incident with ^{147}Pm in 1989, so the same factor of 0.01 factor, along with the GM annual measured air concentration (for all years) from Table 5-3, applies to this period. Beginning in 1990, there is assurance that no significant environmental releases occurred based on the multiagency response findings to the ^{147}Pm incident.

Section 5.0 discusses internal doses for other operational and postoperational periods from natural uranium, Mg-Th, and tritium. Dose reconstructors should assign environmental dose to unmonitored workers who meet the requirement for a given timeframe and work department as indicated in Section 5.2.

Dose reconstructors should assign environmental intakes per Table A-4 in Attachment A for depleted uranium, and in subsection of section 5.2 based on work in those areas.

5.0 OCCUPATIONAL INTERNAL DOSE

KCP has handled numerous types of radioactive sources (Table 2-3). Most of these sources are sealed or contained as components of various types of equipment. There have been no recorded incidents involving confirmed internal intakes (Lund 2004). The primary source of workplace exposure was from machining involving DU oxide from 1958 to about 1971. The program that used DU oxide ended in 1972 (Nasca 2005a).

No other uranium was processed until 1997 when a new program began. From 1997 to 2013 KCP used an electrochemical process to reduce DU metal in size and shape. The process involved the placement of DU metal in an acid bath. The parts were rinsed with water and dried before handling. Because the uranium did not become volatile during the electrochemical process (it remained in the acid solution), there was minimal potential for internal dose from this process. There is no removable contamination with this process (Nasca 2005a). Bioassay data (urine assays) and air monitoring data are available only for 1959 through 1971.

The intakes derived in the following sections apply to workers at the Kansas City Plant involved in several operation eras that are congruent. Where intakes are applied for a full year, a worker is not expected to be exposed to multiple internal hazards simultaneously. Dose reconstructors should evaluate all applicable intakes from the following sections, and apply the intakes resulting in the highest dose when timeframes overlap. i.e., a worker cannot be exposed full-time to uranium and thorium operations at the same time. Dose reconstructors should apply the sourceterm associated with recycled uranium in Section 5.3 for all uranium exposures after 1952.

5.1 DEPLETED URANIUM

The uranium at KCP was DU. Table 5-1 lists typical weight percents and activity fractions of uranium isotopes. When estimating intakes, dose reconstructors should assume exposures to uranium dust were chronic. A chronic exposure pattern best approximates the true exposure conditions for most workers with a potential for intakes. In addition, a chronic exposure pattern approximates a series of acute intakes, which makes it appropriate when there is no specific information for a given individual.

For internal dose calculations, dose reconstructors should evaluate internal doses assuming the uranium mix is 100% U-234.

Table 5-1. Mass and specific constituent activity in mixture[b] of DU.

Isotope	Weight percentage[a]	Bq/mg	pCi/mg	dpm/mg
U-234	0.0010	2.3116	62.4757	138.696
U-235	0.1991	0.1592	4.3028	9.5523
U-236	0.0003	0.0072	0.1941	0.4308
U-238	99.7996	12.4111	335.4345	744.6647
Totals	Not applicable	**14.889**	**402.4071**	**893.3437**

a. Source: IMBA.
b. Could vary from IMBA values due to rounding.

5.1.1 Physical and Radiological Characteristics

KCP had substantial quantities of UO_2 on the site at various times. Order number ICO-020757 (Bendix 1962) shows that UO_2 was ordered in 10,000-lb lots. The relevant specifications from Specification Control No. 4542260-00 (Allied-Signal 1998) were that the minimum density should be no less than 10.8 g/cm^3, the surface area of the powder should be no greater than 1.1 m^2/g, at least 97% by weight of the material should be less than 10 µm in diameter, and 100% by weight should be

less than 15 µm in diameter. These specifications are consistent with a powder having an activity median aerodynamic diameter (AMAD) of 1.175 µm and a Sigma-G of 2.48.

In fitting bioassay data, dose reconstructors may wish to start with a 1-µm AMAD, a GSD of 2.5, a density of 10.97 g/cm^3, a lung solubility Typetype S, and f1 of 0.002 (ICRP 1994b). However, it is not known what impact processes at KCP had on the particle size of uranium. Use of the default 5-µm AMAD particle size is also acceptable unless it is known that the intake was of unaltered UO_2 powder. When using the 5-µm AMAD particle size and other default parameters, dose reconstructors should evaluate solubility types M and S and apply the higest dose.

5.1.2 Workplace Monitoring

Table 5-2 summarizes alpha radiation contamination results from 1962 to 1969 in DU work areas with the most significance to potential worker exposure (HFMT 2004). In addition, from 1958 to 1970 workplaces were routinely monitored with air samplers for DU concentrations (Nasca 2004c). Table 5-3 lists the maximum measured workplace concentrations and the calculated values of the GM and 95th percentile concentrations.

Table 5-2. Measured alpha contamination levels (dpm/100 cm^2), 1962 to 1969 (HFMT 2004).

Facility	Work area	Average	Maximum
D/34C (D/27C)	Air lock	226	20,000
D/34C (D/27C)	Locker room	570	7,000
D/34C (D/27C)	General area	2,564	45,000
D/220-22 (D/443-20D D/216-22, D/217-20D)	Air lock	190	800
D/220-22 (D/443-20D D/216-22, D/217-20D)	Wash-up	180	650
D/220-22 (D/443-20D D/216-22, D/217-20D)	General area	425	1,000
D/22, D/20D	Air lock	206	350
D/22, D/20D	Clean area	468	2,000
D/22, D/20D	General area	892	16,000

Eating and smoking were prohibited in DU processing areas. However, at least one survey report indicated the presence of cigarette butts, candy wrappers, and coffee cups in the exclusion area (Baldwin 1966). This indicates that ingestion of DU was a possible route of occasional intake. To be favorable to claimants, dose reconstructors should assume inhalation or ingestion intakes.

The parameters in Table 5-3 were based on maximum measured air concentrations at several locations in the plant. Some locations were identified only by a number. When locations were available, most were near the walls of the work areas. Other locations were labeled as “Mixing Rm, West,” “Air Lock,” “Over Shower,” “Rubber Mill Rm,” “Mill Stack West,” and “Dispersion Roll.”

5.1.3 Bioassay

KCP monitored some workers for DU intake from 1959 to 1971 using a fluorophotometric method to measure the level of uranium in urine. Author unknown (1962) states that the method was sensitive to concentrations of uranium from 1×10^{-10} to 5×10^{-11} g per 0.25 g of sodium fluoride with a precision of ±10%. This sensitivity equates to 0.5 to 1 µg U/L of urine. However, this sensitivity could be the theoretical best based on ultrapure water blanks rather than urine blanks. The urine volume for bioassay analysis was 0.1 mL, and the smallest amount of uranium used to determine a standard curve was 1×10^{-9} g. The urine concentration that equates to the lowest uranium quantity of the standard curve is 10 µg/L. Bioassay data for four individuals (Nasca 2005b) shows that

Table 5-3. Measured results[a] and lognormal statistical parameters of DU in workplace air (µCi/cm^3).[b]

Year	Number of measurements	Average of measurements	Maximum of measurements	GM	95%	GSD
1958	22	7.18E-12	4.90E-11	4.01E-13	1.74E-10	4.02E+01
1959	27	8.82E-13	1.22E-11	2.89E-13	2.53E-12	3.74E+00
1960	33	1.32E-12	1.50E-11	3.41E-13	3.94E-12	4.43E+00
1961	31	1.00E-12	2.04E-11	1.97E-13	1.52E-12	3.46E+00
1962	31	7.73E-13	1.13E-11	2.50E-13	2.03E-12	3.58E+00
1963	31	1.25E-12	1.63E-11	2.47E-13	1.90E-12	3.46E+00
1964	31	2.21E-12	3.90E-11	3.91E-13	2.98E-12	3.44E+00
1965	31	1.99E-13	8.70E-13	1.05E-13	8.02E-13	3.45E+00
1966	23	7.01E-13	6.24E-12	2.00E-13	2.00E-12	4.06E+00
1967	22	1.40E-12	1.30E-11	5.70E-13	3.12E-12	2.81E+00
1968	19	1.21E-12	9.88E-12	2.31E-13	3.47E-12	5.19E+00
1969	19	1.88E-11	8.55E-11	3.88E-12	1.42E-10	8.92E+00
1970	19	7.32E-14	5.91E-13	4.02E-14	1.98E-13	2.64E+00

a. All departments.
b. Based on maximum measured workplace airborne uranium concentrations at several monitoring locations.

concentrations as low as 1 µg U/L were recorded. However, most sites using fluorophotometry at this time were claiming more modest detection levels. For example, Hanford reported 4 µg/L (ORAUT 2015a), Paducah reported 10 µg/L (ORAUT 2012b), and the University of Rochester (used by many atomic weapons employers) reported 5 to 10 µg/L (ORAUT 2010). Unless there is information to the contrary in the claimant records, a minimum detectable amount of 10 ug/L is to be assumed.

The frequency of bioassay analysis for KCP personnel who worked with DU powders is not known. The available data are annual and might be the sum of one or more bioassay measurements. If the individual case information does not contain additional information, dose reconstructors should make the assumption that the recorded bioassay quantities represent a single bioassay measurement at the end of the calendar year.

By procedure (Bendix undated), KCP was to bioassay for uranium in the urine of workers in radiation areas 20D, 34C, and 443E-20 twice a year (May and November). However, the actual frequency of bioassay analysis for KCP personnel varied from person to person and from year to year (Nasca 2005b). The staff recorded bioassay data on either the individual's film badge envelopes or the annual 3- by 5.5-in. radiation exposure record (Nasca 2005b). The dates and results of individual bioassay results are in each individual's dosimetry file.

The only available electronic bioassay data are the numeric sums of all bioassay measurements during the year for an individual (Nasca 2004d). However, they could be the sum of one or more bioassay measurements because the data do not include the number of measurements. Bioassay data from four individuals (Nasca 2005b) revealed the number of bioassay samples per year ranged from zero to six. Zero samples per year means that there are gaps in the bioassay record where one or more years of no bioassay data are bracketed by years for which there are bioassay data. In 1960 and 1961, there appears to have been more urine sampling and the results were higher than for other years. The available records contain no explanation for the increase. There are no known records of an incident involving DU powder in those years (Nasca 2005a).

Table 5-4 summarizes the analysis of the electronic bioassay records (Nasca 2004d). These data show a peak in 1960 and 1961. The peak is apparently not the result of an incident (Nasca 2005c) but could be due to a large number of bioassay samples in those years for each worker. The bioassay data for 1971 are very low, less than the sensitivity level. The low bioassay levels might

indicate no intakes of uranium during that year. As noted above, the excreta data in Table 5-4 represent the sum of an unstated number of bioassay measurements.

Table 5-4. Measured annual results, lognormal statistical parameters, and chronic intakes of recorded DU in urine.[a]

Year	Number of workers reported[b]	Mean concentration (µg/L)[b]	Maximum concentration (µg/L)[b]	Median concentration (µg/L)	GSD (µg/L)	Chronic intakes, 5th[c] (pCi/d)	Chronic intakes, median[c] (pCi/d)	Chronic intakes, 95th[c] (pCi/d)
1958[d]	N/A	N/A	N/A	N/A	N/A	1.46E+02 See note[d]	8.91E+02	5.43E+03
1959	214	4.125	52.60	2.642	2.675	1.05E+02	6.42E+02	3.92E+03
1960	281	36.58	140.	19.53	3.813	7.79E+02	4.75E+03	2.89E+04
1961	123	51.40	192.1	37.44	2.402	1.49E+03	9.10E+03	5.55E+04
1962	148	4.327	15.75	3.162	2.508	1.26E+02	7.69E+02	4.69E+03
1963	211	10.96	72.00	7.564	2.532	3.02E+02	1.84E+03	1.12E+04
1964	219	5.627	78.38	3.888	2.431	1.55E+02	9.46E+02	5.76E+03
1965	175	9.572	38.00	5.583	3.422	2.23E+02	1.36E+03	8.27E+03
1966	223	6.432	45.05	4.214	2.640	1.68E+02	1.02E+03	6.24E+03
1967	159	5.438	21.50	3.574	2.713	1.43E+02	8.69E+02	5.30E+03
1968	11	6.055	6.600	6.052	1.029	2.42E+02	1.47E+03	8.97E+03
1969	1	0.15	0.150	0.150	1.000	5.99E+00	3.65E+01	2.22E+02
1970	59	11.64	45.00	7.576	2.686	3.02E+02	1.84E+03	1.12E+04
1971	47	0.03596	0.1000	0.02993	1.903	1.19E+00	7.28E+00	4.44E+01
ALL	1,871	14.1	192.1	5.5	4.7	N/A	N/A	N/A

a. All bioassay measurements: N/A = not applicable.
b. The recorded annual sum of urine concentration is the sum of all bioassay results for the year. There is one sum for each person-year record. The listed statistics are based on the analysis of the data, which are the sums of all bioassay data for every person for that year.
c. Chronic intakes that produce the urinary excretion per day on the 365th day of intakes corresponding to the GM excretion from the lognormal fit and 5th and 95th percentile intakes using a GSD of 3. Assumes 5-µm AMAD particle size; intakes for 1-µm AMAD particle size, 10.97 g/cm^3 density, and absorption type S are smaller.
d. 1958 intakes based on air sampling. See discussion below.

Because these data are the sum of all bioassay measurements for each person in each year, they represent the highest possible bioassay result. The use of the default 5-µm AMAD particle size in estimating the intakes also produces a conservatively high result, but the more likely 1-µm AMAD particle size and density of uranium oxide would result in smaller intakes. Therefore, the intakes in Table 5-4 are overestimates when the dose reconstruction includes the whole of each year's intake. Dose reconstructors should use the different percentile intakes from Table 5-4 with the types of exposure Section 5.1.4 discusses.

Due to the nature of the work at KCP, and because no accident reports are available or likely to exist, it is reasonable to assume that intakes of DU from 1959 through 1971 were chronic unless the worker's dosimetry records indicate otherwise.

The persons who received bioassay for uranium had Organization Codes 530001 and 531002. Table 5-5 lists the number of bioassay results for the two organizations and the occupations that had bioassay results. Organization Code 531002 refers to the DOE contractor that operated KCP (e.g., Bendix, Allied-Signal), and Code 530001 refers to DOE workers, so there is little information about what groups of workers were involved. The data in Table 5-5 indicate that nearly all types of workers could have received exposures from uranium. The information in the table be useful to dose reconstructors if a worker's job description and organization code are available. However, see Section 5.1.4 for more general instructions for unmonitored workers.

Table 5-5. Number of recorded bioassay measurements and average of measurements for 1959 through 1971.[a]

Occupation description	Occupation code	Number in organization code 530001	Number in organization code 531002	Total	Total of bioassay measurements[b] (µg/L)	Average of bioassay measurements[c] (µg/L)
Managers and administrators	110	10	342	352	3,210.44	9.12
Engineers	160	NA	228	228	2,017.84	8.85
Scientists	170	NA	15	15	35.16	2.34
Health physicists	184	3	NA	3	12.90	4.30
Miscellaneous professionals	200	NA	17	17	149.64	8.80
Repair technician	350	NA	44	44	580.58	13.19
Health technician	360	NA	3	3	16.17	5.39
Technologist, engineering	370	NA	38	38	519.03	13.66
Miscellaneous technicians	390	NA	47	47	418.52	8.90
Administrative support/clerical/work planners	450	NA	60	60	717.74	11.96
Fire fighter	512	NA	58	58	228.33	3.94
Security inspector & guard	513	3	4	7	11.25	1.61
Food service employees	521	NA	1	1	0.00	0.00
Custodian/janitor	524	NA	11	11	31.33	2.85
Mechanics/repairers	610	NA	350	350	2,687.45	7.68
Electrician	643	NA	153	153	1,371.99	8.97
Pipe fitter	645	NA	177	177	1,566.47	8.85
Machinist	681	NA	152	152	2,140.77	14.08
Sheet metal worker	682	NA	2	2	0.00	0.00
Operators, plant/system/utility	690	NA	2	2	2.45	1.23
Machine setup/operators	710	5	28	33	262.95	7.97
Welders/solderers	771	NA	11	11	77.10	7.01
Miscellaneous precision/production workers	780	14	640	654	6,894.03	10.54
NA	781	NA	1	1	14.05	14.05
Drivers	840	NA	28	28	217.13	7.75
Handlers/laborers/helpers	850	NA	145	145	1,279.55	8.82
All groups	N/A	N/A	N/A	**2,592**	**24,472.87**	**9.44**

a. NA = not available; N/A = not applicable.
b. Grand total of all bioassay measurements for that occupational code for all years (1959 to 1971).
c. Average of recorded bioassay measurements.

