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☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
11/14/2006	00	New Site Profile for Clarksville Base Weapons Storage Area and Modification Center with Supplementary Guidance for Medina. First approved issue. Incorporated responses to internal formal review comments. Added sections 5.2.2 and 6.5 covering guidance for 1966-67 after operations had ceased. Changes made in response to NIOSH formal review comments including: use of "favorable to claimants" throughout; removal of HT-to-HTO conversion factor for all sections dealing with tritium; Sections 4.0 and 5.1.1 – use of Pantex 1989 accident doses as surrogate for Clarksville tritium release accident; Section 5 – clarification of operation years and postoperative years, also added to Glossary; Section 5.2.1 – revised DU intakes during weapons disassembly to include room ventilation and 8-hr shift; Section 5.2.3 – added DU intake from burning contaminated HE; Section 5.3 – added intake from alpha contamination on capsules or pits; Section 6.1 – added description of roles of SNL, AEC, and military personnel; Section 6.4 – clarified that the dose rate from Pu metal is sum of photons and neutrons; Section A1.1 – added to description of Medina site and operation; Section A2.0 – extended period of medical X-rays to October 1958; Section A3.2.2 – clarified dates soil samples were taken; Section A5.0 – enhanced the description of the radiography source incident. There is an increase in assigned dose and a PER is required. Training required: As determined by the Task Manager. Initiated by Donald E. Bihl.
10/05/2012	01	Revision initiated to incorporate Special Exposure Cohort (SEC) Petitions SEC-00202 and SEC-00203. Added Section 1.3 to incorporate the SEC class definition. Revised Section 5.0 and deleted subsections in accordance with dose reconstruction limitations per SEC-00202. Added Section A.1 to incorporate the SEC class definition. Revised Section A.4 in accordance with dose reconstruction limitations per SEC-00203. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Dale D. Thomas.

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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AFB	Air Force Base
AIRS	Aerometric Information Retrieval System
AP	anterior-posterior
CD	compact disk
CFR	Code of Federal Regulations
Ci	curie
cm	centimeter
CONEX	container express
d	day
DOE	U.S. Department of Energy
dpm	disintegrations per minute
DU	depleted uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
ft	foot
g	gram
gal	gallon
GSD	geometric standard deviation
Gy	gray
HEPA	high-efficiency particulate air
HEU	highly enriched uranium
hr	hour
HVL	half-value layer
IAAP	Iowa Army Ammunition Plant
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Analysis
in.	inch
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt
kg	kilogram
L	liter
LAT	lateral
lb	pound
LLI	lower large intestine
LLRW	low-level radioactive waste
m	meter
MDL	minimum detection level
MeV	megaelectron-volt, 1 million electron volts
mGy	milligray
MHSMC	Mason and Hanger-Silas Mason Company, Inc.
mL	milliliter

mm	millimeter
MRD	minimum recordable dose
mrad	millirad
mrem	millirem
MSL	mean sea level
NCRP	National Council on Radiological Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
NTA	Eastman Kodak nuclear track emulsion, type A
PA	posterior-anterior
pCi	picocurie
PM_{10}	particulate matter in the air with an aerodynamic diameter less than or equal to 10 micrometers
POC	probability of causation
s	second
SEC	Special Exposure Cohort
SI	small intestine
SNL	Sandia National Laboratories
ST	stomach
TBD	technical basis document
TLD	thermoluminescent dosimeter
TNT	trinitrotoluene
ULI	upper large intestine
U.S.C.	United States Code
UST	underground storage tank
WSA	Weapons Storage Area
yr	year
Z	atomic number
µCi	microcurie
µg	microgram
µm	micrometer
α	alpha
β	beta
γ	gamma
§	section

1.0 INTRODUCTION

1.1 PURPOSE

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 sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH staff in the completion of the individual work required for each dose reconstruction.

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

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation[1]] guidelines established under subsection (c) …" [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation, 42 C.F.R. Pt. 82) restrict the "performance of duty" referred to in 42 U S. C. § 7384n(b) to nuclear weapons work (NIOSH 2010).

The statute also includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition excludes Naval Nuclear Propulsion Facilities from being covered under the Act, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally-derived radiation exposures at covered facilities in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external occupational radiation exposures are considered valid for inclusion in a dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived (NIOSH 2010):

- Background radiation, including radiation from naturally occurring radon present in conventional structures

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

- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

1.2 SCOPE

This Site Profile provides information about U.S. Atomic Energy Commission (AEC) operations at Clarksville Modification Center in Tennessee pertaining to radiation exposures for monitored or unmonitored workers. Section 2.0 describes the site and operations pertaining to possible radiation exposures and discusses radiation source terms. Section 3.0 provides guidance for determining occupational medical dose. Section 4.0 provides guidance for determining dose to workers outside radiological facilities due to releases of radioactive materials to the environment. Section 5.0 provides guidance for determining intakes of radionuclides inside facilities. Section 6.0 provides guidance for determining external doses from measured doses or for periods when records of measured doses are missing. Because the Medina Modification Center in Texas was similar in purpose and operation to Clarksville Modification Center, Attachment A of this document contains information about Medina.

1.3 SPECIAL EXPOSURE COHORT

On August 23, 2012, as provided for under 42 U.S.C 7384 q(b), the Secretary of Health and Human Services designated the following class of employees as an addition to the Special Exposure Cohort (SEC) (Sebelius 2012a):

> *All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors, who worked at the Clarksville Modification Center, Ft. Campbell, in Clarksville, Tennessee, from August 1, 1949 through December 31, 1967, for a number of work days aggregating at least 250 work days, occurring either solely under this employment, or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort.*

In its evaluation (NIOSH 2012a), NIOSH found it lacks sufficient information to reconstruct internal radiation doses adequately for all Clarksville Modification Center employees for all potential radiation exposures. Specifically, this includes internal personnel monitoring data, air monitoring data, process data, and radiological source term information to allow NIOSH to estimate with sufficient accuracy potential internal exposures to uranium, plutonium, and tritium to which the proposed class might have been subjected. However, NIOSH has decided that the occupational medical dose and external exposures can be reconstructed based on available data. Based on the occupational medical and external data available and the available dose reconstruction methods, NIOSH believes that it is possible to either (1) estimate the maximum external dose for every type of cancer for which radiation doses are reconstructed that could have been incurred under plausible circumstances by any member of the class, or (2) estimate the external doses to members of the class more precisely than a maximum dose estimate. Although NIOSH found that it is not possible to reconstruct internal radiation doses completely for the proposed class, it intends to use any internal monitoring data that might become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Therefore, dose reconstructions for individuals employed at Clarksville Modification Center, during the period from August 1, 1949, through December 31, 1967, but who do not qualify for inclusion in the SEC, can be performed using these data as appropriate to support a partial dose reconstruction.