Table 5-5 also lists the sum of all bioassay results, for all years, for each occupational code and the average of the bioassay measurements for each code. The Managers and Administrators occupation category included job estimators who were commonly in the work areas.

The electronic record of uranium bioassay contains the sum of all measurements during the year for the worker. The record does not indicate the number of samples that make up the recorded measurement. The results of individual measurements were written on cards that are nearly illegible.

5.1.4 Unmonitored Workers

Table 5-4 lists the statistical parameters of measured DU concentrations in the urine of KCP workers and the associated intakes for the years for which urine data are available. Table 5-5 provides some insight about job categories and various departments (Author unknown 2014; KCP 1962). The uncertainties in the intakes in Table 5-4 do not warrant specific intakes for each job category. However, the data do indicate four exposure categories:

1. Workers with routine exposure to airborne or loose material,

2. Workers with occasional exposure,

3. Workers with rare exposure or exposure only to very low workplace airborne or contamination levels, and

4. Workers with little or no potential for radiological exposure.

Dose reconstructors should assign intakes for unmonitored workers as follows:

- Category 1, 95th percentile;
- Category 2, GM;
- Category 3, environmental exposure per Section 4.0.

The dose reconstructor should use the information in Table 5-5, the worker's radiation exposure file, the computer-assisted interviews, and ORAUT-OTIB-0014, *Technical Information Bulletin – Assignment of Environmental Internal Doses for Employees Not Exposed to Airborne Radionuclides in the Workplace* (ORAUT 2004) to assign unmonitored workers to exposure categories. Generally, the occupations for which there are no known bioassay data are nurses, miscellaneous repairers and construction workers, and equipment operators.

The method of calculation of the intakes in Table 5-4 means dose reconstructions must apply the full intake to ensure a result favorable to the claimant, even if the employee only worked part of the year.

For 1958, worker records are unlikely to contain bioassay results, but the air sample data indicate airborne contamination. For 1958, dose reconstructors should assume the following chronic intakes:

- Category 1, 5,430 pCi/d;
- Category 2, 891 pCi/d;
- Category 3, environmental exposure per Section 4.0.

The GM intake for 1958 is the ratio of the GM air concentrations for 1958 to 1959 from the lognormal distributions in Table 5-3 times the GM intake for 1959 in Table 5-4. The default GSD of 3 was applied to the GM intake for 1958 to determine the 5th- and 95th-percentile intakes. This is consistent with the GSD for the intakes for the other years in Table 5-4.

Because several maximizing assumptions affect the intakes in Table 5-4, for doses based on these intakes dose reconstructors should enter the uncertainty distribution into IREP as constants. The intakes should be entered as U-234, type S.

5.2 OTHER NUCLIDES

The sections below discuss the use of other radioactive material along with two incidents during the history of KCP.

KCP operations do include the use of several radioactive sources that can be fragile and relatively unsealed, as occurred with the ^{147}Pm source incident. However, any intakes from various smaller sources would probably be comparatively insignificant.

5.2.1 Natural Uranium Operations, May 1, 1950, to February 28, 1955

Section 2.2 provides details about work at KCP work from May 1, 1950, to February 28, 1955, that might have resulted in uranium contamination.

A chronological list of radioactive materials at KCP (Schiltz 1963, p. 2–17) records inspection and assembly of natural uranium components in Department 3A of the Main Manufacturing Building from May 1950 through February 1955. The list also documents natural uranium machining in Department 49X of the Main Manufacturing Building from February 1951 to December 1952. The machining operations would likely have generated more airborne activity than inspection and assembly. However, dose reconstructors should assume machining operations occurred in both areas from May 1, 1950, to February 28, 1955.

Departments 3A and 49X were enclosed areas. Only workers on the permanent access list (maintained by the Security, Medical and Safety Departments) could enter. No women were permitted in these areas. An "Exclusion Area Register" documented worker entrances (Ceek 1950; Thiel 1955; Schiltz 1962; Stowers 1951b; BAC 1952).

Only Departments 3A and 49X directly handled this uranium. The uranium was in containers for activities in the Receiving, Internal Transportation, and Shipping areas (Schiltz 1963, pp. 2–17).

The KCP machining process is well documented. The amounts of materials and types of machines are known, as are the sequence and description of machining steps, including cutting speeds (Stowers 1951c). KCP used a very high coolant flow rate (coolant type was Texaco Soluble Oil C) and made provisions for reclamation of scrap material, chips, dust, and oxides. The plant had designated storage areas for raw material, finished metal, and reclaimed waste. An accountability officer tracked metal, and uranium metal transportation was always under the supervision of a security guard (Author unknown 1951).

KCP implemented worker protection and monitoring for this work, also known as Project Royal, under AEC Safety Bulletin #5 (Stowers 1951a).

NIOSH compared the operations and known and postulated conditions for KCP to those for determination of "air sampling data for facilities machining uranium" in Table 7.5 of Battelle-TBD-6000 (NIOSH 2011). To accomplish this, NIOSH reviewed a study used as the foundation for radionuclide intake derivations related to uranium machining in Battelle-TBD-6000. NIOSH finds *The Industrial Hygiene of Uranium Fabrication* (Harris, 1958) to be a bounding approximation of KCP work activities under consideration. Therefore, dose reconstructors can estimate KCP worker intakes during natural uranium operations from 1951 to December 31, 1955, using Battelle-TBD-6000 Table 7.8 for inhalation intakes and Table 7.9 for ingestion intakes. Table 5-6 reproduces those values. Dose reconstructors should enter these intakes as U-234, type S, with a distribution of constant.

Table 5-6. Intake rates for uranium machining and material handling, Departments 3A and 49X, May 1, 1950, to February 28, 1955.

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Operator	18,016	369
General Laborer	9,008	185
Supervisor	4,504	92
Clerical	450	9.2

5.2.2 Uranium Postoperations Period, March 1, 1955, to August 31, 1959

The best method for estimating internal exposure at KCP after natural uranium operations ceased in 1955 until the start of the KCP urinalysis program in 1959 is to use the maximum gross-alpha measured air sample (49 pCi/m^3) from before the start of large-scale DU machining and assume that concentration remained constant during this postoperations period. Dose reconstructors should assume machine operators in Departments 3A and 49X breathed this air concentration for 2,000 hr/yr.

Dose reconstructors should use the method in Battelle-TBD-6000 (NIOSH 2011) to determine air concentrations for classes of workers that had less exposure potential or spent less time in Departments 3A and 49X than the machine operators. Dose reconstructors should assume air concentration for the general laborers was half that for the operators. Supervisors had half the air concentration of the general laborers. Other worker types, such as clerical workers, had 10% of the supervisors' air concentration.

The analysis used the methods of OCAS-TIB-009 (NIOSH 2004) to calculate the ingestion rates (Table 5-7). Dose reconstructors should enter these intakes as U-234, type S, with a distribution of constant.

Table 5-7. Intake rates for uranium machining and material handling, Departments 3A and 49X, March 1, 1955, to August 31, 1959.

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	322	6.71
General Laborers	161	3.36
Supervisors	80.6	1.68
Administrative Workers	8.06	0.168

5.2.3 Uranium Postoperations Period, January 1, 1972, to May 31, 1984

Uranium residual data provides the best method for reconstruction doses to workers in former uranium operations areas for uranium operations during this period, before D&D.

The maximum measured surface contamination survey during DU operations provided the basis to model a starting point air concentration for this period. That maximum value during operations of 4.5×10^6 dpm/m^2 alpha reduced over time until the initial D&D characterization survey on May 31, 1984.

Applying a resuspension factor of 1×10^{-5}/m yields an air concentration of 45 dpm/m^3 for the start of the postoperations period on January 1, 1972.

The characterization survey before D&D began reported the maximum "accessible" contamination level as 6×10^4 dpm/m^2. Applying a resuspension factor of 1×10^{-5}/m yields an air concentration of 0.6 dpm/m^3 for the end of the postoperations period on May 31, 1984.

These two concentrations were inserted into the exponential interpolation (depletion) equation from ORAUT-OTIB-0070 (ORAUT 2012c):

$$\lambda = \frac{-\ln(A_{1984} \div A_{1972})}{t} = 9.52 \times 10^{-4} \quad (5\text{-}1)$$

This depletion rate (9.52×10^{-4}/d) along with the initial air concentration determined the remaining activity available for inhalation and ingestion for each year of this period. The analysis assumed machine operators breathed air at this concentration for 2,000 hr/yr at a rate of 1.2 m^3/hr.

The analysis used the method in Battelle-TBD-6000 (NIOSH 2011) to determine air concentrations for classes of workers with exposure potential or who spent less time in Departments 3A and 49X (later renamed as D20, D22, D34, D61) than the machine operators. The analysis assumed the air concentration for general laborers was that for the operators, that supervisors had half the concentration of general laborers, and that all other worker types, such as those performing primarily administrative and clerical duties with no reason to enter the restricted, radiological areas, had 10% of the supervisors' concentration.

The analysis used the methods of OCAS-TIB-009 (NIOSH 2004) to calculate the ingestion rates (Table 5-8).

Table 5-8. Intake rates for uranium machining and material handling, Departments 3A and 49X, January 1, 1972, to May 31, 1984 . Dose reconstructors should enter these intakes as U-234, type S, with a distribution of constant.

1972, fraction remaining 1.00E+00

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	1.33E+02	2.77E+00
General Laborers	6.67E+01	1.39E+00
Supervisors	3.33E+01	6.94E-01
Administrative Workers	3.33E+00	6.94E-02

1973, fraction remaining 7.06E–01

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	9.41E+01	1.96E+00
General Laborers	4.73E+01	9.82E-01
Supervisors	2.36E+01	4.91E-01
Administrative Workers	2.36E+00	4.91E-02

1974, fraction remaining 4.99E–01

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	6.67E+01	1.39E+00
General Laborers	3.32E+01	6.94E-01
Supervisors	1.66E+01	3.46E-01
Administrative Workers	1.66E+00	3.46E-02

1975, fraction remaining 3.53E–01

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	4.68E+01	9.77E-01
General Laborers	2.35E+01	4.91E-01
Supervisors	1.18E+01	2.45E-01
Administrative Workers	1.18E+00	2.45E-02

1976, fraction remaining 2.49E–01

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	3.32E+01	6.94E-01
General Laborers	1.66E+01	3.46E-01
Supervisors	8.29E+00	1.73E-01
Administrative Workers	8.29E-01	1.73E-02

1977, fraction remaining 1.76E–01

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	2.35E+01	4.86E-01
General Laborers	1.17E+01	2.44E-01
Supervisors	5.86E+00	1.22E-01
Administrative Workers	5.86E-01	1.22E-02

1978, fraction remaining 1.24E–01

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	1.66E+01	3.45E-01
General Laborers	8.29E+00	1.73E-01
Supervisors	4.14E+00	8.65E-02
Administrative Workers	4.14E-01	8.65E-03

1979, fraction remaining 8.78E–02

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	1.17E+01	2.44E-01
General Laborers	5.86E+00	1.22E-01
Supervisors	2.93E+00	6.08E-02
Administrative Workers	2.93E-01	6.08E-03

1980, fraction remaining 6.20E–02

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	8.29E+00	1.72E-01
General Laborers	4.14E+00	8.60E-02
Supervisors	2.07E+00	4.31E-02
Administrative Workers	2.07E-01	4.31E-03

1981, fraction remaining 4.38E–02

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	5.86E+00	1.22E-01
General Laborers	2.92E+00	6.08E-02
Supervisors	1.46E+00	3.05E-02
Administrative Workers	1.46E-01	3.05E-03

1982, fraction remaining 3.10E–02

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	4.13E+00	8.60E-02
General Laborers	2.06E+00	4.30E-02
Supervisors	1.03E+00	2.15E-02
Administrative Workers	1.03E-01	2.15E-03

1983, fraction remaining 2.19E–02

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	2.91E+00	6.08E-02
General Laborers	1.46E+00	3.04E-02
Supervisors	7.30E-01	1.52E-02
Administrative Workers	7.30E-02	1.52E-03

January 1 to May 31, 1984, fraction remaining 1.55E–02

Job title	Inhalation (pCi/d)	Ingestion (pCi/d)
Machine Operators	2.06E+00	4.29E-02
General Laborers	1.03E+00	2.14E-02
Supervisors	5.14E-01	1.07E-02
Administrative Workers	5.14E-02	1.07E-03

5.2.4 Magnesium-Thorium Exposures, August 23, 1961, to March 31, 1963, and August 28, 1970, to December 31, 1977

Section 2.2 provides details about KCP work during these two periods with the potential to produce thorium contamination.

An engineering control limit of 3×10^{-11} µCi/mL alpha for exposure during Mg-Th operations was established in 1959 (Foster ca. 1959, p. 16). KCP performed gross alpha fixed-filter air monitoring from 1958 through 1971 in the Main Manufacturing Building and maintained operations at 2.85×10^{-12} µCi/mL (average measured level for the period).

In 1970, an evaluation of Mg-Th machining operations in the Model Shop validated that the process did not generate airborne radioactivity. The staff used breathing-zone air samplers at each machining station during operation. The airborne levels during this test were at background (0 cpm) for long-lived activity and $<3.22 \times 10^{-9}$ µCi/mL for short-lived activity. Although the sensitivity of these results is not adequate for dose reconstruction, it does add to the argument that this process probably did not result in airborne contamination levels above the engineering control limit.

To assess exposures from Mg-Th operations, the analysis assigned the engineering control limit of 3×10^{-11} µCi/mL alpha as a constant distribution to estimate an exposure rate for identified Mg-Th workers (e.g., Mg-Th on the worker's medical card). In addition, the analysis used the method in Battelle-TBD-6000 (NIOSH 2011) to determine air concentrations for classes of workers that had less exposure potential or spent less time in the Mg-Th machining areas (Department 20 or the Model Shop, a.k.a. D-823 and D851) than the machine operators. The exposure rate to general laborers is half of the operator's exposure rate, and the exposure to supervisors is half that of general laborers. For all other worker types, such as those with primarily administrative and clerical duties and no reason to enter the restricted, radiological areas, the exposure rate is 10% of that for supervisors.

Table 5-9 provides ingestion intake rates based on guidance in OCAS-TIB-009 (NIOSH 2004). Table 5-10 provides the percent alpha activities of the radionuclides of concern in both triple-

separated and natural thorium. Tables 5-11 and 5-12 provide inhalation and ingestion intake rates for Operators, respectively for triple-separated thorium. Tables 5-13 and 5-14 provide the same for natural thorium.

Dose reconstructors should compare the resulting doses for triple-seperated versus natural thorium intakes, and apply the higher doses. Dose reconstructors should apply all intakes as constants, types M and S. For partial years, dose reconstructors should apply daily intakes for employment within the dates for each year. The exposure rate to general laborers is half of the operator's exposure rate, and the exposure to supervisors is half that of general laborers. For all other worker types, such as those with primarily administrative and clerical duties and no reason to enter the restricted, radiological areas, the exposure rate is 10% of that for supervisors.

Table 5-9. Alpha intake rates from Mg-Th operations, August 23, 1961, to March 31, 1963, and August 28, 1970, to December 31, 1977.

Job Category	Inhalation (dpm/calendar d)	Ingestion (dpm/calendar d)
Operator	438	9.1
General Laborer	219	4.6
Supervisor	109	2.3
Administrative	11	0.2

Table 5-10. Alpha ratios (percent alpha activity).

Radionuclide	Th-232	Ac-228 [b]	Ra-228 [b]	Th-228	Ra-224
Triple-separated [a, c]	1 (72.46%)	Not applicable	Not applicable	0.19 (13.77%)	0.19 (13.77%)
Natural [a]	1 (33.33%)	Not applicable	Not applicable	1 (33.33%)	1 (33.33%)

a. The more favorable of the two mixtures should be used to assess the gross alpha intake rates.
b. Beta emitter. Activity assumed equivalent to Th-228.
c. Based on ORAUT-OTIB-0076, *Guiding Reconstruction of Intakes of Thorium Resulting from Nuclear Weapons Programs assuming Triple Separated Thorium* (ORAUT 2014b)

Table 5-11. Inhalation intake rates for triple-separated thorium (pCi/d) for Operators.

Dates	Th-232	Ac-228, Ra-228, Th-228, Ra-224
8/23/1961-12/31/1961	142.94	27.16
1962	142.94	27.16
1/1/1963-3/31/1963	142.94	27.16
8/28/1970-12/31/1970	142.94	27.16
1971	142.94	27.16
1972	142.94	27.16
1973	142.94	27.16
1974	142.94	27.16
1975	142.94	27.16
1976	142.94	27.16
1977	142.94	27.16

Table 5-12. Ingestion intake rates for triple-separated thorium (pCi/day) for Operators.

Dates	Th-232	Ac-228, Ra-228, Th-228, Ra-224
8/23/1961-12/31/1961	2.98	0.57
1962	2.98	0.57
1/1/1963-3/31/1963	2.98	0.57
8/28/1970-12/31/1970	2.98	0.57
1971	2.98	0.57
1972	2.98	0.57
1973	2.98	0.57
1974	2.98	0.57
1975	2.98	0.57
1976	2.98	0.57
1977	2.98	0.57

Table 5-13. Inhalation rates for natural thorium (pCi/d) for Operators. Apply the intake for all nuclides listed.

Date	Th-232, Ac-228, Ra-228, Th-228, Ra-224
8/23/1961-12/31/1961	65.75
1962	65.75
1/1/1963-3/31/1963	65.75
8/28/1970-12/31/1970	65.75
1971	65.75
1972	65.75
1973	65.75
1974	65.75
1975	65.75
1976	65.75
1977	65.75

Table 5-14. Ingestion intake rates for natural thorium (pCi/d) for Operators.

Date	Th-232, Ac-228, Ra-228, Th-228, Ra-224
8/23/1961-12/31/1961	1.37
1962	1.37
1/1/1963-3/31/1963	1.37
8/28/1970-12/31/1970	1.37
1971	1.37
1972	1.37
1973	1.37
1974	1.37
1975	1.37
1976	1.37
1977	1.37

5.2.5 Routine Radiological Waste Handlers and Decontamination Workers

The records show a category of workers (laborers), who performed routine radioactive waste handling, radiation area maintenance, housekeeping, and decontamination, that is different from uranium or thorium workers. Based on interviews, these workers did not receive routine monitoring. Several of these workers had bioassays in their records; dose reconstructors should use those records when available.

Interviews at KCP in March 2015 revealed that laborers had a substantial role in cleaning floors, walls, and equipment, whether on a day-to-day basis or in periodic room cleanups, and that a clear distinction was made between "laborers" who handled cleaning duties and various crafts responsible for moving, maintaining, and operating equipment such as lathes. While the "KCP machine repair group" was responsible for taking equipment apart, the laborers were responsible for cleaning the internal parts of that equipment (Fitzgerald 2015).

To assign doses to unmonitored personnel doing this work, dose reconstructors should use the guidance in Section 5.1.4 and assigning them to exposure category 2 (i.e., workers with occasional exposure).

5.2.6 Thorium Oxide Powder Operations

Part of a chronological list of radioactive material at KCP states, "July 23, 1958 to July 1959 – Thorium oxide ThO_2 powder was handled in the plant" (Schiltz 1963, p. 12). Inventories of radiological sources show use of some ThO_2 sources and that KCP made a thorium nitrate solution at a rate of 20 g/yr (Allied-Signal 1989–1990). With the currently available information, including personal communication with KCP site experts (ORAUT 2013b), it appears ThO_2 operations consisted only of laboratory analysis and solution preparation for analytical procedures. These operations occurred under hoods and did not present an exposure potential.

5.2.7 Tritium Operations

5.2.7.1 Hi-Lo Switch Plates, 1963 to 1968

A February 8, 1963, memorandum shows KCP used tritiated phosphor in the production of luminescent dials. Based on memos that discuss the work with the phosphor on Hi-Lo switch plates, KCP workers were exposed to tritium for this work between 1963 and 1968.

The chemical form of the tritium in the phosphor was an organic compound known as Tung Oil, also known as China Wood Oil (used as a finish in woodworking). The Sigma-Aldrich safety data sheet states Tung Oil is an ester of eleostearic acid and other fatty acids (Sigma-Aldrich 2015). It is a waxy solid with a near-zero vapor pressure at room temperature, which makes inhalation unlikely. The data sheet gives no precautions and instructs the user to wash it off with soap and water if it gets on the skin. In addition, Eucerin pH5 hand cream contains stearic acid as a thickening agent. Because the tritium was in a stearic acid similar to those in common hand creams, with properties that would cause it to coagulate or thicken and dry on the skin, this provides a plausible skin-contact mechanism for transfers of organically bound tritium through a worker's skin.

In consideration of these physical characteristics and KCP operations, the most probable exposure pathway would have been through skin absorption. However, there would have been a slow and incomplete translocation of surface contamination across the skin membrane. To be favorable to claimants, the analysis assumed instantaneous 100% activity transport across skin.

KCP had 500 orders and had shipped 181 units by February 1966 (Lovell 1966). To assess the contamination level on 330 switch plates, the analysis used data from 110 swipes in 1965 (Bendix 1965). Fit to a lognormal distribution, the data have a geometric mean (GM) of 4,246 dpm/100 cm^2 and a GSD of 2.32. The upper 95th-percentile value of this distribution is 16,900 dpm/100 cm^2, which the analysis assumed is the bounding exposure scenario for the contamination level.

No documentation on the size of the Hi-Lo switches is available other than their thickness of 0.1875 in, so the analysis assumed they were about the size of a plate covering a light switch or standard wall outlet, two-sided (front and back), and nominally 100 cm^2 on each side for a total of 200 cm^2. This is reasonable based on the documentation that each plate was soaked in 100 mL of distilled water for the 24-hour leak test determinations. A plate of this size would have been covered and soaked in this volume of water. Therefore, each switch plate would have had 33,800 dpm distributed over the entire surface.

The analysis further assumed the worker handled each switch plate enough for all of the surface contamination to transferred to the skin, which completely absorbed it. Procurement records indicate KCP ordered at least 500 of the plates. Therefore, workers could have handled several per day over the intermittent manufacturing periods. Based on these procurement records, the analysis assumed a worker handled three switch plates each day. This means that the bounding intake rate of organically bound tritium through skin absorption would be 101,400 dpm (1,690 Bq). This bounding intake rate would have been chronic throughout the year for 1963 through 1968.

Using the DCFs for organically bound tritium from ICRP Publication 68 (ICRP 1994b) (4.1×10^{-9} rem/Bq for all organs), the worker dose would be 1.73 mrem/yr. Dose reconstructors should apply this dose to all radiological workers and apply a constant distribution.

5.2.7.2 Manufacturing of Tritium Monitors, 1959 to 1975

Both the military and AEC used these instruments during nuclear testing. Manufacturing began in 1959 and produced four monitoring kits in February 1960 (Schiltz 1959). Manufacturing continued periodically through the 1970s.

At first, in 1959, KCP purchased small bottles of standard solution (400 mL of 250 µCi/L) from the Sandia National Laboratories and stored them under ventilation until use or packaging for shipment with a completed urinalysis kit. By 1964, the standardized tritiated water came in 1-gal units KCP repackaged into 400 mL bottles. The date of this change (sometime between 1959 and 1964) is not known. There are records from 1964 of two shipments of 8 gal of standardized tritiated water for a total of 16 gal (60,600 mL). KCP shipped a 400-mL bottle of the calibration standard solution with each urinalysis kit. Decanting the gallon-sized units into 400 mL bottles would result in nominally 150 bottles of standard solution. Based on this, it is reasonable to assume that about 150 decanting operations occurred in 1964. To ensure results favorable to claimants, the analysis assumed some part of the decanting operation occurred in the chemistry laboratory every workday (250 days per year) beginning in 1959 and ending in 1975.

Based on the care that went into the procurement process and cautionary notes about handling that in the purchase order, it is reasonable to assume the chemistry technicians who handled the standardized tritiated water would have been careful with it due both to its value and to its hazardous nature. KCP stored the unopened bottles it procured in 1959 under ventilation when not in use. Therefore, it is also reasonable to assume all work with standard tritiated water, including decanting from one bottle to another, would have taken place under a ventilated enclosure such as a fume hood.

Although decanting could have occurred on a single day soon after receipt, it is possible KCP filled smaller bottles in separate operations. The process of receiving and transfer tritiated water from

Sandia in gallon bottles and transferring some of the liquid to smaller volumes (i.e., 400 mL and about 2.5-mL vials), could have provided reasonable opportunity for losses through unreported splashes or spills. It is plausible that these small splashes or spills occurred during the liquid-transfer processes in the preparation of the final standard's volumetric configuration.

For this bounding scenario, the analysis assumed all of a 400-mL bottle of tritiated water spilled over the course of a year and that a worker absorbed all of it. This is favorable to claimants because there are no known reports of incidents or spills during the tritiated water decanting. The analysis also assumed none of the water evaporated, which the room or hood ventilation systems would have removed. This assumption allows the worker's skin to absorb the entire spilled volume (i.e., 400 mL of 250 µCi/L tritiated water). The activity in the 400 mL of standardized tritiated water was 100 µCi. A swipe that collects 100% of the contamination of the spill area under these conditions would yield a total removable contamination level of 2.22×10^8 dpm. In this bounding scenario, this tritium contamination is completely transferred to the skin of the hand of the chemistry technician during the year. Therefore, the chemistry technician's skin is contaminated with 2.22×10^8 dpm (3.7×10^6 Bq) of tritiated water on an annual basis. This bounding intake rate would have been chronic throughout the year for 1959 through 1975.

Using the tritiated water DCF from ICRP Publication 68 (1.8×10^{-9} rem/Bq; ICRP 1994b), the worker dose would be 6.66 mrem/yr. Dose reconstructors should apply this dose to all radiological workers and apply a constant distribution.

5.2.8 Nickel Plating

There is evidence that KCP used ^{63}Ni over an extended period in the manufacturing of tritium-in-air and urine monitoring instruments. This manufacturing involved plating ^{63}Ni on a small aluminum metal coupon for use as an internal calibration standard.

Exposure occurred during small-scale chemical-plating operations because the plating solution contained ^{63}Ni. A 1-in.^{2} (Bendix 1984) ^{63}Ni-plated area was incorporated into the precipitator plate (Courtright 1967a) of the Tritium in Air Monitor, Bendix/Sandia Model T446 Courtright 1967b).

The bounding dose to workers involves the potential inhalation of ^{63}Ni from a microaerosol in the laboratory room that can result from aeration of the plating solution. The analysis assumed the plating shop operated without ventilation and that a bubbler stirred the plating bath. Bursting hemispherical bubbles at the surface of the plating solution produced aerosolized droplets of ^{63}Ni.

The analysis assumed the radioactivity uniformly distributed into the air of a 5- by 5-m room with a 3-m ceiling height (75 m^3 volume) and that the worker breathed at the standard ICRP Publication 66 occupational breathing rate of 1.2 m^3/hr (ICRP 1994a). To be favorable to claimants, the analysis further assumed that neither local exhaust ventilation nor room exhaust ventilation reduced the air concentration.

Uniformly mixing an activity of 6.37×10^{-3} µCi of ^{63}Ni into this air volume results in an airborne activity concentration of 8.49×10^{-11} µCi/mL. Therefore, during the 60-minute plating operation, the worker would have inhaled 1.02×10^{-1} nCi, which is equivalent to 3.8 Bq. Assuming this operation occurred 100 times each year, the annual intake rate would be 377 Bq. This results in a committed dose to all organs of less than 1 mrem. Therefore, dose reconstructions should not include dose from ^{63}Ni.

5.2.9 Decontamination and Decommissioning

In 1984, KCP contracted with Rockwell International Corporation to perform major facility D&D of the Main Manufacturing Building (Rockwell 1985). Phase I of the work began May 29, 1984, with a

survey to locate buried waste trenches and to measure radiological activity both in the trenches and in the Machining Area. Phase II occurred from August 7 to November 7, 1984, and involved the decontamination of the trenches and the Tool Setup Area of the Machining Area. Rockwell (1985) reports neither radiological contamination at the trenches nor radioactive or hazardous waste contamination in the surrounding soil. Phase III was the decontamination of the Inspection Area portion of the Machining Area in the Main Manufacturing Building. It occurred from August 15 to September 3, 1986. Preliminary surveys found fixed contamination only in floor cracks, holes, drains, and some surface spots on the concrete columns. During all three phases, Rockwell noted in their final reports KCP decontamination requirements were below U.S. Nuclear Regulatory Commission and American National Standards Institute requirements for release of an area for unrestricted use (Rockwell 1985). Further, the report states no personnel received radiation exposure and no internal deposition of radioactive material occurred as a result of the decontamination of the classified waste and machining areas (Rockwell 1985).

Monitoring for radioactive material during the Phase II decontamination of the trenches and Tool Setup Area of the Machining Area, and the Phase III decontamination of the Inspection Area of the Machining Area, included continuous air monitors, high-volume air samplers, and environmental samples to compare with preliminary samples. None of these monitoring activities indicated measureable radioactivity above background levels (Rockwell 1985).

Decontamination of the machining area consisted of the use of scabblers, concrete chipping hammers, and concrete saws that removed thin layers and small and large portions of concrete. During these activities, “radioactive materials vacuums” were used to control and remove any dust created from the decontamination activities. Continuous monitoring for airborne and removable activity recorded no levels above background (Rockwell 1985). Removal of floor drains consisted of cutting away the concrete that formed the drains and sumps, and then removing the soil underneath. Rockwell disposed of material from the sumps along with related items as radioactive waste.

Radioactive contamination levels during the survey of the machining area were as high as 500,000 dpm/100 cm^2 in drains and sumps and up to 1.75 million dpm/100 cm^2 in cracks. The contamination was fixed. Personnel monitoring consisted of continuous air monitors, high-volume air samplers, and contamination surveys. None of these monitoring activities indicated measureable radioactivity above background levels (Rockwell 1985).

Table 5-15 provides the inhalation intake rate based on the air sample control level of 1×10^{-12} µCi/mL, a breathing rate 1.2 m^3/hr, and a period of 2,000 hr/yr. The table also provides the ingestion rate based on information in OCAS-TIB-009 (NIOSH 2004). Dose reconstructors should assign these intakes as ^{234}U, Types M and S, using a constant distribution.

Table 5-15. Alpha intake rates from D&D of uranium operations areas, May 29, 1984, to November 7, 1984, and August 15, 1986, to September 3, 1986.

Job category	Inhalation (pCi/day)	Ingestion (pCi/day)
All workers in Department 20	6.76	0.135

5.3 RECYCLED URANIUM

For all DOE uranium after 1952, this analysis assumed the possibility that uranium from refineries was or contained recycled uranium. Table 5-16 provides the activity fractions for uranium intakes after 1952 (NIOSH 2011). Dose reconstructors should evaluate the nuclides below by multiplying the

activity fraction times the uranium intake. Refer to ORAUT-OTIB-0060, *Internal Dose Reconstruction* (ORAUT 2014a) Table 3-1 for selection of solubility types for contaminants.

Table 5-16. Activity fraction of contaminant in recycled uranium.

Contaminant	Activity fraction
Pu-239	0.00246
Np-237	0.00182
Tc-99	0.379
Th-232	2.73E–06
Th-228	2.73E–06

5.4 INCIDENTS

An incident occurred on February 10, 1989, involving ^{147}Pm. The response to the incident initially concluded, apparently in error, that an intake had occurred according to an extensive investigation (ASAC 1989). According to the report, DOE, the U.S. Environmental Protection Agency, Radiological Health Division representatives from the Missouri Department of Health were notified at the time of the incident. A DOE team of investigators arrived February 14 to assume technical management of the situation. Based on what were, in the end, false-positive bioassay results, investigators inspected the homes of four workers and found some contamination. There were many activities to identify the cause and extent of this contamination. Promethium-147 is a relatively low-energy, 100% beta-emitting nuclide with maximum energy of 224.7 keV and average energy of 62 keV. Its half-life is 2.6 years. The primary concern with this type of nuclide is direct skin contamination and intake. The report addressed the chronology of steps, and the results, to examine potential exposure and contamination.