2.0 SITE DESCRIPTION AND OPERATIONAL HISTORY

2.1 SITE DESCRIPTION

The Clarksville Modification Center was one of 13 Weapons Storage Areas (WSAs) created under the Armed Forces Special Weapons Project. The Base was constructed in the mid- to late 1940s (the first weapon components arrived in July 1949) and supported by Sandia Corporation [now Sandia National Laboratories (SNL); for convenience, this Site Profile uses SNL throughout] for the AEC and the U.S. Navy. SNL, AEC, and the Navy were all active at Clarksville Modification Center from 1949 until 1958 performing maintenance and quality assurance on nuclear components of weapons. From 1958 until 1965, Mason and Hanger-Silas Mason Company, Inc. (MHSMC) operated Clarksville Modification Center for the AEC as a weapons modification and disassembly facility (Lamb Associates and Halliburton NUS 1996; McConn 2006; Mitchell 2003).

Clarksville Modification Center was originally separate from Fort Campbell, which was operated by the U.S. Army. In 1965, AEC activities transferred elsewhere, although the AEC was responsible for the Base through 1967. The Base was returned to the Army and incorporated into Fort Campbell in 1969 (Last, Gilmore, and Bronson 1998). It is unclear what activities occurred between 1967 and 1969 but storage of nuclear materials had ceased.

During the AEC tenure, nuclear weapons and weapon components were stored by the AEC and maintained by SNL and military personnel at the WSAs. WSAs consisted of storage buildings that housed nuclear capsules, maintenance structures, waste burial sites, and bunkers for storage of weapons casings. SNL personnel worked at Clarksville Modification Center under contract to the AEC until early 1962 (Lamb Associates and Halliburton NUS 1996; Last, Gilmore, and Bronson 1998; McConn 2006).

Storage of nuclear capsules at Clarksville Modification Center was in an underground complex known as the ABC Structure. The ABC Structure consisted of the “A” Structure, which was the nuclear capsule storage area that was secured behind a bank-type locking vault door at the end of a 600-ft-long tunnel; the “C” Structure, which was used for nuclear materials inspection and maintenance; and the “B” Structure, which was a backup facility for the C Structure but was used only as a medical wing. C Structure activities involved dismantling the nuclear assembly system, checking the activity of the fissile material, and replacing the polonium-beryllium (Po-Be) initiators (Lamb Associates and Halliburton NUS 1996; Last, Gilmore, and Bronson 1998; McConn 2006). Figure 2-1 is an overall plan view of the ABC Structure. Figure 2-2 shows a close-up plan view of the A Structure and Figure 2-3 shows a cross-sectional view. Figure 2-4 shows a plan view of the B and C Structures. [Figures 2-1 through 2-4 are from Last, Gilmore, and Bronson (1998); they refer to “Fort Campbell” because they were inactive facilities on Fort Campbell in 1998; however, at the time of use they were the Clarksville WSA.]

A second C Structure, constructed in 1957, was an above-ground brick building used only to service non-nuclear components. Once this structure opened, the original C Structure ceased to be used due to moisture intrusion. In addition, the Clarksville WSA included a Gravel Gertie that was used for weapons maintenance and modification. The newer C Structure and Gravel Gertie had large overhead rails to support weapon subassemblies during maintenance. Standard above-ground igloos were used for storage, including the storage of sealed weapons. No nuclear maintenance activities occurred in these igloos (Lamb Associates and Halliburton NUS 1996; Last, Gilmore, and Bronson 1998; McConn 2006).

Some of the NIOSH Dose Reconstruction Project Computer-Assisted Telephone Interviews refer to the “bird cage.” This term was used officially to describe the criticality-safe framework built around a nuclear package (see Figure 2-5); however, the term appears to have been used unofficially