On August 12, 1987, KCP received a W80 Data Analyzer that contained erbium tritide from Sandia National Laboratories. Operations testing at Sandia exposed the analyzers to tritium and normally decontaminated them before returning them to KCP for follow-up testing. On September 30, 1987, a worker removed the analyzer's protective cover. The outside cover had a visibly clean appearance, but the inside did not. The worker immediately replaced the cover and contacted the Health and Safety group. That group took swipe samples the next day inside and outside of the cover of the assembly and from nearby work surfaces. These detected contamination only on the inside of the cover at 986 dpm/100 cm^2. The plant returned the analyzer to Sandia for decontamination. Urinalysis for the worker who opened and closed the case indicated there was no detectable activity for tritium as erbium tritide.

There were other events of tritium contamination reported at KCP. There are reports of four instances where contamination greater than 100 dpm/100 cm2 was detected at KCP during acceptance tests in 1985 and 1988 (Evans 1985, 1988a, 1988b). There are three other events described as unusual occurrences where low-levels of contamination were discovered at KCP from 1987 to 1990 (Krueger and Meunier 1987; Kircher 1990). Because of these incidents, Sandia and KCP decided to revise their procedures to protect against similar incidents (Krueger and Meunier 1987). In August 2013, KCP Health Physics stated this incident was unique and did not reoccur (ORAUT 2013b).

6.0 OCCUPATIONAL EXTERNAL DOSE

As described in Section 2.0, AEC operations at KCP began in 1949. Some of the information about the early history of nuclear weapons work is classified, and not all details of events at that time are clear. The primary work activity that might have involved external radiation exposure was fabrication and quality control testing of nonnuclear components of nuclear weapons.

6.1 BASIS OF COMPARISON

Since the initiation of the Manhattan Engineer District (a DOE predecessor agency) project in the early 1940s, different DOE facilities have used various concepts and quantities to measure and record occupational radiation dose. This analysis chose the personal dose equivalent, *Hp(d), as a* common basis of comparison to assess the consistency of the available historical recorded dose at KCP with current KCP dosimetry performance. With the known dates of changes in KCP dosimetry systems, comparisons of recorded doses before and after these changes provide an ability to assess consistency. Similar sources have been used to calibrate and conduct performance testing of dosimetry systems (AEC 1955; Unruh et al. 1967; McDonald et al. 1983).

The *d* in *Hp(d) d* identifies the depth in millimeters and represents the point of reference for dose in tissue. For weakly penetrating radiation of significance to skin dose, *d* is 0.07 mm [*Hp(0.07*)]. For penetrating radiation of significance to whole-body dose, *d* is 10 mm [*Hp(10)*]. The International Commission on Radiological Units and Measurements (ICRU) has recommended both *Hp(0.07)* and *Hp(10)* for use as the quantities for radiological protection (ICRU 1993). The DOE Laboratory Accreditation Program (DOELAP) has used them since the 1980s to accredit personnel dosimetry systems in the DOE complex, including KCP (DOE 1986).

6.2 WORKPLACE EXTERNAL RADIATION FIELDS

Section 2.5 describes the primary sources of workplace radiation fields at KCP. These sources historically involved industrial RGDs (X-rays and electron accelerators); isotopic beta, gamma-ray, and neutron sources; and DU. The isotopic sources were typically part of the manufacturing or quality control processes that monitored fabrication of nonnuclear weapons components.

6.2.1 Beta Radiation

Section 2.0 describes handling of radioactive materials from the early 1950s until 1978. Table 2-3 includes beta radiation fields in KCP workplaces, and Table 2-4 includes RGD-produced electrons. The potential for exposure to beta radiation sources is typically from maintenance activities or failures. For example, KCP used a ^{147}Pm source to measure the thickness of a film. The failure of the integrity of this source did result in some worker exposure and was the subject of an official investigation (ASAC 1989). Worker exposure to electrons is typically from operator error or equipment failure.

6.2.2 Photon Radiation

Photon radiation (X- and gamma rays) from KCP work covers a broad energy range. Table 2-3 includes several photon emitters. KCP typically used these to check or calibrate processes to gauge thicknesses, perform instrument calibrations, and so forth. Many sources were beta and photon emitters of the types and source strengths typical of mainstream industrial or process-related users. These sources are in widespread use, and doses from proper use are comparatively negligible. In addition, KCP used a variety of larger photon-emitting radiation sources and X-ray RGDs (Table 2-4). These were typically used to radiograph parts or perform operational tasks. There were numerous X-ray machines in locations around the Plant.

KCP had no measurements of the photon energy spectra in its workplaces. The spectra derive from the configuration of the X-ray machines, the process, and the extent of shielding. However, regardless of the precise spectra, the dosimeters in use throughout operations would have registered significant photon radiation.

6.2.3 Neutron Radiation

Sources of neutron radiation at KCP involve neutron generators and alpha-neutron interaction sources (Table 2-4). Neutron-emitting sources were apparently present sometime after 1965 based on Schiltz (1966a).

6.3 DOSIMETER TECHNOLOGY

KCP used beta/photon and neutron dosimeters to measure potential radiation exposure of personnel.

6.3.1 Beta/Photon Dosimeters

Beta and photon dosimeters at KCP included:

- Pocket ionization chambers (PICs).
- KCP film dosimeter (Bendix 1964), a two-piece, stainless-steel, film holder with front and rear matching rectangular windows. The front and rear faces had a 1-mm-thick cadmium filter in the open window. Two different types of personal dosimetry film packets were used, Kodak Type 2 for mixed beta and gamma radiation and DuPont Type 558 for X-ray and gamma radiation. The DuPont 558 film packet contains two films. Type 508 film has a range of 0.003 to 30 R, and Type 1290 has a range of 0.68 to 3,000 R. KCP calibration data using uranium and ^{60}Co sources are available (Bendix 1964).
- KCP two-chip thermoluminescent dosimeter (TLD-100) from 1973 to 1982.
- Eberline standard three-chip TLD-100 from 1983 through 1990. This dosimeter employed one chip under a 10-mg/cm^2 filter to measure the shallow or skin dose and one or two chips under a 285-mg/cm^2 filter to measure the deep or whole-body dose (TMA 1990). KCP stopped using this dosimeter because it could not meet DOELAP standards (Allied-Signal 1991).
- The Landauer K1 three-chip TLD-700 starting April 1, 1991, to measure beta, X-ray, and gamma radiation exposure.
- Landauer optical stimulated luminescent (OSL) aluminum-oxide dosimeters starting in 2000.

6.3.2 Neutron Dosimeters

KCP used the Landauer Neutrack I dosimeter, a polycarbonate (Lexan) neutron recoil track registration device for monitoring fast neutron interactions. The Lexan responds to neutrons by recording ionization damage from neutron interactions with carbon and oxygen atoms, which leaves a track. It has a uniform energy response from 3 to over 14 MeV with a threshold of 1 MeV. In 2001, KCP began using the Neutrak 144 for neutrons, a plastic polymer recoil track dosimeter.

6.3.3 Dosimetry Techniques and Exchange Frequencies

The dosimeters provided the dose of record; health physics staff used the PICs for administrative control until dosimeter results were available. Table 6-1 summarizes personnel dosimetry techniques and exchange frequencies.

Table 6-1. Personnel dosimetry systems.

Beta/photon dosimeters measuring beta/nonpenetrating, X-ray, and gamma

Period	Description	Routine exchange period
1950–1954	KCP in-house film badge system	Weekly
1955	KCP in-house film badge system	Biweekly
1956–1964	KCP in-house film badge system	Monthly
1965–1972	KCP in-house film badge system	Bimonthly
1973–1982	KCP two-chip TLD	Bimonthly
1983–1990	Eberline three-chip TLDs	Quarterly
1991–2000	Landauer three-chip TLDs	Quarterly
2001–2014	Landauer OSL	Semiannual

Neutron dosimeters

Period	Description	Routine exchange period
1961–1967	Controls for Radiation	Biweekly
1967–1973	Landauer, film	Biweekly
1974–1982	Landauer NTA film	Biweekly[b]
1983–1990	Landauer Lexan track-etch	Monthly
1991–2000	Landauer Neutrak I Poly carb	Quarterly
2001–2014	Landauer Neutrak 144	Semiannual

a. NTA = nuclear track emulsion, type A.
b. From review of Landauer badge form data (Landauer 1969–1986).

KCP participated in DOELAP performance testing using Landauer-provided services beginning in October 1992, and most recently passed DOELAP performance testing in May 1995. KCP became exempt from DOELAP accreditation in May 1998 based on the low-level potential for worker dose and accreditation by NVLAP.

6.4 DOSE RECONSTRUCTION

To ensure the dose for each claim is not underestimated, dose reconstructors must consider:

- Potential unmonitored dose for fully unmonitored workers (throughout their employment at KCP).
- Potential missed dose for monitored workers because of missing dosimeter results, actual dose that was less than the detection capabilities of the dosimeters, or unrecorded doses in a worker's exposure history.
- Potential adjustments to the recorded dose considering the dosimetry technology, calibration methods, and workplace radiation fields, that could have resulted in error in the recorded dose.

6.4.1 Monitored Dose Records

KCP monitored personnel using external dosimetry beginning in 1950. Before 1965, hand-entered film badge data had several columns labeled "RADS," "ROENT.," and "REM." These represent:

- RADS, the open window dose (gamma/X-ray + beta);
- ROENT., the shielded gamma/X-ray dose; and
- REM is the sum of RADS plus ROENT.

NOTE: As the sum of RADS and ROENT, the REM value is not useful for assigning dose. The value for nonpenetrating dose can be determined by subtracting ROENT from RADs.

6.4.2 Potential Unmonitored Dose

Based on KCP safety policies and the recorded dose to categories of workers, monitoring occurred for most categories of workers. However, for workers without a recorded dose, a reasonable assumption is that unmonitored dose would be less than the dose to monitored workers.

Penetrating and Nonpenetrating Dose
Attachment B provides an analysis of recorded doses and calculated coworker doses for unmonitored workers. Tables B-1 and B-2 summarize the annual penetrating and nonpenetrating dose for unmonitored workers.

Table B-1 penetrating dose values should adjusted using the guidance in Section 8.0 of ORAUT-OTIB-0052, *Parameters to Consider When Processing Claims for Construction Trade Workers* (ORAUT 2014a). This guidance is applicable for construction trade workers who meet the criteria in Section 3.0 of that document. The full coworker penetrating annual dose should multiplied by a factor of 1.4, as the missed dose cannot be seperated.. This correction is suitable for best estimate cases.

Neutron Dose
There should not, typically, be a significant neutron exposure of unmonitored workers because of the limited sources of neutron radiation. However, for workers who worked with neutron sources or neutron-generating equipment who were unmonitored, dose reconstructors should assign unmonitored neutron dose as follows.

The sources of neutrons at KCP are essentially the same throughout KCP operations, and annual doses are likely less than 0.100 rem (the dosimetry data reviewed from the site confirm that doses greater than 0.100 rem are very infrequent). Since the predominant neutron energy is well above 0.5 MeV, a correction factor (which is applied at other sites with lower-energy neutrons) is not needed. The dosimetry records from the site consisted of 13,745 entries, of which 2,188 had neutron monitoring (35 with recorded positive neutron dose; remaining all had zero recorded neutron dose). Three dosimetry records were greater than 0.100 rem (0.200 rem in 1966, 0.180 rem in 1988, 0.140 rem in 1970). The 95th percentile dose of the dosimetry records with recorded neutron dose (limited set of 35 records) results in a value of 0.154 rem. To account for unmonitored neutron dose that may have been received, dose reconstructors should assign a bounding dose of 0.154 rem/year neutron for unmonitored workers who worked with neutron sources or neutron-generating devices as indicated in the CATI or other available DOL/DOE information. Th neutron energy range is 2–20 MeV. This approach is an overestimate for unmonitored employees. Dose reconstructors should assign this dose using a constant distribution and apply the ICRP 60 (ICRP 1991) correction factor of 1.32 (ORAUT 2006a).

Table 6-2. Neutron unmonitored dose.

Unmonitored neutron Dose (rem)	IREP neutron energy (MeV)	ICRP 60 Correction factor	IREP distribution
0.154	2–20 MeV	1.32	Constant

Summary of unmonitored doses
Dose reconstructors should assign the ambient environmental dose from Section 4.1 to an unmonitored worker with minimal potential for radiation exposure from operations, GM coworker dose (Attachment B, Tables B-1 and B-2) to an unmonitored worker with minimal likelihood of actual workplace exposure, and the 95th-percentile coworker dose (Attachment B, Tables B-1 and B-2) to workers with a potential for workplace radiation exposure for each year of employment without a recorded dose. Assign unmonitored neutron dose as discussed above to unmonitored workers who worked with neutron sources or neutron-generating equipment.

6.4.3 Potential Missed Dose for Monitored Workers

Missed dose occurs when the dose of record:

- Is zero because the interpreted dose has a negative bias,
- Dosimeter response was less than the minimum detectable level (MDL), or
- There is no dose of record for an assigned badge for a period.

There is no evidence of a systematic negative bias, as could occur from background control dosimeters in locations of elevated ambient dose. A response that is less than the MDL is typically the most important consideration. Dose reconstructors should follow OCAS-IG-001 (NIOSH 2007) to calculate the missed dose. The typical method for estimating the potential missed dose is to assign missed dose based on the MDL and the number of responses that are less than the MDL (NIOSH 2007) for the respective dosimetry systems in Table 6-3.

Dose reconstructors should also use this method for occasional unrecorded doses. For workers who worked in an area where positive dose was likely but unrecorded for extended periods, dose reconstructors should assign coworker doses (see Attachment B).

6.4.4 Neutron Dose Adjustments

The neutron radiation from the sources and neutron-generating equipment is within the range of 2-10 MeV. There is no adjustment necessary for the response characteristics of the neutron dosimeters. The recorded and unmonitored neutron doses need adjustment to include conversion to the ICRP Publication 60 neutron weighting factor for input into IREP (ICRP 1991). Dose reconstructors should use the assumed neutron energy and dose fraction in Table 6-4.

6.4.5 Adjustments to Recorded Deep Dose

The photon deep dose in the worker records from DOE is a reasonable estimate of the actual photon dose. The dosimetry technology was capable of detecting and measuring the photon dose based on studies of historical performance (AEC 1955; Unruh et al. 1967). The energy of prevalent photons based on the radiation sources is readily measurable, so no adjustment of recorded dose should be necessary for the response characteristics of the different dosimeters.

Table 6-3. Potential missed dose for monitored workers.

Dosimeter	Period	MDL shallow (mrem)	MDL deep (mrem)	MDL Neutron (mrem)
Film Badge	1950–1972	40[b]	40[b]	100[b]
2-chip TLD	1973–1982	30	30	20
3-chip TLDs	1983–1990	10	10	20
Landauer OSL	2001–2014	10	10	20

a. Earliest estimated exchange for radiation workers is weekly.
b. Estimated MDL typical of film dosimeter capabilities.

Table 6-4. Neutron dose fractions and associated ICRP 60 correction factors.

Description	IREP neutron energy (MeV)	Default dose fraction (%)	ICRP 60 correction factor
KCP workplace exposures	2–20 MeV	100	1.32

6.4.6 Radiation Dose Fraction

Table 6-5 summarizes the recommended energy fractions for dose reconstruction. For deep dose, 50% has photon energy from 30 to 250 keV and 50% has energy greater than 250 keV. For neutron dose, 100% has energy from 0.1 to 2 MeV. For shallow dose, the relative contribution from beta and photon radiation is unknown. Therefore, the dose reconstructor should calculate the maximum dose to the organ of interest assigning 100% to the beta radiation >15 keV category or assigning 100% to the photon radiation <30-keV category. This produces results favorable to the claimant.

Table 6-5. Beta, photon, and neutron radiation energies and percentages for estimating dose to whole-body organs, 1949 to 2004.