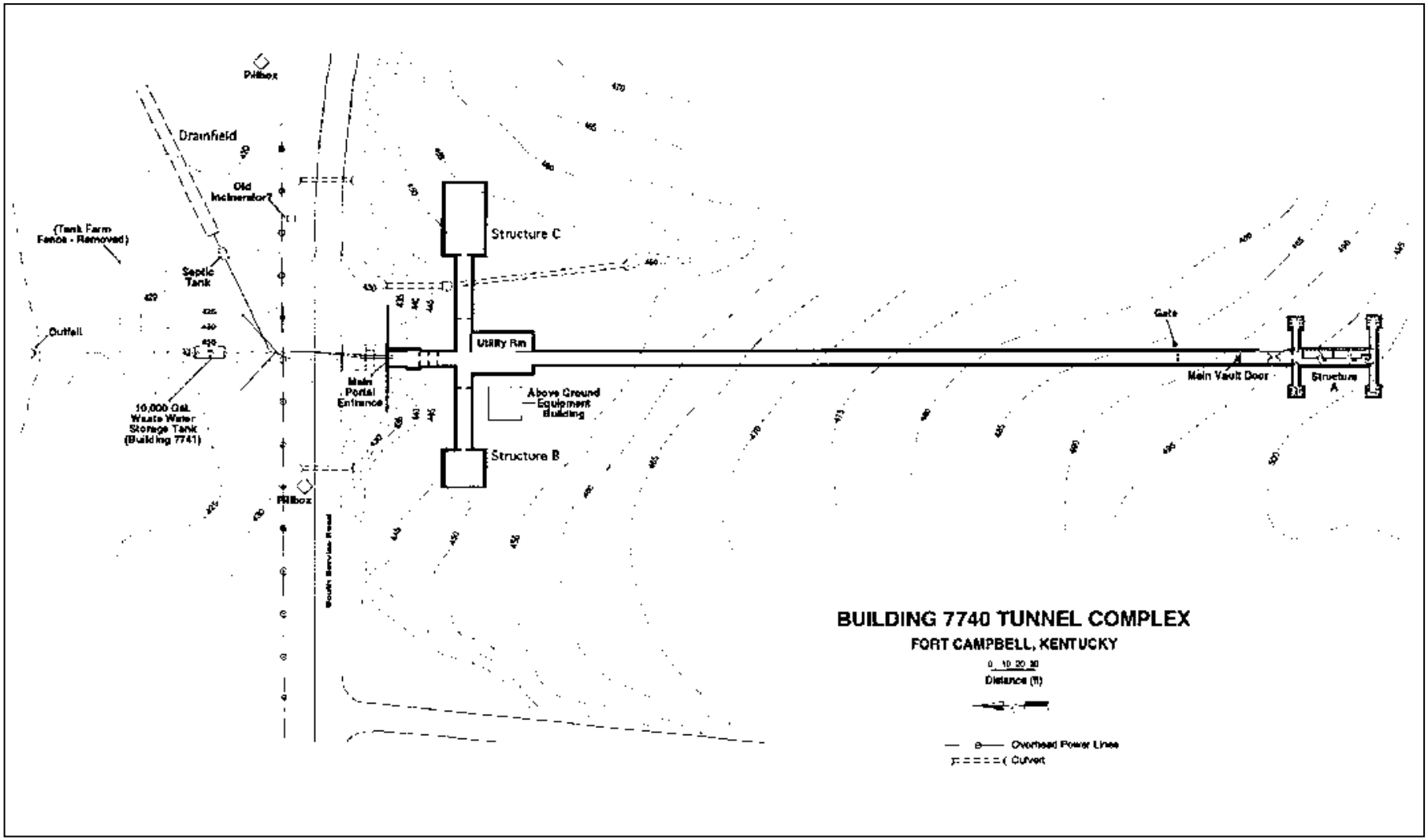

Figure 2-1. General plan view of ABC Structure.

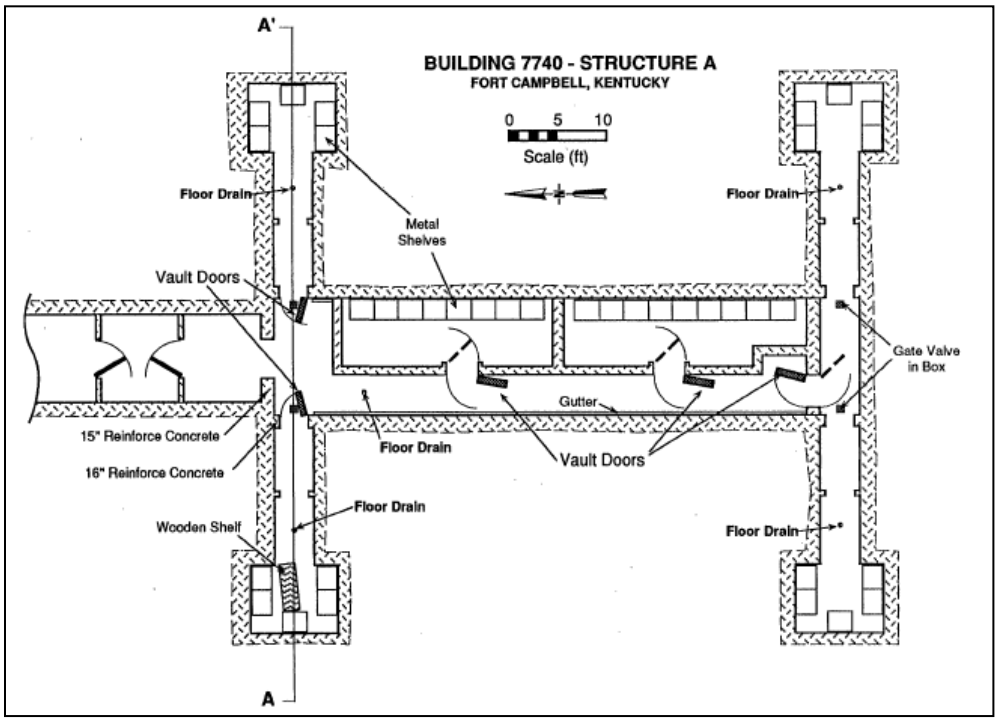

Figure 2-2. Plan view of the A Structure.

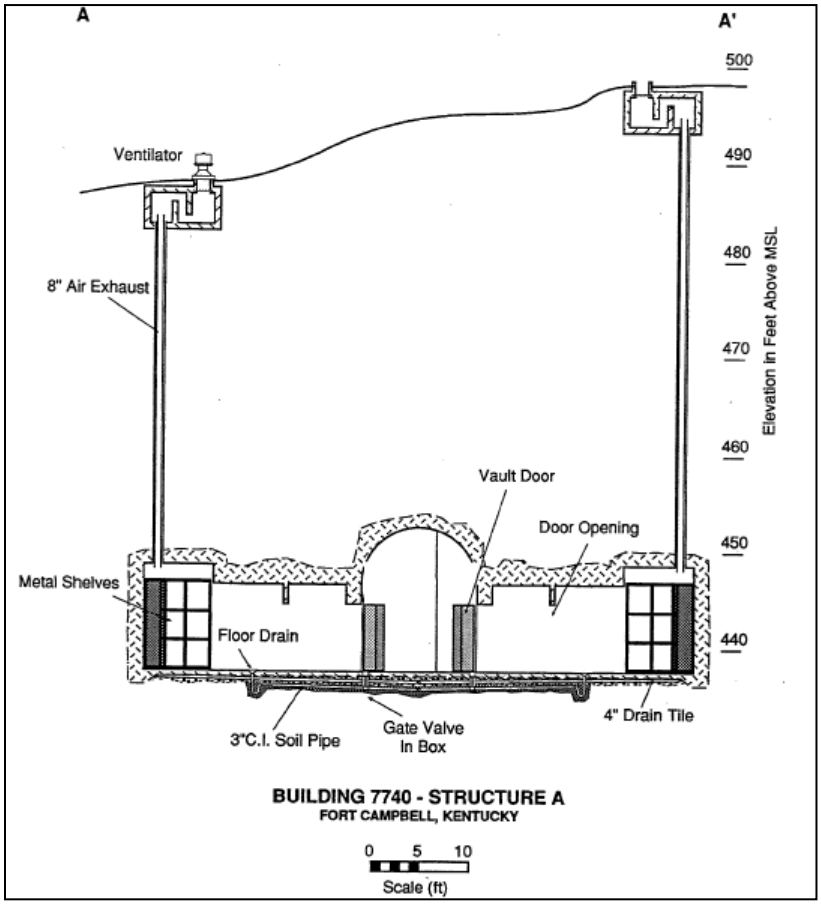

Figure 2-3. Cross-sectional view of the A Structure.