Radiation type	Energy selection	Percent
Beta	>15 keV	100[a]
Photon	30–250 keV	50[b]
Photon	>250 keV	50[c]
Neutron	2–20 MeV	100

a. Beta particles from DU, sealed sources, and electron accelerators have energy higher than 15 keV.
b. Workplace photon energies from scattered X-rays and DU have energy higher than 30 keV. Primary photon energies for DU have energy between 30 and 250 keV.
c. Workplace photon energies cover a broad range. Photons from sealed sources and RGDs are typically of higher energies but are also heavily shielded.

6.5 UNCERTAINTY

The uncertainty in recorded dose results from various parameters such as dosimeter response, calibration, and workplace radiation fields.

Dose reconstructors should incorporate consideration of uncertainty in the dose calculation for measured and missed doses as follows:

- The technology for measuring worker dose at KCP was similar to the technology at commercial and DOE laboratory facilities. The estimated errors in the penetrating and non-penetrating dose are about ±30% and normally distributed. Assume errors are all positive (i.e., use only +30%), and multiply the measured dose by a factor of 1.3 (i.e., increase of 30%) for IREP Parameter 1. Set Parameter 2 to zero.

- For missed dose, assume a lognormal distribution. Calculate the unmonitored dose using Section 6.4.1 and the missed dose using Section 6.4.2 for Parameter 1. Set Parameter 2 to 1.52.

Few KCP workers received a significant neutron dose. The recommendation for uncertainty for photon dose above sufficiently addresses the uncertainty because of the low probability of significant neutron dose.

6.6 ORGAN DOSE

After calculating the photon and neutron doses and their associated standard errors for each year, dose reconstructors should calculate doses to the organ(s) of interest using NIOSH (2007).

7.0 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the reference section of this document.

REFERENCES

AEC (U.S. Atomic Energy Commission), 1955, "Intercomparison of Film Badge Interpretations," *Isotopics*, volume 2, number 5, pp. 8–23. [SRDB Ref ID: 3640]

Allied-Signal, 1989–1990, collection of radioactive inventory information, Kansas City Plant, Kansas City, Missouri. [SRDB Ref ID: 128430]

Allied-Signal, 1991, *Remedial Action Plan for DOE Laboratory Accreditation Program (DOELAP)*, Revised, Kansas City Plant, Kansas City, Missouri, February 22. [SRDB Ref ID: 14680]

Allied-Signal, 1995, *Site Safety Assessment for the Kansas City Plant*, Kansas City Plant, Kansas City, Missouri, September. [SRDB Ref ID: 14890]

Allied-Signal, 1998, *Uranium Dioxide Powder (U),* 4562260-00, Issue H, Kansas City Plant, Kansas City, Missouri, October. [SRDB Ref ID: 14693]

ASAC (Allied-Signal Aerospace Company), 1989, *Report of Investigation of Pm 147 Contamination, February 10, 1989, Kansas City Plant, Kansas City*, Kansas City Plant, Kansas City, Missouri, September. [SRDB Ref ID: 6216]

Author unknown, 1951, "Machining of U-238," September 13. [SRDB Ref ID: 75263]

Author unknown, 1952, "Tonawanda Area Progress Report August, 1952," memorandum to R. J. Smith, Atomic Energy Commission, New York Operations Office, New York, New York, August 22. [SRDB Ref ID: 77595]

Author unknown, 1962, *The Fluorophotometric Determination of Uranium in Urine*, August 20. [SRDB Ref ID: 14691]

Author unknown, 1987, list of radioactive sources, major use, and major energies, August 20. [SRDB Ref ID: 14692]

Author unknown, 2014, spreadsheet of job classifications, departments, dates and associated work activities. [SRDB Ref ID: 137737]

BAC (Bendix Aviation Corporation), 1952, "Roster of Dept. 49B," memorandum, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, January 16. [SRDB Ref ID: 128336]

BAC (Bendix Aviation Corporation), 1958, *Health and Safety Measures - Department 22, 34 and I1L (Ra Lab) Operations*, Procedure No. S-306, Revised, Kansas City Plant, Kansas City, Missouri, November 24. [SRDB Ref ID: 14690]

Baldwin, R. R., 1966, *Floor Monitoring Survey Results,* Bendix Corporation, Kansas City Plant, Kansas City, Missouri, January 17. [SRDB Ref ID: 14681]

Bendix Corporation, 1958–2009, collection of documents about magnesium-thorium processing and worker safety, Kansas City Plant, Kansas City, Missouri. [SRDB Ref ID: 137074, p. 57]

Bendix Corporation, 1960–1964, collection of Radiation Protection Surveys of Department 213, Kansas City Plant, Kansas City, Missouri. [SRDB Ref ID: 14698]

Bendix Corporation, 1962, Purchase Order ICO-020757 to Union Carbide and Nuclear Corporation for 10,000 pounds of uranium-dioxide powder, Kansas City Plant, Kansas City, Missouri. [SRDB Ref ID: 14683]

Bendix Corporation, 1962–1976, collection of Radiation Protection Surveys, Bendix Corporation, Kansas City Plant, Kansas City, Missouri. [SRDB Ref ID: 128476]

Bendix Corporation, 1963, "Magnesium-Thorium (3.5% Nax.) Alloy Suggested Care and Handling Methods," Kansas City Plant, Kansas City, Missouri, March 12. [SRDB Ref ID: 137074, p. 57]

Bendix Corporation, 1964, *Film Dosimetry Manual*, Kansas City Plant, Kansas City, Missouri. [SRDB Ref ID: 14684]

Bendix Corporation, 1964–1965, collection of survey information on the Sciaky electron beam welder, Kansas City Plant, Kansas City, Missouri. [SRDB Ref ID: 14687]

Bendix Corporation, 1965, "Hi-Lo Switch Plates, CF 1831 Cable Assembly," memorandum to Distribution, Kansas City Plant, Kansas City, Missouri, November 19. [SRDB Ref ID: 137063]

Bendix Corporation, 1974, *Radioactive Waste Management Site Plan*, Kansas City Plant, Kansas City, Missouri. [SRDB Ref ID: 134675, p. 313]

Bendix Corporation, 1976, "Radiation Protection Survey," Kansas City Plant, Kansas City, Missouri, October 10. [SRDB Ref ID: 128476, p. 2]

Bendix Corporation, ca. 1981, *Survey of Average Patient Radiation Exposure for Chest Diagnostic Procedures*, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, January 29. [SRDB Ref ID: 128171, p. 34]

Bendix Corporation, 1984, "Box #2, Radioactive Waste Unclassified, Contents," radioactive material packing information, Kansas City Plant, Kansas City, Missouri, June 14. [SRDB Ref ID: 138164, p. 8]

Bendix Corporation, undated, *Uranium in Urine and Lead List*, Kansas City Plant, Kansas City, Missouri. [SRDB Ref ID: 14694]

Brendlinger, R. L., 1974, "MOCA Physicals," letter to J. Morris, Mid-Con Cable, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, May 30. [SRDB Ref ID: 128146]

Cayou, S., 1958, letter to Distribution regarding fabrication of magnesium thorium, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, October 9. [SRDB Ref ID: 128181, p. 22]

Ceek, H. L., 1950, "Physical Examinations (Area 3A)," memorandum to J. S. Stowers, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, July 25. [SRDB Ref ID: 128319]

Courtright, E. L., 1967a, "T446," memorandum to R. P. Baker and E. E. Hipsher, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, May 5 and 8. [SRDB Ref ID: 138157]

Courtright, E. L., 1967b, "T446," memorandum to E. E. Hipsher and R. P. Baker, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, May 11 and 12. [SRDB Ref ID: 138159]

Darnell, P., P. McCloskey, and M. Sharfi, 2015, "KCP dosimetry database validation and verification (V&V)," National Institute for Occupational Safety and Health, Division of Compensation Analysis and Support, Cincinnati, Ohio, November 12. [SRDB Ref ID: 159899]

DeCloud, M. F., 1981a, "Survey to Determine Average Patient Radiation Exposure from Medical X-Ray Equipment," memorandum to File, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, January 29. [SRDB Ref ID: 128171, p. 12]

DeCloud, M. F., 1982, "Survey to Determine Average Patient Radiation Exposure from Medical X-Ray Equipment," memorandum to File, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, February 4. [SRDB Ref ID: 128171, p. 7]

DeCloud, M. F., 1983, "Survey to Determine Average Patient Radiation Exposure from Medical X-Ray Equipment," memorandum to Distribution, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, March 3. [SRDB Ref ID: 128171, p. 2]

DeCloud, M. F., 1984, *Radiation Protection Survey*, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, October 3. [SRDB Ref ID: 128171, p. 39]

DOE (U.S. Department of Energy), 1986, *Department of Energy Standard for the Performance Testing of Personnel Dosimetry Systems, DOE Laboratory Accreditation Program for Personnel Dosimetry Systems*, DOE/EH-0027, Office of Environment, Safety and Health, Washington, D.C., December. [SRDB Ref ID: 12294]

DOE (U.S. Department of Energy), 1997, *Linking Legacies: Connecting the Cold War Nuclear Weapons Production Processes to Their Environmental Consequences*, DOE/EM-0319, Office of Environmental Management, Washington, D.C., January. [SRDB Ref ID: 11930]

DOE (U.S. Department of Energy), 2013, Final Environmental Assessment for the Transfer of the Kansas City Plant, Kansas City, Missouri, DOE/EA-1947, Department of Energy (DOE)/National Nuclear Security Administration (NNSA), Washington, D.C., May. [SRDB Ref ID: 127459]

Evans, M. R, 1985, "W80-0JTA Telemetry Assembly - Swipe Testing," letter to P. D. Startz (Mason Hanger-Silas Mason Company), Bendix Aerospace, Kansas City Plant, Kansas City, Kansas, October 24. [SRDB Ref ID: 123862, p. 30]

Evans, M. R, 1988a, "Release of W80-0 Telemetry Assemblies, WES 1007 and EAS 1007, for Rework and Recertification," memorandum to J. L. Bowers, Bendix Allied Signal, Kansas City Plant, Kansas City, Kansas, March 15. [SRDB Ref ID: 123862, p. 97]

Evans, M. R, 1988b, "Release of W80-O Telemetry Assemblies, WES 1006 and EAS 1006, (Both Date Coded L84), for Rework and Recertification," memorandum to J. L. Bowers, Bendix Allied Signal, Kansas City Plant, Kansas City, Kansas, February 2. [SRDB Ref ID: 123862, p. 143]

Fitzgerald, J., 2015, "SC&A's Evaluation of NIOSH's January 2015 Response to KCP SEC Matrix Issues 7, 15, 17, 18, and 20," memorandum to KCP Work Group, SC&A, Inc., Vienna, Virginia, April 20. [SRDB Ref ID: 159896]

Foster, R. T., ca. 1959, *Magnesium-Thorium (3.5% Max.) Alloy Recommended Care and Handling Methods*, Bendix Corporation, Kansas City Plant, Kansas City, Missouri. [SRDB Ref ID: 14685, p. 14]

Foster, R. T., 1960, "Revised Copy of Organizational Policies Procedure, S-306, Health and Safety Measures, Depts., 22, 34, 216-22 & 8650L," memorandum to J. Graves, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, November 17. [SRDB Ref ID: 14685]

Foster, R. T., 1961, "Recommendations for Handling Magnesium-Thorium Alloy at BEC," memorandum to All Concerned, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, August 23. [SRDB Ref ID: 108264, p. 44]

Foster, R. T., 1962, "Proposed Procedure," memorandum to F. T. Tate, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, May 7. [SRDB Ref ID: 14686]

Foster, R. T., 1970, "Development Support Project Using Magnesium-Thorium Alloy," memorandum to V. J. Smeltzer, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, August 28. [SRDB Ref ID: 128433, p. 26]

Harris, W. B. and I. Kingsley, 1958, *The Industrial Hygiene of Uranium Fabrication*, HASL-39, U.S. Atomic Energy Commission, New York Operations Office, New York, New York, June 6. [SRDB Ref ID: 15785]

Harrison, R. J., J. J. Meunier, and J. O. Schiltz, 1964, "Completed radiation protection survey form for Main Medical X-ray installation," internal memorandum, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, January 16. [SRDB Ref ID: 14688.

Helsel, D. R., 2012, *Statistical Methods for Censored Environmental Data Using Minitab and R*, John Wiley & Sons, New York, New York, February. [SRDB Ref ID: 150353]

HFMT (Honeywell Federal Manufacturing & Technologies), 2004, attachment from letter to Oak Ridge Associated Universities Team, Kansas City Plant, Kansas City, Missouri, June 23. [SRDB Ref ID: 14695]

HFMT (Honeywell Federal Manufacturing & Technologies), 2012, "KCP Rad Dosimetry Database XP1," Kansas City Plant, Kansas City, Missouri. [SRDB Ref ID: 111136]

HFMT (Honeywell Federal Manufacturing & Technologies), 2016, "Transformation," Kansas City National Security Campus, Kansas City, Missouri. [SRDB Ref ID: 159898]

Hobert, R. H., 1953, "Fernald Office History," letter to J. C. Woodhouse, E. I. Du Pont de Nemours & Company, Wilmington, Delaware, June 11. [SRDB Ref ID: 76834]

Hoecker, F. E., 1953, untitled letter to E. G. Applegate (Bendix Aviation Corporation), Lawrence, Kansas, September 24. [SRDB Ref ID: 14689]

ICRP (International Commission on Radiological Protection), 1982, *Protection of the Patient in Diagnostic Radiology*, Publication 34, Pergamon Press, Oxford, England. [SRDB Ref ID: 32466]

ICRP (International Commission on Radiological Protection), 1991, *1990 Recommendations of the International Commission on Radiological Protection*, Publication 60, Pergamon Press, Oxford, England. [SRDB Ref ID: 11517]

ICRP (International Commission on Radiological Protection), 1994a, *Human Respiratory Tract Model for Radiological Protection,* Publication 66, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection), 1994b, *Dose Coefficients for Intakes of Radionuclides by Workers*, Publication 68, Pergamon Press, Oxford, England. [SRDB Ref ID: 22731]

ICRU (International Commission on Radiation Units and Measurements), 1988, *Determination of Dose Equivalents from External Radiation Sources—Part 2*, Report 43, Bethesda, Maryland, December 15. [SRDB Ref ID: 8774]

ICRU (International Commission on Radiation Units and Measurements), 1993, *Quantities and Units in Radiation Protection Dosimetry*, Report 51, Bethesda, Maryland, September 1. [SRDB Ref ID: 13521]

Jacobson, G.A., 1988, untitled letter to J. G. Ochoa (Allied/Bendix), U.S. Department of Health and Human Services, Foot and Drug Administration, Kansas City, Missouri, October 27. [SRDB Ref ID: 128151, p. 3].

Kircher, C. F., 1990, "Final Unusual Occurrence Report KCP-90-02," memorandum to P. T. Hoopes, Allied-Signal Aerospace Corporation, Kansas City Plant, Kansas City, Missouri, June 6. [SRDB Ref ID: 128248, p. 7]

Kolbay, M. L., 2014, "Response to Review Request (20140007897-DH)," memorandum to G.S. Lewis, U. S. Department of Energy, Washington, D. C., September 8. [SRDB Ref ID: 135987]

Krueger, R. L., and J. J. Meunier, 1987, "Personal Concern Regarding Possible Exposure to Radioactive Material, Erbium Tritide Particulate, Inside Contaminated MC3847 Data Analyzer Case," investigation report, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, October 12. [SRDB Ref ID: 108267, p. 2]

Laing, E. C., 1952, "April Triple Dip Canning Program," memorandum to L. R. Kelman, Argonne National Laboratory-East, Argonne, Illinois, April 5.