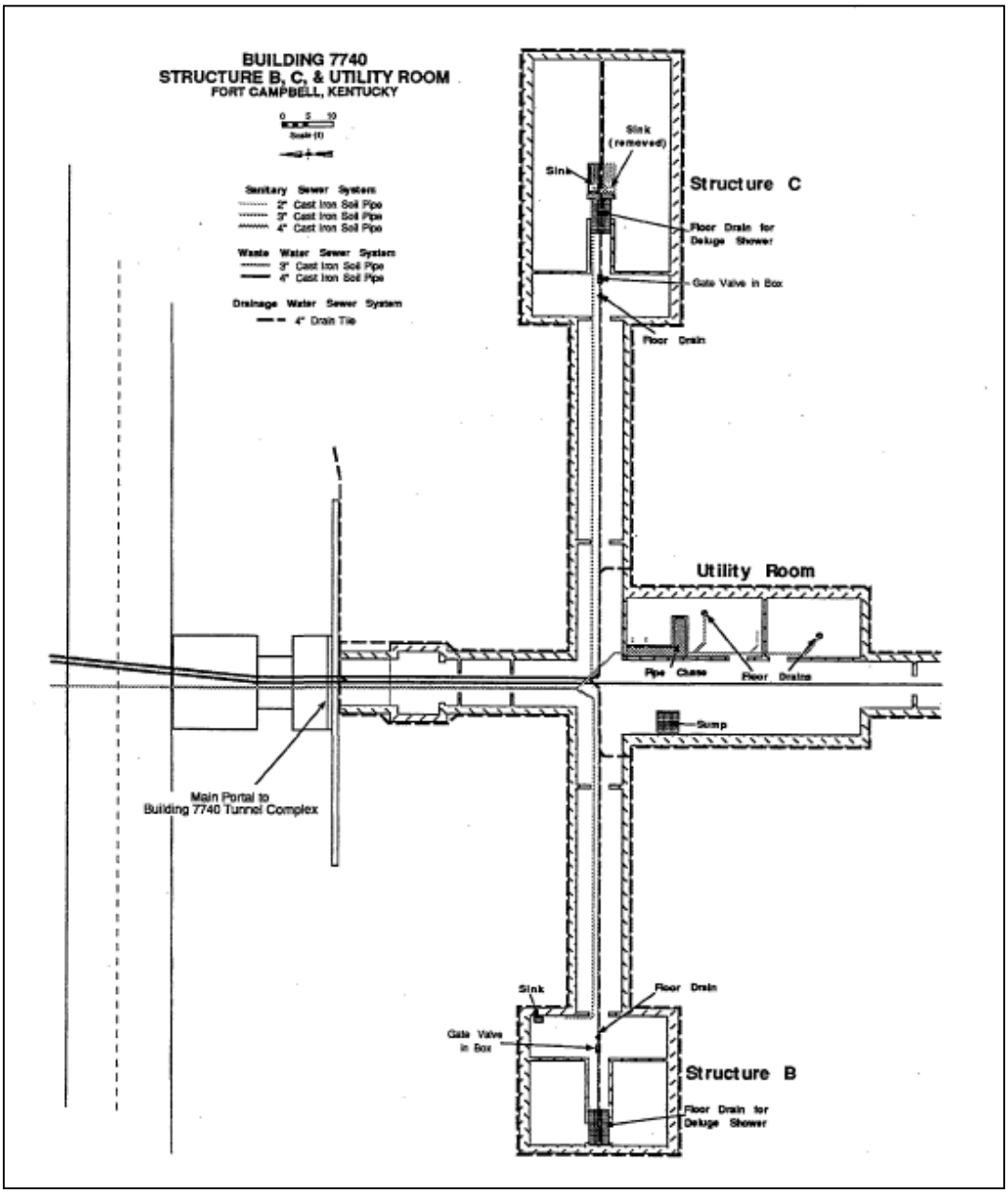

Figure 2-4. Plan view of the B and C Structures in the tunnel complex.

to refer to the whole Clarksville Modification Center, meaning the fenced, heavily guarded area where an AEC Q-level clearance was required (more than just the tunnel complex).

2.2 SOURCE TERMS

Early weapons designs were of the in-flight insertable variety. Weapons of this type had removable nuclear capsules (also known as the physics package or pit) and were stored in a bird cage. The bird cage ensured storage in a criticality-safe manner. The capsules were pressure-sealed. Figure 2-5 shows a typical bird cage. The bird cages would hold the nuclear capsule, comprised of plutonium, highly enriched uranium (HEU), and Po-Be initiator. Periodic maintenance was required on these early weapon pits to exchange the Po-Be initiators due to the short half-life of ^{210}Po. This would require disassembly of the weapon pit to remove the initiator, which was at the pit center.

Figure 2-5. Typical bird cage.

Later weapon designs did not utilize the in-flight insertable concept or the Po-Be initiator, thereby eliminating the need to disassemble the weapon pit for modification. The Po-Be initiator was phased out over time, until 1956, and replaced by external neutron generators. The weapon pits are referred to as sealed pit designs. These designs included the potential for exposure to tritium. The introduction of tritium could have occurred as early as 1954 (McConn 2006; Mitchell 2003).

Another source of radioactive material used in early nuclear weapons was the spark gap tube. These tubes, which were part of the firing circuits, were used to switch large amounts of electrical current. A small amount of ^{137}Cs was used in spark gap tubes to stabilize the electrical properties. These tubes, which were manufactured of thick glass to prevent breakage, would be a minor exposure pathway (McConn 2006).

As part of the maintenance activities, Clarksville personnel performed radiographs of the weapon components using a large ^{60}Co source. The exact location of this source was not discovered but the newer C Structure is a likely candidate (McConn 2006).

In summary, the radioactive materials of interest at Clarksville Modification Center are tritium as a gas, weapons-grade plutonium, HEU, depleted uranium (DU; also used in weapons construction), ^{210}Po in a Po-Be neutron initiator, a ^{60}Co radiograph source, and small activities of ^{137}Cs.

2.3 JOB DESCRIPTIONS

Table 2-1 lists job descriptions described in the claims files or by interviews of former employees (Bihl 2006a,b).

Table 2-1. Clarksville Modification Center job categories.