Lalos, G., editor, 1989, *Film Badge Dosimetry in Atmospheric Nuclear Tests*, National Academy of Sciences, National Academy Press, Washington, D.C. [SRDB Ref ID: 1905]

Landauer (R. S. Landauer and Company), 1969–1986, collection of dosimeter badge forms. [SRDB Ref ID: 128265]

Lovell, P. K., 1966, "Report on Trip to U. S. Radium Corp., Bloomsburg, Pa. Feb. 10, 1966," memorandum to G. L. Rhodes, Sandia Corporation, Livermore Laboratory, Livermore, California. [SRDB Ref ID: 128439, p. 4]

Lund, A., 2004, "Confirmed Intakes," e-mail to Oak Ridge Associated Universities Team, Honeywell Federal Manufacturing & Technologies, Kansas City Plant, Kansas City, Missouri, May 10. [SRDB Ref ID: 14705]

Mahaffey, J. W., 1952, *History of Production Machining of Uranium*, FMPC-28, National Lead Company of Ohio, Cincinnati, Ohio, June 16. [SRDB Ref ID: 44238]

Malone, F. W., 1952a, "Weekly Progress Report February 14, 1952," memorandum to R. J. Smith, Atomic Energy Commission, New York Operations Office, New York, New York, February 18. [SRDB Ref ID: 73509]

Malone, F. W., 1952b, "Weekly Progress Report February 28, 1952," memorandum to R. J. Smith, Atomic Energy Commission, New York Operations Office, New York, New York, March 3. [SRDB Ref ID: 73512]

McDonald, J. C., P. L. Roberson, J. J. Fix, G. W. R. Endres, R. T. Hadley, L. L. Nichols, K. L. Holbrook, R. B. Schwartz, and R. C. Yoder, 1983, *Response Characteristics of Selected Personnel Neutron Dosimeters*, PNL-3982, Pacific Northwest Laboratory, Richland, Washington. [SRDB Ref ID: 13345]

Meunier, J. J., 1963, "MC1465, Industrial Hygiene Handling Procedure," memorandum to H. Sego (D-17), Bendix Corporation, Kansas City Plant, Kansas City, Missouri, February 8. [SRDB Ref ID: 137154, p. 16]

Meunier, J. J., 1966, "Inspection of Hi-Lo Switch Plates in Department 212," memorandum to C. F. Poynter, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, May 27. [SRDB Ref ID: 128439, p.

Meunier, J. J., 1977, "Survey To Determine Average Patient Radiation Exposure from Medical X-Ray Equipment," memorandum to File, Bendix Corporation, Kansas City Plant, Kansas City, Missouri. [SRDB Ref ID: 128174, p. 2].

Meunier, J. J., and DeCloud, M. F., 1980, "Survey to Determine Average Patient Radiation Exposure from Medical X-Ray Equipment," memorandum to File, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, May 7. [SRDB Ref ID: 128171, p. 12]

Meunier, J. J., A. E. Stewart, and J. C. Schiltz, 1962, *Radiation Protection Survey,* Bendix Corporation, Kansas City Plant, Kansas City, Missouri, December 18. [SRDB Ref ID: 128476, p. 66].

Meunier, J. J., 1970, "Evaluation of Roof Exhaust Stack Air Volume Rates from Departments 20D and 27C (Old 34C*)*," memorandum to J. O. Schiltz, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, April 22. [SRDB Ref ID: 128391, p. 3].

Nasca, B. M., 2004a, "Questions for KCP Technical Basis Document," attachment from e-mail to Oak Ridge Associated Universities Team, Honeywell Federal Manufacturing & Technologies, Kansas City Plant, Kansas City, Missouri, August 5. [SRDB Ref ID: 14711]

Nasca, B. M., 2004b, untitled e-mail to Oak Ridge Associated Universities Team, Honeywell Federal Manufacturing & Technologies, Kansas City Plant, Kansas City, Missouri, April 2. [SRDB Ref ID: 14708]

Nasca, B. M., 2004c, "air sampling data," electronic mail to J. Fix (U.S. Department of Energy, Pacific Northwest Laboratory), Honeywell Federal Manufacturing & Technologies, Kansas City Plant, Kansas City, Missouri, September 8, [SRDB Ref ID: 14716].

Nasca, B. M., 2004d, "External Doses and Total Uranium Intakes Spreadsheet," spreadsheet, Honeywell Federal Manufacturing & Technologies, Kansas City Plant, Kansas City, Missouri, March 31. [SRDB Ref ID: 14707]

Nasca, B. M., 2005a, "Subject: Re; Email dated 2/8/05, Uranium Bioassay," letter to Oak Ridge Associated Universities Team, Honeywell Federal Manufacturing & Technologies, Kansas City Plant, Kansas City, Missouri, February 9. [SRDB Ref ID: 15928]

Nasca, B. M., 2005b, "Subject: Re: Uranium at KCP," e-mail to Oak Ridge Associated Universities Team, Honeywell Federal Manufacturing & Technologies, Kansas City Plant, Kansas City, Missouri, February 24. [SRDB Ref ID: 24424]

Nasca, B. M., 2005c, "Subject: Re: Uranium Bioassays," e-mail to Oak Ridge Associated Universities Team, Honeywell Federal Manufacturing & Technologies, Kansas City Plant, Kansas City, Missouri, February 3. [SRDB Ref ID: 15926]

NBS (National Bureau of Standards), 1955, *X-Ray Protection*, Handbook 60, U.S. Department of Commerce, Washington, D.C. [SRDB Ref ID: 73173]

NCRP (National Council on Radiation Protection and Measurements), 1996, *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground,* Report 123, Bethesda, Maryland. [SRDB Ref ID: 79896]

NCRP (National Council on Radiation Protection and Measurements), 1997*, Medical X-Ray Electron Beam and Gamma-Ray Protection for Energies Up to 50 MeV (Equipment Design, Performance and Use),* Report 102, Bethesda, Maryland.

NIOSH (National Institute for Occupational Safety and Health), 2004, *Estimation of Ingestion Intakes*, OCAS-TIB-009, Rev. 0, Office of Compensation Analysis and Support, Cincinnati, Ohio, April 13.

NIOSH (National Institute for Occupational Safety and Health), 2007, *External Dose Reconstruction Implementation Guideline*, OCAS-IG-001, Rev. 3, Office of Compensation Analysis and Support, Cincinnati, Ohio, November 21.

NIOSH (National Institute for Occupational Safety and Health), 2010, *Radiation Exposures Covered for Dose Reconstructions Under Part B of the Energy Employees Occupational Illness Compensation Program Act*, DCAS-IG-003, Rev. 1, Division of Compensation Analysis and Support, Cincinnati, Ohio, October 5.

NIOSH (National Institute for Occupational Safety and Health), 2011, *Site Profiles for Atomic Weapons Employers that Worked Uranium Metals*, Battelle-TBD-6000, Rev. 1, Division of Compensation Analysis and Support, Cincinnati, Ohio, June 17.

NIOSH (National Institute for Occupational Safety and Health), 2014, *SEC Petition Evaluation Report, Petition SEC-00210*, Division of Compensation Analysis and Support, Cincinnati, Ohio, January 7. [SRDB Ref ID: 159903]

ORAUT (Oak Ridge Associated Universities Team), 2004, *Technical Information Bulletin – Assignment of Environmental Internal Doses for Employees Not Exposed to Airborne Radionuclides in the Workplace*, ORAUT-OTIB-0014, Rev. 00, Oak Ridge, Tennessee, June 22.

ORAUT (Oak Ridge Associated Universities Team), 2006a, *Technical Basis for Conversion from NCRP Report 38 Neutron Quality Factors to ICRP Publication 60 Radiation Weighting Factors for Respective IREP Input Neutron Energy Ranges*, ORAUT-OTIB-0055, Rev 00, Oak Ridge, Tennessee, June 5.

ORAUT (Oak Ridge Associated Universities Team), 2006b, *Occupational Onsite Ambient Dose Reconstruction for DOE Sites*, ORAUT-PROC-0060, Rev. 01, Oak Ridge, Tennessee, June 28.

ORAUT (Oak Ridge Associated Universities Team), 2010, *Basis for Development of an Exposure Matrix for the Mallinckrodt Chemical Company St. Louis Downtown Site and the St. Louis Airport Site, St. Louis, Missouri*, ORAUT-TKBS-0005, Rev. 03, Oak Ridge, Tennessee, November 22.

ORAUT (Oak Ridge Associated Universities Team), 2011a, *Dose Reconstruction from Occupational Medical X-Ray Procedures*, ORAUT-OTIB-0006, Rev. 04 PC-1, Oak Ridge, Tennessee. June 20.

ORAUT (Oak Ridge Associated Universities Team), 2011b, *Use of Coworker Dosimetry Data for External Dose Assignment*, ORAUT-OTIB-0020, Rev. 03, Oak Ridge, Tennessee, November 14.

ORAUT (Oak Ridge Associated Universities Team), 2012a, *Dose Reconstruction Method for Chronic Lymphocytic Leukemia*, ORAUT-OTIB-0082, Rev. 00 PC-1, Oak Ridge, Tennessee. December 20.

ORAUT (Oak Ridge Associated Universities Team), 2012b, *Paducah Gaseous Diffusion Plant – Occupational Internal Dose*, ORAUT-TKBS-0019-5, Rev. 03, Oak Ridge, Tennessee, August 24.

ORAUT (Oak Ridge Associated Universities Team), 2012c, *Dose Reconstruction During Residual Radioactivity Periods at Atomic Weapons Employer Facilities*, ORAUT-OTIB-0070, Rev. 01, Oak Ridge, Tennessee, March 5.

ORAUT (Oak Ridge Associated Universities Team), 2013a, "Thorium Oxide Powder Question," *documented communication with former KCP employees*, Oak Ridge, Tennessee, November 27. [SRDB Ref ID: 129196]

ORAUT (Oak Ridge Associated Universities Team), 2013b, "KCP Tritide Investigation," *documented communication with former KCP employees*, September 4. [SRDB Ref ID: 127657]

ORAUT (Oak Ridge Associated Universities Team), 2014a, *Parameters to Consider When Processing Claims for Construction Trade Workers*, ORAUT-OTIB-0052, Rev 02, Oake Ridge, Tennessee, July 24.

ORAUT (Oak Ridge Associated Universities Team), 2014b, *Guiding Reconstruction of Intakes of Thorium Resulting from Nuclear Weapons Programs*, ORAUT-OTIB-0076, Rev. 00, Oak Ridge, Tennessee, July 10.

ORAUT (Oak Ridge Associated Universities Team), 2015a, *Hanford Site – Occupational Internal Dose*, ORAUT-TKBS-0006-5, Rev. 06, Oak Ridge, Tennessee, November 16.

ORAUT (Oak Ridge Associated Universities Team), 2015b, *External Dose Coworker Methodology*, ORAUT-RPRT-0071, Rev. 00, Oak Ridge Associated Universities, Tennessee, July 2.

ORAUT (Oak Ridge Associated Universities Team), 2016a, *Guidance on Assigning Occupational X-Ray Dose Under EEOICPA for X-Rays Administered Off Site*, ORAUT-OTIB-0079, Rev. 01, Oak Ridge, Tennessee. March 18.

ORAUT (Oak Ridge Associated Universities Team), 2016b, *KCP Fit Plots*, July. [SRDB Ref ID: 162562]

ORAUT (Oak Ridge Associated Universities Team), 2016c, *KCP Imputation Plots*, July. [SRDB Ref ID: 162572]

Patterson, J., 1984, untitled letter to J. Meunier (Bendix Corporation), U.S. Department of Health & Human Services, Food and Drug Administration, Rockville, Maryland, June 28. [SRDB Ref ID: 128167, p. 2]

Pettie, C.B., 1958, "Survey of Medical X-Ray Facilities." [SRDB Ref ID: 128476, p. 93]

Reis, V. H., 1998, *Statement of Dr. Victor H. Reis, Assistant Secretary for Defense Programs, Department of Energy, Before the Subcommittee on Military Procurement, Committee on National Security, U.S. House of Representatives,* 1998, U.S. Department of Energy, Washington, D.C., March 19. [SRDB Ref ID: 14696]

Rockwell (Rockwell International), 1985, *Waste Trenches and Machining Area Decontamination Final Report*, RI/RD85-265-1, Rocketdyne Division, Canoga Park, California, October 30. [SRDB Ref ID: 123905]

Rockwell (Rockwell International), 1987, *Heavy Machining Inspection Area Contamination Reports*, RI/RD87-138, Rocketdyne Division, Canoga Park, California, March 12. [SRDB Ref ID: 123906, p. 106]

Schiltz, J. O., 1959, "T-329–Radiological Urinalysis Kit," memorandum to O. E. Lanborn, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, September 18. [SRDB Ref ID: 137065]

Schiltz, J. O., 1961, *Radiation Protection Survey,* Bendix Corporation, Kansas City Plant, Kansas City, Missouri, October 26. [SRDB Ref ID: 128476, p. 86].

Schiltz, J. O., 1962, "Experience with Radioactive Sources at Bendix Corporation Prior to 1954 (T219 Testing)," memorandum to R. T. Foster, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, August 17. [SRDB Ref ID: 128310, p. 106]

Schiltz, J. O., 1963, untitled memorandum, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, January 8. [SRDB Ref ID: 128349, p. 2]

Schiltz, J. O., 1964, *Radioactive Sources*, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, May 19. [SRDB Ref ID: 14697]

Schiltz, J. O., 1966a, *Special Physical Examination Program*, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, May 12. [SRDB Ref ID: 14699]

Schiltz, J. O., 1966b, *Radiation Detection Equipment*, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, April. [SRDB Ref ID: 14700]

Sharpe, W. E., 1977, "Health and Environmental Protection Survey--Bendix Kansas City Plant--May 17-20, 1977," internal memorandum to R. Bulcock, Bendix Corporation, Kansas City Plant, Kansas City, Missouri, July 5. [SRDB Ref ID: 128174, p. 2].

Sigma-Aldrich Corporation, 2015, *Safety Data Sheet, Tung Oil*, Version 5.1, January 26. [SRDB Ref ID: 140801]

Smock, J. W., 2014, "Response to Review Request (20140007645-HS)," memorandum to G. S. Lewis, U. S. Department of Energy, Washington, D. C., May 19. [SRDB Ref ID: 137786]

Staggs, R. P., and J. O. Schiltz, 1961, *Radiation Protection Survey,* Bendix Corporation, Kansas City Plant, Kansas City, Missouri, February 22. [SRDB Ref ID: 128476, p. 75].

Stowers, J. C., 1951a, *Safety Regulations for Handling and Storing of Normal Uranium*, U.S. Atomic Energy Commission Project Royal, August 17. [SRDB Ref ID: 128346]

Stowers, J. C., 1951b, "Procedures Pertaining to Work Performed in Area X," memorandum to W. B. Paine (Bendix Aviation Corporation), Atomic Energy Commission, Kansas City Field Office, Kansas City, Missouri, June 8. [SRDB Ref ID: 128333]

Stowers, J. C., 1951c, "Machining of U-238," memorandum to W. B. Paine, Atomic Energy Commission, Kansas City Field Office, Kansas City, Missouri, April 23. [SRDB Ref ID: 128332, p. 3]

Thiel, G. E., 1955, "Exit Physical Examinations," memorandum to M. Keese, Atomic Energy Commission, Kansas City Field Office, Kansas City, Missouri, March 1. [SRDB Ref ID: 129320]

Tiehen, G.L., 1987, "D/823 Radioactive Materials Usage," memorandum to D. Stoltz, Allied Bendix Aerospace, Bendix Kansas City Plant, Kansas City, Missouri, August 10. [SRDB Ref ID: 128420]

TMA (Thermo Analytical), 1990, *Radiation Dosimetry: TLD Service for Personnel & Environmental Monitoring,* TMA Eberline, Albuquerque, New Mexico. [SRDB Ref ID: 14889]

Todd, M., 2004a, "KCP Occupationally Related Routine Chest X-Rays," e-mail to Oak Ridge Associated Universities Team, Honeywell Federal Manufacturing & Technologies, Kansas City Plant, Kansas City, Missouri, April 8. [SRDB Ref ID: 14701]

Todd, M., 2004b, "KCP Medical X-Rays," attachment from e-mail to Oak Ridge Associated Universities Team, Honeywell Federal Manufacturing & Technologies, Kansas City Plant, Kansas City, Missouri, June 2. [SRDB Ref ID: 14702]

Todd, M., 2004c, "Questions for KCP Technical Basis Document," e-mail to Oak Ridge Associated Universities Team, Honeywell Federal Manufacturing & Technologies, Kansas City Plant, Kansas City, Missouri, August 19. [SRDB Ref ID: 14706]

Unruh, C. M., H. V. Larson, T. M. Beetle, and A. R. Keene, 1967, *The Establishment and Utilization of Film Dosimeter Performance Criteria*, BNWL-542, Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, Washington, September. [SRDB Ref ID: 14914]

Watson, J. E. Jr., J. L. Wood, W. G. Tankersley, and C. M. West, 1994, "Estimation of Radiation Dose for Workers Without Monitoring Data for Retrospective Epidemiologic Studies," *Health Physics*, volume 67, number 4, pp. 402–405. [SRDB Ref ID: 8601]

GLOSSARY

beta dose
Designation (i.e., beta) on some records for external dose from beta and less-energetic X-ray and gamma radiation, often for shallow dose or dose to the lens of the eye.

beta radiation
Charged particle emitted from some radioactive elements with a mass equal to 1/1,837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is a positron.

curie (Ci)
Traditional unit of radioactivity equal to 37 billion (3.7×10^{10}) becquerels, which is approximately equal to the activity of 1 gram of pure ^{226}Ra.

deep dose equivalent [*Hp(10)*]
Dose equivalent in units of rem or sievert for a 1-centimeter depth in tissue (1,000 milligrams per square centimeter). See *dose*.

density times thickness (DXT) device
Radiation-generating gauge for density or thickness measurements. Given a known value for either density or thickness, DXT devices measure the other value with about 0.5% accuracy using X-ray generators or radionuclide sources such as ^{137}Cs.

depleted uranium (DU)
Uranium with a percentage of ^{235}U lower than the 0.7% found in natural uranium.

dose equivalent (*H*)
In units of rem or sievert, product of absorbed dose in tissue multiplied by a weighting factor and sometimes by other modifying factors to account for the potential for a biological effect from the absorbed dose. See *dose*.

dose of record
(1) Dose records that the U.S. Department of Energy provided to the National Institute for Occupational Safety and Health as part of each worker's file. (2) Individual recorded dose such as that on a dosimetry card or in a dosimetry database.

dosimeter
Device that measures the quantity of received radiation, usually a holder with radiation-absorbing filters and radiation-sensitive inserts packaged to provide a record of absorbed dose received by an individual. See *film dosimeter*, *neutron film dosimeter*, *pocket ionization chamber*, and *thermoluminescent dosimeter*.

dosimetry
Measurement and calculation of internal and external radiation doses.

dosimetry system
System for assessment of received radiation dose. This includes the fabrication, assignment, and processing of external dosimeters, and/or the collection and analysis of bioassay samples, and the interpretation and documentation of the results.

exchange period (frequency)
Period (weekly, biweekly, monthly, quarterly, etc.) for routine exchange of dosimeters.

exposure

(1) In general, the act of being exposed to ionizing radiation; see *acute exposure* and *chronic exposure*. (2) Measure of the ionization produced by X- and gamma-ray photons in air in units of roentgens.

extremities

The arms from and including the elbow through the fingertips and the the legs from and including the knee and patella through the toes.

field calibration

Dosimeter calibration based on radiation types, intensities, and energies in the work environment.

film

(1) In the context of external dosimetry, radiation-sensitive photographic film in a light-tight wrapping. See *film dosimeter*. (2) X-ray film.

film density

See *optical density*.

film dosimeter

Package of film for measurement of ionizing radiation exposure for personnel monitoring purposes. A film dosimeter can contain two or three films of different sensitivities, and it can contain one or more filters that shield parts of the film from certain types of radiation. When developed, the film has an image caused by radiation measurable with an optical densitometer. Also called film badge.

gamma radiation

Electromagnetic radiation (photons) of short wavelength and high energy (10 kiloelectron-volts to 9 megaelectron-volts) that originates in atomic nuclei and accompanies many nuclear reactions (e.g., fission, radioactive decay, and neutron capture). Gamma photons are identical to X-ray photons of high energy; the difference is that X-rays do not originate in the nucleus.

gray

International System unit of absorbed radiation dose, which is the amount of energy from any type of ionizing radiation deposited in any medium; 1 Gy equals 1 joule per kilogram or 100 rads.

ionizing radiation

Radiation of high enough energy to remove an electron from a struck atom and leave behind a positively charged ion. High enough doses of ionizing radiation can cause cellular damage. Ionizing particles include alpha particles, beta particles, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, photoelectrons, Compton electrons, positron/negatron pairs from photon radiation, and scattered nuclei from fast neutrons.

minimum detectable activity or amount (MDA)

Smallest amount (activity or mass) of an analyte in a sample that can be detected with a probability β of nondetection (Type II error) while accepting a probability α of erroneously deciding that a positive (nonzero) quantity of analyte is present in an appropriate blank sample (Type I error).

minimum detectable level (MDL)

See *minimum detectable activity or amount*.

neutron (n)

Basic nucleic particle that is electrically neutral with mass slightly greater than that of a proton. There are neutrons in the nuclei of every atom heavier than normal hydrogen.

neutron film dosimeter

Film dosimeter with a nuclear track emulsion, type A, film packet.

nuclear emulsion

Thick photographic coating in which the tracks of various fundamental particles show as black traces after development. The number of tracks in a given area is a measure of the dose from that radiation. See *nuclear track emulsion, type A*.

nuclear track emulsion, type A (NTA)

Film made by the Eastman Kodak Company that is sensitive to fast neutrons. The developed image has tracks caused by neutrons that become visible under oil immersion with about 1,000-power magnification. The number of tracks in a given area is a measure of the dose from that radiation.

open window

Area of a film dosimeter that has little to no radiation shielding (e.g., only a holder and visible light protection). The open window measures nonpenetrating as well as penetrating dose, which minimizes the potential for beta radiation to contribute to the interpreted penetrating dose. See *film dosimeter*.

optical density

Measure of the degree of opacity of photographic or radiographic film defined as $OD = \log_{10} (I_0/I)$, the base-10 logarithm of the ratio of the reference light intensity I_0 (without film) to the transmitted light intensity (through the film) Also called film density and density reading.

personal dose equivalent, *Hp(d)*

Dose equivalent in units of rem or sievert in soft tissue below a specified point on the body at an appropriate depth *d*. The depths selected for personal dosimetry are 0.07 millimeters (7 milligrams per square centimeter) and 10 millimeters (1,000 milligrams per square centimeter), respectively, for the skin (shallow) and whole-body (deep) doses. These are noted as *Hp(0.07)* and *Hp(10)*, respectively. In 1993 the International Commission on Radiological Measurement and Units recommended *Hp(d)* as the dose quantity for radiological protection.

photon

Quantum of electromagnetic energy generally regarded as a discrete particle having zero rest mass, no electric charge, and an indefinitely long lifetime. The entire range of electromagnetic radiation that extends in frequency from 10^{23} cycles per second (hertz) to 0 hertz.

photon X-ray

Electromagnetic radiation of energies between 10 keV and 100 keV whose source can be an X-ray machine or radioisotope.

radiation

Subatomic particles and electromagnetic rays (photons) with kinetic energy that interact with matter through various mechanisms that involve energy transfer. See *ionizing radiation*.

radioactivity

Property possessed by some elements (e.g., uranium) or isotopes (e.g., ^{14}C) of spontaneously emitting energetic particles (electrons or alpha particles) by the disintegration of their atomic nuclei.

radiograph

Static images produced on radiographic film by gamma rays or X-rays after passing through matter. In the context of the Energy Employees Occupational Illness Compensation Program Act of 2000, radiographs are X-ray images of the various parts of the body used to screen for disease. See *radiology*.

rem

Traditional unit of radiation dose equivalent that indicates the biological damage caused by radiation equivalent to that caused by 1 rad of high-penetration X-rays multiplied by a quality factor. The sievert is the International System unit; 1 rem equals 0.01 sievert. The word derives from roentgen equivalent in man; rem is also the plural.

roentgen (R)

Unit of photon (gamma or X-ray) exposure for which the resultant ionization liberates a positive or negative charge equal to 2.58×10^{-4} coulombs per kilogram (or 1 electrostatic unit of electricity per cubic centimeter) of dry air at 0 degrees Celsius and standard atmospheric pressure. An exposure of 1 R is approximately equivalent to an absorbed dose of 1 rad in soft tissue for higher energy photons (generally greater than 100 kiloelectron-volts).

shallow dose equivalent [*Hp(0.07)*]

Dose equivalent in units of rem or sievert at a depth of 0.07 millimeters (7 milligrams per square centimeter) in tissue equal to the sum of the penetrating and nonpenetrating doses.

shielding

Material or obstruction that absorbs ionizing radiation and tends to protect personnel or materials from its effects.

skin dose

See *shallow dose equivalent*.

thermoluminescence

Property that causes a material to emit light as a result of heat.

thermoluminescent dosimeter (TLD)

Device for measuring radiation dose that consists of a holder containing solid chips of material that, when heated, release the stored energy as light. The measurement of this light provides a measurement of absorbed dose.

U.S. Atomic Energy Commission (AEC)

Federal agency created in 1946 to assume the responsibilities of the Manhattan Engineer District (nuclear weapons) and to manage the development, use, and control of nuclear energy for military and civilian applications. The U.S. Energy Research and Development Administration and the U.S. Nuclear Regulatory Commission assumed separate duties from the AEC in 1974. The U.S. Department of Energy succeeded the U.S. Energy Research and Development Administration in 1979.

whole-body dose

Dose to the entire body excluding the contents of the gastrointestinal tract, urinary bladder, and gall bladder and commonly defined as the absorbed dose at a tissue depth of 10 millimeters (1,000 milligrams per square centimeter). Also called penetrating dose. See *dose*.

X-ray

(1) See *X-ray radiation*. (2) See *radiograph*.

X-ray radiation

Electromagnetic radiation (photons) produced by bombardment of atoms by accelerated particles. X-rays are produced by various mechanisms including bremsstrahlung and electron shell transitions within atoms (characteristic X-rays). Once formed, there is no difference between X-rays and gamma rays, but gamma photons originate inside the nucleus of an atom.

ATTACHMENT A
EXTERNAL AND INTERNAL AMBIENT ENVIRONMENTAL DOSE ASSIGNMENT GUIDELINE

TABLE OF CONTENTS

LIST OF TABLES

ATTACHMENT A
EXTERNAL AND INTERNAL AMBIENT ENVIRONMENTAL DOSE ASSIGNMENT GUIDELINE (continued)

This attachment examines potential ambient environmental exposures, both external and internal, for unmonitored workers. The analysis used measured workplace data as the basis.

A.1 EXTERNAL RADIATION

There are no known measurements of environmental external dose from KCP operations. Site documents indicate little if any radiological ambient environmental impact. However, in spite of no evidence, this analysis recommends that dose reconstructors assign an external dose of 25 mrem/yr to an unmonitored, nonradiological worker for each year of employment at KCP. This assignment is favorable to claimants. Table A-1 lists the IREP input for calculation of organ dose. This potential external radiation dose is based on the calculated 95% variability amongst background control personnel dosimeters in Table A-3 (i.e., 2-sigma = 25 mrem).

Table A-1. IREP input for ambient external dose calculation.

Exposure rate	Radiation type	Dose distribution type	Parameter 1	Parameter 2	Parameter 3
Chronic	Photons E=30–250keV	Constant	0.025	0.000	0.000

A.2 INTERNAL RADIATION

The primary and apparently only radionuclide at KCP in large quantities was DU from 1959 through 1971. The recommended approach to assign an ambient environmental internal dose to unmonitored nonradiological workers based on analysis of dispersion to the outside of measured laboratory uranium concentrations. There were no windows in the building, so all potential releases were from stacks. If the stacks had filtration and what kind is unknown. As seen in Table A-2, KCP had two primary laboratories where workers handled DU, with the following characteristics:

Table A-2. Laboratories where workers handled DU.

Department	Stack velocity (ft^3/min)	Work room area (ft^2)
Machining area (20D)	2,400	8,800
Mixing/curing (27C)	1,987	7,000

Source: Meunier (1970).

Based on this information, the analysis estimated the dispersion factor between outside and inside air concentrations as 0.01 (Section A.2.1) based on National Council on Radiation Protection and Measurements (NCRP) Report 123, *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground* (NCRP 1996). To estimate potential daily intake, the analysis multiplied an annual intake fraction of 0.01 by the GM annual measured laboratory air concentrations in Table 5-4 (i.e., multiply annual concentrations in Table 5-4 by 6.58×10^{10} to intake in picocuries per day). For the period after 1970, there are no workplace air sampling data available for analysis. Because there was potential for unknown small releases or residual contamination, such as the incident with ^{147}Pm in 1989, dose reconstructors should use the GM concentration from Table 5-4 with the factor of 0.01 for each year of employment after 1970 until 1990. The 1990 end of this period is when the multi-agency response findings to the ^{147}Pm incident found no significant environmental releases. Table A-4 shows the resulting input for IMBA.

ATTACHMENT A
EXTERNAL AND INTERNAL AMBIENT ENVIRONMENTAL DOSE ASSIGNMENT GUIDELINE (continued)

Table A-3. Personnel dosimeter control dosimeter data.[a]

Account series	Photon deep dose equivalent (mrem)	Photon shallow dose equivalent (mrem)	Days	mrem/d	mrem/hr
DUO	37	37	206	0.179612	0.007
DUO	34	34	210	0.163726	0.007
DUO	41	42	216	0.188441	0.008
DUO	40	39	223	0.179878	0.007
ENG	35	34	206	0.169734	0.007
ENG	35	37	210	0.16878	0.007
ENG	36	38	216	0.167176	0.007
ENG	39	38	223	0.174036	0.007
FMT	30	29	206	0.145881	0.006
FMT	29	28	210	0.135928	0.006
FMT	33	33	216	0.152259	0.006
FMT	33	32	223	0.148526	0.006
GEN	30	30	206	0.146249	0.006
GEN	32	33	210	0.151753	0.006
GEN	35	36	216	0.161556	0.007
GEN	34	34	223	0.152212	0.006
MET	53	53	206	0.259466	0.011
MET	52	53	210	0.247593	0.010
MET	59	62	216	0.271173	0.011
MET	58	57	223	0.260149	0.011
NDE	45	45	206	0.220097	0.009
NDE	48	50	210	0.226797	0.009
NDE	49	52	216	0.228593	0.010
NDE	52	52	223	0.235022	0.010
NGA	41	41	206	0.200631	0.008
NGA	37	36	210	0.174383	0.007
NGA	42	44	216	0.196286	0.008
NGA	42	41	223	0.189626	0.008
RAD	29	29	206	0.14282	0.006
RAD	32	32	210	0.153984	0.006
RAD	34	34	216	0.155472	0.006
RAD	35	35	223	0.156726	0.007
ULT	41	40	206	0.200863	0.008
ULT	41	40	210	0.194969	0.008
ULT	45	46	216	0.208939	0.009
ULT	47	46	223	0.209522	0.009
WMT	39	39	206	0.188718	0.008
WMT	35	35	210	0.168635	0.007
WMT	44	47	216	0.201806	0.008
WMT	44	44	223	0.197593	0.008
XRY	40	39	206	0.194161	0.008
XRY	43	43	210	0.203215	0.008
XRY	49	51	216	0.224537	0.009
XRY	48	47	223	0.213842	0.009
Average	N/A	N/A	N/A	**0.1888947**	N/A
Standard deviation	N/A	N/A	N/A	**0.0345245**	N/A

ATTACHMENT A
EXTERNAL AND INTERNAL AMBIENT ENVIRONMENTAL DOSE ASSIGNMENT GUIDELINE
(continued)

Account series	Photon deep dose equivalent (mrem)	Photon shallow dose equivalent (mrem)	Days	mrem/d	mrem/hr
Annual, 1-sigma	N/A	N/A	N/A	**12.60143**	mrem
Annual, 2-sigma	N/A	N/A	N/A	**25.20286**	mrem

a. N/A = not applicable.

Table A-4. GM measured air concentration for IMBA input for ambient internal dose calculation.

Year	µCi/cm^3	pCi/d	GSD
1958	4.01E-13	2.64E-02	3.0
1959	2.89E-13	1.90E-02	3.0
1960	3.41E-13	2.24E-02	3.0
1961	1.97E-13	1.30E-02	3.0
1962	2.50E-13	1.65E-02	3.0
1963	2.47E-13	1.63E-02	3.0
1964	3.91E-13	2.57E-02	3.0
1965	1.05E-13	6.91E-03	3.0
1966	2.00E-13	1.32E-02	3.0
1967	5.70E-13	3.75E-02	3.0
1968	2.31E-13	1.52E-02	3.0
1969	3.88E-12	2.55E-01	3.0
1970	4.02E-14	2.65E-03	3.0
1971–1989	5.49E-13	3.62E-02	3.0

Air Concentrations Outside the Plant from Activities Inside the Plant
The analysis calculated the possible air concentration of DU outside the KCP facility due to activities inside the building based on the measured inside air concentration and engineering details of the primary laboratories.