Title	Description
Material handler	Moved nuclear devices to and from storage and disassembly areas or among magazines; unloaded devices from trucks, railcars, and aircraft and drove them to storage areas.
Production operator, operator, operator trainee	Assembled/disassembled nuclear devices.
Inspector, quality control specialist, quality control inspector	Nuclear components inspectors observed assembly/disassembly, recorded condition of components, and ensured correct assembly of components; it is possible these workers performed gamma/X-ray inspections of devices. Not all inspectors were responsible for nuclear components and would have had only incidental exposure to complete weapons. Latter should be considered in same category as material handlers.
Warehouseman	Received, stored, shipped nuclear devices; conducted inventory of nuclear devices. One Computer Assisted Telephone Interview stated about every 6 months a warehouseman worked in storage igloos for 1 week conducting inventory.
Safety/security inspector	Performed security inspection and control of all buildings including magazines; probably spent some time in all secure locations but did not handle nuclear devices.
Mechanic	Repaired equipment, moved nuclear devices; Computer Assisted Telephone Interview indicates mechanics might have been responsible for replacing filters in ventilation systems including contaminated filters; spent time in igloos when necessary.
Truck driver, heavy equipment operator	Probably involved with transporting nuclear devices to/from railcars, airport.
Fireman	Computer Assisted Telephone Interview claims that a fireman stood by with a fire extinguisher during disassemblies.
Sheet metal worker, electrician, refrigerator/cooling mechanic, janitor	Probably worked anywhere and might have had some exposure in igloos.
Clerk-typist	Worked in offices in Bird Cage; might have entered disassembly areas to deliver messages.
Accountant	Had office in Bird Cage; occasionally entered igloos.
Bus driver, grounds laborer, power plant operator, sewage disposal operator	Probably did not have any exposure except environmental.

3.0 OCCUPATIONAL MEDICAL DOSE

It is not known if medical X-rays were required for all workers or selected workers as a condition of employment. No documentation on X-ray policies, procedures, or equipment has been found. [Name redacted], an SNL safety engineer familiar with work at WSAs, did not recall X-rays being part of medical examinations at any of the WSAs during the period when SNL was the principal AEC contractor (McConn 2006). Records on Clarksville workers from Pantex do not list any X-rays before 1960, even for workers who continued employment into the years when MHSMC was the principal AEC contractor. A review of the claims information revealed that, for employment between 1960 and 1965, 53% of the Energy Employees had at least one chest X-ray and 35% had at least one lumbar spine X-ray. Most of the X-rays are either labeled as “pre-employment” or occurred in the first year of employment. The pattern does not support additional routine X-rays; only four workers had more than one chest X-ray and only one had a second lumbar spine X-ray. In terms of job categories, no pattern

was evident in relation to who had pre-employment X-rays and who did not. For instance, the records for the two claims showed one chest X-ray each, whereas some craft workers had no record of X-rays.

Based on the limited information available for workers during 1960 through 1967 with no X-ray records, the dose reconstructor should assume one chest X-ray and one lumbar spine examination for the entire employment period (not annual). (As described below, a lumbar spine examination is assumed to consist of four exposures.) The dose from X-rays should be assigned in 1960 or the first year of employment after 1960. Do not assign X-rays for employment before 1960.

No information about X-ray equipment manufacturers, models, examination techniques, and exposure rates for those techniques has been found. Therefore, assumptions that are favorable to claimants and guidance in *Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures* (ORAUT 2011) were used. The actual film was not sent to the Pantex Plant for archiving, only the information that an X-ray occurred, the type, and the date; the film size and, hence, type of radiography are not known. For small DOE sites conventional chest X-rays are assumed.

Lumbar spine X-rays at the Pantex Plant were given only to men. None of the lumbar spine X-rays in the Clarksville claim files were given to women; however, the number of women Energy Employees among the Clarksville claims is small. Nevertheless, because lumbar spine X-rays were given to screen for back injuries that might preclude heavy lifting, and considering that heavy lifting was culturally a man's job in the workplace in 1960–1965, it is reasonable to assign the default lumbar spine X-ray only to men.

3.1 ORGAN DOSE CALCULATIONS

ORAUT (2011) organ doses should be used, since no site specific information is available for Clarksville. Dose reconstructors should use the most recent update of that document. Dose reconstructors should assume that a PA chest projection was performed on Clarksville workers. Organ dose equivalents for chest projections for all periods can be found in Table A-7 of ORAUT (2011), and skin doses from chest projections in Tables A-8 and A-9 of that document.

According to ORAUT (2011), two anterior-posterior (AP) and two lateral (LAT) exposures should be assumed for lumbar spine examinations when the site specific protocol is not known; however, the doses in ORAUT (2011) include only one exposure per projection. The organ doses for lumbar spine X-rays in ORAUT (2011) for one exposure per projection are listed in Table A-10 of that document. Dose reconstructors should double these doses when assuming 2 exposures per projection for Clarksville claims (see footnote b to Table A-10). Skin doses from lumbar spine projections can be found in Table A-11 of ORAUT (2011). These values should also be doubled when assuming 2 exposures per projection. Dose reconstructors should use the most recent update of ORAUT (2011). Enter the doubled values from ORAUT (2011) into the Interactive RadioEpidemiological Program (IREP) as an acute dose due to photons with energies between 30 and 250 keV. Assume a normal distribution with a standard deviation of ±30%.

4.0 OCCUPATIONAL ENVIRONMENTAL DOSE

Occupational environmental dose refers to the dose received by workers outside normal production facilities. These doses can be internal or external (e.g., from effluents or scattered radiation through building walls or ceilings). No records on environmental releases from Clarksville Modification Center have been discovered. Before 1959, complete disassemblies were not performed at Clarksville Modification Center, only storage, maintenance, and inspection. Maintenance included replacement of major components.

Plutonium and enriched uranium sources in the weapons were always sealed, as were polonium in the initiators and other radionuclides in the radiography sources. There was risk of DU oxide contamination in the cells. The underground C Structure had exhaust vents at the top of the hillside under which the tunnel was located (Last, Gilmore, and Bronson 1998). Whether the exhaust passed through high-efficiency particulate air (HEPA) filters is not known. According to [Name redacted], portable gloveboxes with HEPA-filtered exhausts were used to contain oxidized DU when weapons underwent inspections, maintenance, and refurbishment during the SNL years (McConn 2006). The DU was cleaned from the nuclear components and deposited as solid waste on cleaning rags.

[Name redacted] mentioned that the DU contamination came from spalling, which produced large nonrespirable particles. Environmental intake of DU was insignificant because (1) the likelihood of a significant release outside the tunnel was small and (2) the location of the exhaust vent makes it unlikely that DU that might have exhausted from the C Structure would have returned to occupied areas of Clarksville Modification Center.

After tritium reservoirs became part of the weapons, leaks of tritium into the disassembly cell and out the cell exhaust duct were possible. [Name redacted] was not aware of any releases of tritium from the disassembly cells; however, most handling of the tritium reservoirs occurred during the years MHSMC operated the facility (McConn 2006). No documentation about tritium releases into the cells or through exhaust stacks has been found. Tritium in the reservoirs was in the form of tritiated gas, which has essentially no significance for intakes. Tritium gas converts slowly to tritiated water vapor as it mingles with humid air. Not all the gas would convert to water vapor during the time workers would be exposed (Peterson and Davis 2002); however, it is favorable to claimants to assume 100% water vapor.

Based on similar work performed at the Pantex Plant, the release of tritium from the reservoirs during normal operations does not produce airborne concentrations which could result in intakes that result in annual organ doses of greater than 0.001 rem (ORAUT 2007a). Thus, with the exception of 1962 as described below, environmental intakes and the resultant internal dose for the Clarksville Modification Center are not assigned.

[Name redacted], a Clarksville worker described an accident involving a damaged weapon returned to Clarksville Modification Center from the military (Bihl 2006a). The accident was corroborated in a claimant Computer Assisted Telephone Interview. At the time of the accident, both individuals were told the damaged weapon was leaking tritium. No documentation of the accident or information about the amount of tritium that might have leaked has been found. The Computer Assisted Telephone Interview indicated that the accident occurred in 1962.

Because [Name redacted] was told he had been exposed to tritium while moving the weapon from the airport to the storage igloo, it is assumed that the tritium leak had been occurring for some time before its discovery. The reservoirs were under considerable pressure so most of the contents would have leaked before arrival at Clarksville; however, there was sufficient leakage still occurring to set off the tritium monitors the next day when the weapon was taken into the cell, according to the Computer Assisted Telephone Interview.

An accidental release of tritium during a disassembly occurred at the Pantex Plant in 1989 (ORAUT 2007a). This was a major release that caused severe contamination of a cell. Workers were present at the initiation of the release and therefore subject to the highest release rate. All of the release occurred at Pantex, whereas most of the 1962 leak probably did not occur at Clarksville. It is unlikely that the accidental release at Clarksville was worse than the Pantex release. According to the Computer Assisted Telephone Interview, Clarksville workers stopped the leak within a few hours of its discovery, whereas the release at Pantex was so significant no attempt was made to stop the leak until it had run its course. Therefore, it is reasonable to conclude that the amount of tritium released at Clarksville was much less than the amount released during the 1989 accident. Therefore, because NIOSH has concluded that it lacks sufficient information, which includes monitoring data, sufficient air monitoring information, or sufficient process and radiological source information, that would allow it to estimate the intakes of tritium to which the proposed class may have been exposed, no internal dose for intakes at environmental airborne concentrations are assigned for the Clarksville Modification Center.

External radiation dose greater than the ambient rate outside a building where frequent radiography was performed might have occurred via direct radiation penetration through walls or from scattered radiation. Dose rates are usually quite small in noncontrolled areas near radiography sources. For instance, at the Hanford Radiological Calibration Facility, the total annual dose measured by thermoluminescent dosimeters (TLDs) on the outside of an interior wall at about 25 ft from a 20-Ci ^{137}Cs source (662-keV gamma ray) used almost daily was 7 mrem. A ^{60}Co radiography source would be expected to have less activity, but the gamma radiation strength of ^{60}Co (1,173- and 1,332-keV gamma rays) is about 4 times that of ^{137}Cs. Assuming a smaller activity ^{60}Co source produces about the same annual dose rate outside the radiography building as the 20-Ci ^{137}Cs source and, assuming an environmental occupancy factor outside the building of 0.5, dose reconstructors should assign a 4-mrem whole-body dose per year from external radiation (see Table 4-1). Assume a 100% 30-to-250-keV photon energy category. Calculate organ doses of interest using the external dose reconstruction implementation guidelines (NIOSH 2002). Because this dose rate was made by inference from a similar situation, rather than by direct measurement, an uncertainty factor of 2 is reasonable.

Table 4-1. Summary environmental external dose.

Period of application	Annual whole-body dose	Photon energy category	Distribution
July 1949–1965	4 mrem	30-250 keV	GSD = 2
1966–1967	None		

5.0 OCCUPATIONAL INTERNAL DOSE

NIOSH has concluded that is not possible to reconstruct internal doses completely during any period at the Clarksville Modification Center. Therefore, in the absence of monitoring data for an individual claim, no occupational internal doses are assigned. For claims in which individual internal monitoring data are available, the internal dose will be reconstructed based on interpretation of the monitoring data using existing NIOSH dose reconstruction processes and procedures.

6.0 OCCUPATIONAL EXTERNAL DOSE

6.1 INTRODUCTION

Workers at Clarksville Modification Center were employed by either SNL or MHSMC, but not both. A few SNL workers (fewer than 20) performed the maintenance operations involving nuclear components between July 1949 and September 1958 (McConn 2006). A similar number of MHSMC workers performed inspections and modifications on nuclear weapons from 1959 to September 1965 (Mitchell 2003).

Work activities at Clarksville Modification Center undoubtedly varied over time. Analysis of historical information showed that maintenance activities at Clarksville began in 1949, which corresponds to the first record of personnel monitoring (McConn 2006). The nature of the radiation fields a Clarksville worker could have encountered depends on the type of weapon on which work occurred. Nuclear weapons components emit alpha, beta, X- and gamma rays, and neutrons; however, doses to workers depend strongly on the configuration (i.e., material and shielding) of the source of radiation and the work performed (Oxley 2001).

There were three major groupings of workers at Clarksville. AEC employees served primarily in oversight positions and generally did not perform hands-on work. SNL, and later MHSMC, employees were responsible for maintenance of the weapons and would be expected to have the highest doses. Military personnel would be expected to receive doses that were less than the SNL or MHSMC employees; the military primarily loaded the weapons on airplanes and performed in-flight operations that were necessary.

6.2 EXTERNAL RADIATION DOSIMETERS AND RECORDS

External dosimetry records for Clarksville Modification Center are sparse and the connection between the dose record and the worker might be missing. Statistical analysis of doses received at Clarksville cannot be performed with the few records found to date.

Dosimetry data for nine SNL workers have been found. These data are analyzed in Section 6.3.1. Recorded doses have been found for other workers but they do not contain sufficient information to determine which individuals performed a particular task.

The Pantex Plant maintains a limited database for MHSMC workers at Clarksville Modification Center that contains weekly dose information for a few workers from October 1960 to 1965. Although MHSMC began its management of Clarksville Modification Center in early 1959, no dosimetry records were found for 1959 through September 1960. Annual dose reports supplied to AEC for 1960 to 1965 included individual whole-body dose equivalent from photons and neutrons. At Clarksville, dosimeters were issued to only a few workers who had direct contact with nuclear weapon components.