For dilution factors, the analysis assumed the measured room air concentration was 1 Bq/m^3 (a unit air concentration), then used he results of the calculated outside air concentration to calculate the potential occupational dose for selected receptor locations.

A.2.1 Receptor on the Roof

Using the Machining Area (20D) as an example, the quantity of DU exhausted from the room is: 1.133 Bq/s.

The analysis used Equation A-1 (Equation 2.8 from NCRP 1996) to calculate the air concentration downwind of the release point but on the same surface as the release point (i.e., both the source and receptor are on the roof).

$$C = B_0 \frac{Q}{u_h x^2} \qquad \text{(A-1)}$$

where

B_0 = 30

ATTACHMENT A
EXTERNAL AND INTERNAL AMBIENT ENVIRONMENTAL DOSE ASSIGNMENT GUIDELINE
(continued)

Q = the release rate (1.133 Bq/s)
u_h = mean wind speed (4.74 m/s)
x = downwind distance (m)

the distance where C = 0.01 is from Equation A-21, rewritten to solve for x:

$$x = \sqrt{\frac{B_0 Q}{C u_h}} \quad \text{(A-2)}$$

With substitution of the numerical values above, C = 0.01 when x exceeds 26.7 m (87.9 ft) and the wind always blows towards the recipient.

A.2.2 Receptor on the Ground Downwind from the Source on the Roof

For this case the calculations use Equation A-3 (Equation 2.6 from NCRP 1996):

$$C = \frac{fQP}{u} \quad \text{(A-3)}$$

where

f = fraction of time the wind blows from the source to the receptor
P = dilution factor from Figure 2.2 of NCRP (1996)

The greatest air concentrations result when the height of the building is zero, in which case the value of P is 3.6×10^{-2}. Substituting the above-given values, C is 8.6×10^{-3} Bq/m^3. The dilution factor of 0.0086 is for a distance of 100 m from the source point (the closest distance plotted in the reference figure). This analysis includes the assumption that the wind is always blowing toward the receptor, which is favorable to claimants.

ATTACHMENT B
EXTERNAL COWORKER DOSE ASSIGNMENT GUIDELINE

TABLE OF CONTENTS

LIST OF TABLES

ATTACHMENT B
EXTERNAL COWORKER DOSE ASSIGNMENT GUIDELINE (continued)

B.1 PURPOSE

This attachment provides information that allows dose reconstructors to base external doses on known site coworker data for workers who have no or limited monitoring data or for gaps in the dosimetry record. Please note, however, that if the unmonitored period is short and the record has monitoring results from before and after the gap, with no apparent change in work assignments, the dose reconstructor can use the average of the surrounding measurements for the gap period (see NIOSH 2007).

In cases where the monitoring records list a recorded "0," dose reconstructors should assume KCP issued the dosimeter, processed it, and that the result was less than the dosimeter limit of detection (LOD). In cases in which the records show monitoring for occupational external exposures and one or more dosimeter exchange cycles are blank (or listed as a dash, slash, or hash mark), dose reconstructors should assume the absence of an entry indicates:

- The worker was not issued a dosimeter in that exchange cycle,
- The worker might have been issued a dosimeter, but it was not processed due to loss or damage, or
- That the results of processing were incomplete or suspect and no dose was assigned because of the absence of processing or an errant result.

B.2 BACKGROUND

The Oak Ridge Associated Universities (ORAU) Team has prepared a series of coworker data studies to permit dose reconstructors to complete certain cases for which external or internal monitoring data are unavailable or incomplete. Cases that do not have complete monitoring data could fall into one of several categories:

- The worker was unmonitored and, even by today's standards, did not need to be monitored (e.g., a nonradiological worker).
- The worker was unmonitored but, by today's standards, would have been monitored.
- The worker might have been monitored, but the data are not available to the dose reconstructor.
- Partial information is available, but it is insufficient to facilitate a dose reconstruction.

ORAUT-OTIB-0020, *Use of Coworker Dosimetry Data for External Dose Assignment*, notes dose reconstructors can evaluate some cases without complete monitoring data based on assumptions and methodologies that do not involve coworker data (ORAUT 2011a). For example, the assignment of ambient external and internal doses based on information in the relevant site technical basis documents (TBDs) allows evaluation of many cases in the first category.

KCP used a variety of film and TLD dosimetry systems (Section 6.0).

ATTACHMENT B
EXTERNAL COWORKER DOSE ASSIGNMENT GUIDELINE (continued)

B.3 GENERAL APPROACH

A dosimeter measures external dose over a given length of time (e.g., a month or quarter). The total of the doses from all measurements in a year is the annual dose. Many sites used a censoring level, usually referred to as the LOD, and reported the results as "less than" that value. For example, the reported dose for a given month might be "<0.050 rem." These censored data are problematic for the development of coworker models.

The previous approach to handling censored dosimeter readings (ORAUT 2011b) was to substitute one-half of the censoring level for the censored results and then calculate the empirical 50th and 95th percentiles of the dataset. In statistics, this substitution is referred to as an imputation. In general, the imputation of a constant value like LOD/2 is not recommended (Helsel 2012) because it biases parameter estimates high. ORAUT-RPRT-0071, *External Dose Coworker Methodology* (ORAUT 2015b), outlines an alternative approach to analyzing the censored data that:

- Uses a lognormal probability model to generate a distribution of values to use for imputation rather than a constant one-half of the censoring level,
- Uses survival analysis techniques like those now in use for internal dose coworker modeling to estimate the parameters of a lognormal fit (i.e., the GM and GSD) to the data rather than using the empirical 50th and 95th percentile, and
- Uses multiple imputation to account for the uncertainty in the parameter estimates due to the imputation process.

B.4 APPLICATIONS AND LIMITATIONS

Some KCP employees could have worked at one or more other major sites in the DOE complex during their employment histories. Therefore, dose reconstructors should use the data in this attachment with caution to ensure, for likely noncompensable cases, that unmonitored external doses from multiple site employments are overestimates. This typically requires the availability of the recorded doses or guidance in site documents that covers external coworker dosimetry data for all relevant sites.

The data in this document address penetrating deep dose and nonpenetrating shallow dose.

External onsite ambient dose should be applied as specified in the latest revision of ORAUT-PROC-0060*, Occupational Onsite Ambient Dose Reconstruction for DOE Sites* (ORAUT 2006b).

B.5 COWORKER DATA DEVELOPMENT

KCP provided information for coworker analysis in a database entitled "KCP Rad Dosimetry Database XP1" (HFMT 2012) This analysis used the table "Worker Exposure History Table" from that database.

B.6 STATISTICAL ANALYSIS

The analysis used the instructions in Section B.9 and ORAUT-RPRT-0071 (ORAUT 2015b) to analyze the data from the KCP table. ORAUT (2016b) contains the imputation model plots fit with lognormal regression on order statistics. Censored badge readings were imputed from these lognormal imputation distributions, summed to compute annual doses, and yearly lognormal fits were

ATTACHMENT B
EXTERNAL COWORKER DOSE ASSIGNMENT GUIDELINE (continued)

made. After multiple imputations (K = 30), the parameters were averaged, resulting in the plots in ORAUT (2016c). For this analysis, a histogram analysis of the data for a year (or a period of years) determined the censoring levels for each year. The censoring level is a positive value in the "grey zone" between zero and the MDL values in Table B-3 below.

B.7 COWORKER ANNUAL DOSE SUMMARIES

Tables B-1 and B-2 provide the results of the analysis for deep and shallow dose, respectively. The tables include the 95th percentile of the specified lognormal distribution, the number of workers in each year, and the censoring level (discussed above and in Section B.9). Dose reconstructors should use these data in the same manner as described in ORAUT-OTIB-0020 in relation to using either the GM (50th percentile) or the 95th-percentile value as a constant depending on work history (ORAUT 2011b). Section 6.0 discusses energy ranges for these doses.

Table B-1. Annual external deep doses (rem).

Year	GM	GSD	95th percentile	Number of workers	Censoring level
1950	0.009	21.47	1.346	46	0.01
1951	0.011	27.16	2.553	227	0.01
1952	0.019	9.61	0.802	231	0.01
1953	0.006	14.57	0.509	101	0.01
1954	0.002	36.07	0.696	65	0.01
1955	0.011	24.68	2.213	41	0.01
1956	0.130	3.71	1.119	26	0.01
1957	0.011	49.05	6.393	65	0.01
1958	0.001	24.82	0.262	301	0.01
1959	0.001	15.45	0.053	461	0.01
1960	0.001	16.10	0.059	1043	0.01
1961	0.002	20.96	0.322	946	0.01
1962	<0.001	12.32	0.027	700	0.01
1963	0.001	16.04	0.061	596	0.01
1964	<0.001	13.05	0.032	530	0.01
1965	<0.001	10.92	0.019	436	0.01
1966	<0.001	11.26	0.020	415	0.01
1967	<0.001	10.77	0.019	369	0.01
1968	<0.001	10.01	0.014	466	0.01
1969	<0.001	9.72	0.012	575	0.01
1970	<0.001	10.69	0.018	580	0.01
1971	<0.001	10.26	0.016	574	0.01
1972	0.001	15.90	0.120	195	0.01
1973	0.001	16.25	0.116	199	0.01
1974	0.002	19.72	0.252	169	0.01
1975	0.001	13.43	0.067	149	0.01
1976	0.002	14.92	0.130	126	0.01
1977	<0.001	12.35	0.027	123	0.01
1978	0.001	13.76	0.038	152	0.01
1979	<0.001	12.22	0.028	162	0.01
1980	0.001	12.74	0.035	185	0.01
1981	<0.001	13.02	0.032	210	0.01
1982	<0.001	12.50	0.028	209	0.01
1983	<0.001	10.68	0.019	227	0.01
1984	<0.001	11.85	0.024	216	0.01

ATTACHMENT B
EXTERNAL COWORKER DOSE ASSIGNMENT GUIDELINE (continued)

Year	GM	GSD	95th percentile	Number of workers	Censoring level
1985	0.001	14.45	0.064	201	0.01
1986	0.001	13.15	0.036	194	0.01
1987	<0.001	11.45	0.023	196	0.01
1988	<0.001	11.76	0.022	186	0.01
1989	<0.001	10.98	0.020	233	0.01
1990	<0.001	11.29	0.021	216	0.01
1991	<0.001	10.67	0.018	193	0.01
1992	<0.001	9.72	0.013	169	0.01
1993	<0.001	9.12	0.012	113	0.01
1994	<0.001	9.83	0.015	55	0.01
1995	<0.001	11.08	0.022	96	0.01
1996	<0.001	10.07	0.015	104	0.01
1997	<0.001	9.44	0.014	123	0.01
1998	<0.001	9.65	0.013	101	0.01
1999	<0.001	10.50	0.015	93	0.01
2000	<0.001	4.78	0.006	84	0.001
2001	0.001	4.91	0.007	86	0.001
2002	0.001	5.43	0.009	78	0.001
2003	0.001	5.77	0.011	84	0.001
2004	0.001	5.17	0.008	99	0.001
2005	<0.001	4.51	0.005	104	0.001
2006	<0.001	5.07	0.006	102	0.001
2007	<0.001	4.52	0.005	91	0.001
2008	0.001	4.55	0.007	89	0.001
2009	<0.001	4.17	0.003	60	0.001
2010	<0.001	4.08	0.003	59	0.001

Table B-2. Annual external shallow doses (rem).

Year	GM	GSD	95th percentile	Number of workers	Censoring level
1950	0.010	19.10	1.227	46	0.01
1951	0.012	23.62	2.206	227	0.01
1952	0.020	9.34	0.777	231	0.01
1953	0.007	12.56	0.453	101	0.01
1954	0.003	28.74	0.670	65	0.01
1955	0.014	20.16	1.889	41	0.01
1956	0.130	3.71	1.119	26	0.01
1957	0.012	39.84	5.171	65	0.01
1958	0.002	19.92	0.314	301	0.01
1959	0.002	17.78	0.209	461	0.01
1960	0.002	22.65	0.408	1043	0.01
1961	0.005	20.62	0.676	946	0.01
1962	0.006	17.07	0.589	700	0.01
1963	0.001	17.54	0.149	596	0.01
1964	0.001	13.92	0.072	530	0.01
1965	0.001	10.07	0.031	436	0.01
1966	0.001	15.42	0.099	415	0.01
1967	0.001	10.65	0.036	369	0.01
1968	0.001	9.52	0.024	466	0.01
1969	0.000	8.51	0.016	575	0.01

ATTACHMENT B
EXTERNAL COWORKER DOSE ASSIGNMENT GUIDELINE (continued)

Year	GM	GSD	95th percentile	Number of workers	Censoring level
1970	0.001	9.41	0.023	580	0.01
1971	0.001	9.00	0.020	574	0.01
1972	0.002	12.69	0.129	195	0.01
1973	0.002	21.95	0.400	199	0.01
1974	0.005	14.76	0.415	169	0.01
1975	0.002	13.68	0.146	149	0.01
1976	0.003	11.33	0.185	126	0.01
1977	0.001	10.40	0.031	123	0.01
1978	0.001	12.13	0.049	152	0.01
1979	0.001	10.21	0.034	162	0.01
1980	0.001	11.65	0.052	185	0.01
1981	0.001	12.21	0.056	210	0.01
1982	0.001	11.23	0.048	209	0.01
1983	0.001	10.14	0.030	227	0.01
1984	0.001	10.26	0.031	216	0.01
1985	0.001	12.03	0.069	201	0.01
1986	0.001	11.24	0.054	194	0.01
1987	0.001	9.45	0.027	196	0.01
1988	0.001	10.44	0.033	186	0.01
1989	0.001	10.09	0.030	233	0.01
1990	0.001	9.73	0.030	216	0.01
1991	0.001	9.29	0.023	193	0.01
1992	0.001	8.23	0.016	169	0.01
1993	0.001	8.78	0.019	113	0.01
1994	0.001	9.43	0.024	55	0.01
1995	0.001	9.66	0.026	96	0.01
1996	0.001	9.14	0.021	104	0.01
1997	0.001	9.00	0.022	123	0.01
1998	0.001	7.94	0.016	101	0.01
1999	0.001	9.37	0.026	93	0.01
2000	0.001	3.85	0.009	84	0.001
2001	0.001	4.29	0.011	86	0.001
2002	0.001	4.64	0.012	78	0.001
2003	0.001	4.45	0.012	84	0.001
2004	0.001	4.12	0.011	99	0.001
2005	0.001	4.13	0.011	104	0.001
2006	0.001	4.62	0.013	102	0.001
2007	0.001	4.37	0.012	91	0.001
2008	0.001	4.33	0.015	89	0.001
2009	0.001	4.24	0.008	60	0.001
2010	0.001	3.50	0.005	59	0.001

B.8 EXTERNAL DOSE COWORKER STUDY INSTRUCTIONS, 1950 TO 2010

B.8.1 Data Sources

The data are from the following fields in “Worker Exposure History Table” (HFMT 2012):

- Year,
- SSN,

ATTACHMENT B
EXTERNAL COWORKER DOSE ASSIGNMENT GUIDELINE (continued)

- Begin Date,
- End Date,
- Deep (Rem), and
- Shallow (Rem).

B.8.2 General Comments

- A blank cell means an individual was not monitored during between Begin Date and End Date.
- A cell containing zero means the individual was monitored but the results were below the MDL. In this case, use the MDL values from Table B-3 (derived from Table 6-3).
- No correction factors are necessary for deep dose or shallow dose.

B.9 INSTRUCTIONS

The following data fields are required:

- The year in which the dosimeter was worn,
- The Social Security Number for the individual who wore the dosimeter,
- Begin Date and End Date to determine the year the dosimeter was worn, and
- The dosimeter deep and shallow dose quantities.

For this analysis, the censoring level for each year should be determined by a histogram analysis of the data for that year (or a period of years). The censoring level will be a positive value in the "grey zone" between zero and the MDL values in Table B-3. Tables B-1 and B-2 list the censoring levels for these analyses.

Table B-3. Periods and MDLs (mrem) for imputation models.

Period	Deep	Shallow
1950–1972	40	40
1973–1982	30	30
1983-2003	10	10