The first dosimetry records found for MHSMC workers are dated October 1960. Commercial film badge service was supplied by Tracerlab from 1960 to 1965. During this period, a small number of workers (from 3 to 27) were monitored with mostly negative results (less than the minimum recordable dose). Only about 40 positive (nonzero) results were reported of approximately 5,900 individual weekly film badges. The highest annual dose to a worker from film data was less than 200 mrem in a year. Eastman Kodak nuclear track emulsion, type A (NTA) film was probably added for neutron dosimetry in January 1960; the exact date NTA film was used for neutron dosimetry has not been determined. [Name redacted] thought the first use of neutron dosimetry might have been 1959. Pantex Plant dosimetry data show that NTA film was in use by January 1960 (McConn 2006). Because Clarksville and Pantex were operated by the same contractor, it is reasonable to assume that identical dosimetry service was provided for both sites. Only one positive (12-mrem) result was reported from nearly 3,900 individual weekly film badges (Tracerlab 1965).

6.2.1 Historical Administrative Practices

Clarksville Modification Center started monitoring workers for radiation exposure in July 1949. Dosimeters used at that time to measure worker radiation doses were provided by SNL. Table 6-1 summarizes the monitoring technique and exchange frequency. The SNL minimum recordable dose (MRD) for nonpenetrating skin and penetrating whole-body dose was probably similar to the minimum detection levels (MDLs) determined by others (Wilson 1960, 1987; NIOSH 1993; NRC 1989; Wilson et al. 1990). Dosimeters were supplied by Tracerlab from October 1960 to 1965 for MHSMC workers.

No dosimetry records were found for 1959 through September 1960. The MRDs reported by Tracerlab were 30 and 10 mrem, respectively (Tracerlab 1965). Actual MDLs are typically higher because of additional uncertainty in field use and the use of dose recording thresholds. Table 6-1 lists reasonable MDLs for most applications for film dosimeters based on Wilson (1960, 1987), NIOSH (1993), NRC (1989), and Wilson et al. (1990). MRDs varied with time and processor, as listed in Table 6-1.

The routine practice at Clarksville Modification Center appears to have required assigning dosimeters to personnel designated as radiation workers who could receive an external radiation dose greater than 10% of the Radiation Protection Guidelines in effect. Dosimeters were exchanged on a routine schedule. However, during the 1960–1965 period when Tracerlab provided film badges, individual worker names were not recorded with specific film badge numbers. In addition, dose components appear to be missing for some workers based on such designations as blanks or "damaged film" in records. These missing components can be reconstructed from other recorded dosimeter data by using recommended methods described below in this Site Profile.

Table 6-1. Dosimeter type, period of use, exchange frequency, MRD, and MDL.

Dosimeter type–provider	Period	Exchange frequency	MRD (mrem)			MDL (mrem)		
			Skin	β/γ deep	Neutron	Skin	Deep	Neutron
βγ film–SNL	7/1949–1958	Monthly	40	40		40[a]	40[a]	
βγ film–Tracerlab	10/1960–1962	Weekly[b]	30[c]	10[c]		40[a]	40[a]	
βγ film and NTA film–Tracerlab	1962–1965	Weekly[b]	30[c]	10[c]	15[b]	40[a]	40[a]	(d)

a. Estimated MDL typical of film dosimeter capabilities (Wilson 1960, 1987; NIOSH 1993; NRC 1989; Wilson et al. 1990).
b. The weekly exchange frequency was established from dosimetry reports. No dosimetry reports for July 1949 through 1958 or 1959 through October 1960 have been found.
c. Based on minimum doses recorded on dosimetry reports (Tracerlab 1965).
d. For years of NTA film use, between 1960 and 1965, the reconstructed neutron dose is calculated using the adjusted photon dose and a neutron-to-photon dose ratio.

6.2.2 Dosimetry Technology

SNL radiation workers were monitored by film badges provided by SNL. Initially the "film badge" consisted of a piece of dental X-ray film in a plastic pouch with a pin for fastening to clothing. A lead filter was later added to the plastic pouch. The Oak Ridge metal film badge holder with three filters was used from 1957 through 1958. NTA film for neutron dosimetry was added in 1959 or 1960. Results from film badges were reported on "cardex" dosimetry records. However, records from these dosimeters have not been found in the SNL archives (McConn 2006). [Name redacted] stated that the maximum reported radiation dose was as high as 1 rem/yr from 1949 to 1952 (McConn 2006). After 1952, maximum radiation doses were about 100 mrem/yr, according to [Name redacted].

The first commercial dosimeter used by MHSMC at Clarksville Modification Center was a two-element film badge supplied by Tracerlab for measuring beta, X-ray, and gamma exposures (Tracerlab 1965). Beginning in July 1962, Clarksville used a multielement film badge that incorporated NTA film to measure beta, X-rays, gamma rays, and fast neutrons (Tracerlab 1965).

6.2.2.1 Beta/Photon Dosimeters

Figure 6-1 shows the response of a film badge to photon radiation of different energies; it also shows the *Hp(10)* response. The figure shows two responses for film badges: one for a sensitive DuPont 502 emulsion in a two-element badge (Pardue, Goldstein, and Wollan 1944), and one for a sensitive DuPont 555 emulsion in the multielement badge (Thornton, Davis, and Gupton 1961). The response of the sensitive Eastman Type 2 film in a multielement film badge is similar to that of the sensitive DuPont 555 emulsion. The film badges show an over-response at photon energies around 100 keV,

due primarily to relatively (compared with tissue) high atomic numbers (*Z*) [silver (47) and bromine (35)] in the film emulsions. The film badges under-respond to lower energy photons, but the relative response of the two-element film badge to 60-keV photons from ^{241}Am is nearly unity. The multielement film badge typically over-responds to 60-keV photons.

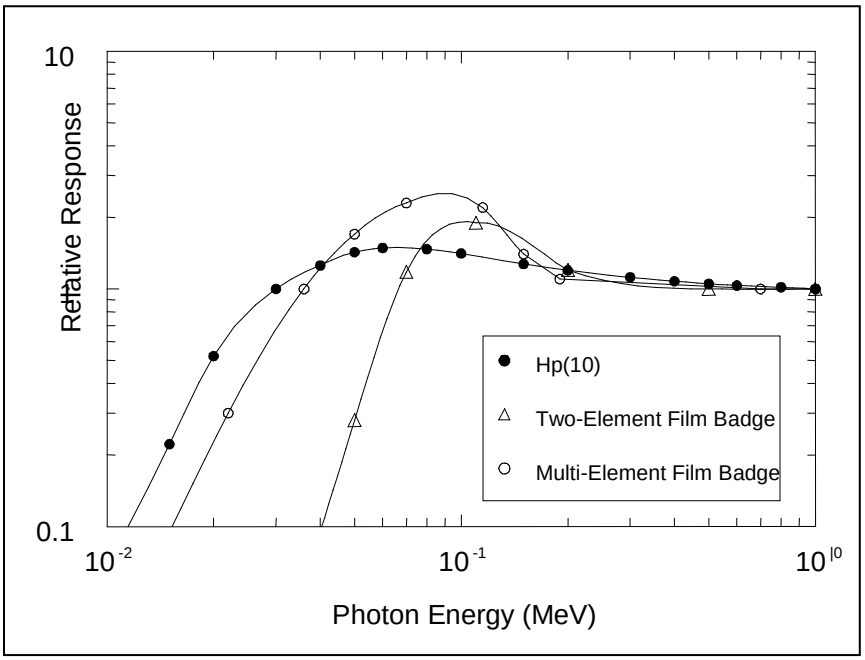

Figure 6-1. Comparison of *Hp(10)* for photons with energy responses for sensitive DuPont 502 emulsion in two-element film badge (Pardue, Goldstein, and Wollan 1944) and sensitive DuPont 555 emulsion in multielement film badge (Thornton, Davis, and Gupton 1961).

6.2.2.2 Neutron Dosimeters

The response of film dosimeters to neutron radiation was not good. NTA film was added to the holder used for the Clarksville beta/gamma dosimeter in 1958 and from July 1962 through 1965 (Martin 2005). In general, the response of the NTA film decreases with decreasing neutron energies greater than a minimum threshold energy for laboratory studies, estimated to be about 500 keV (IAEA 1990). The minimum threshold energy for routine use in Clarksville mixed photon and neutron radiation fields is probably about 1 MeV. Results reported at the first AEC Neutron Dosimetry Workshop indicated that laboratory dose measurements with NTA film were about one-half to one-fourth of those measured with other methods, including the neutron TLD (Vallario, Hankins, and Unruh 1969). See Table 6-7 in Section 6.3 for information on methods to obtain estimates of neutron dose. The results of the NTA film should not be used for dose calculations because NTA is too unreliable.

6.2.3 Dosimeter Calibration Procedures

6.2.3.1 Beta/Photon Dosimeters

Clarksville film badges were originally calibrated with ^{226}Ra sources, with exposure measured by Victoreen R chambers. Deliberately irradiated film badges were sent periodically to SNL and Tracerlab, and reported doses were compared with measured doses for calibration (McConn 2006).

6.2.3.2 Neutron Dosimeters

An account of the historical aspects of the calibration of Clarksville neutron dosimeters is not available.

6.2.4 Workplace Radiation Fields

The main workplace radiation fields at Clarksville Modification Center arose from the handling of nuclear weapon components containing plutonium, HEU, Po-Be initiators, and DU. The highest dose rates were encountered from the handling of bare pits and Po-Be initiators. The nuclides in the sealed nuclear weapon component pits emit alpha, beta, X-, gamma, and neutron radiation. From an external dosimetry perspective, the radiations of concern are beta particles, photons (X- and gamma rays), and neutrons. Radiation exposure to workers depends significantly on processes used in the preparation, design, and construction of the weapons.

With few exceptions, the following sections show that, for external dose reconstruction purposes, all beta radiation fields are greater than 15 keV, all photon radiation fields are between 30 and 250 keV, and all neutron fields are between 0.1 and 2 MeV. Presuming that 100% of the radiation fields are within these ranges is a simplifying, conservative assumption that is generally favorable to claimants. Table 6-2 summarizes the radiation energy categories.

Table 6-2. Beta, photon, and neutron radiation energies and percentages for Clarksville facilities.

Process/ buildings	Description	Operations period	Radioactive material	Radiation type	Energy selection	Percent (notes)
Bays Cells Tunnel complex	Assembly/disassembly of nuclear weapons	1949–1965	DU	Beta	>15 keV	100[a]
				Photons	30–250 keV	100[b]
		1958–1965	Tritium	Beta	<15 keV	100[c]
		1949–1965	Plutonium, HEU	Photons	30–250 keV	100
				Neutrons	0.1–2 MeV	100[d]
	Casual surveillance, minor maintenance	1966–1967	DU	Beta	>15 keV	100
		1966–1967	DU	Photons	30–250 keV	100
Igloos	Staging of weapons and plutonium pits	1949–1965	Plutonium, HEU	Photons	30–250 keV	100
				Neutrons	0.1–2 MeV	100[d]
	Casual surveillance, minor maintenance	1966–1967	DU	Beta	>15 keV	100
		1966–1967	DU	Photons	30–250 keV	100
Transportation	Movement of weapons	1949–1965	DU, HEU, plutonium	Photons	30–250 keV	100[b]
				Neutrons	0.1–2 MeV	100[d]
Warehouse	Packaging components	1949–1965	Weapon components	Beta	>15 keV	100[a]
				Photons	30–250 keV	100[b]
				Neutrons	0.1–2 MeV	100[d]
		1954–1965	Tritium	Beta	<15 keV	100[c]

a. Workplace beta radiation has energy greater than 15 keV.
b. Most photons from DU have energies greater than 30 keV; some have energies greater than 250 keV. If shielding materials are present, fewer photons are in the categories less than 30 keV or greater than 250 keV. The simplifying conservative assumption that 100% of the photons from DU are between 30 and 250 keV is recommended as generally favorable to claimants.
c. Beta particles from tritium are classified in the less-than-15-keV category.
d. The energy of neutrons in the workplace is predominately in one of two ranges: Between 0.1 and 2 MeV or between 2 and 20 MeV. In some cases, with significant moderating materials, some neutrons are less than 0.1 MeV. However, the simplifying conservative assumption that 100% of the neutrons are between 0.1 and 2 MeV is recommended as generally favorable to claimants.

6.2.4.1 Depleted Uranium

Clarksville workers handled DU (primarily ^{238}U) during assembly and disassembly of weapon components and during maintenance operations. An important progeny nuclide for potential worker

exposure in ^{238}U decay is ^{234m}Pa with a half-life of 24 days. In a few months after purification, DU components have ^{234m}Pa activities nearly equal to that of ^{238}U. Protactinium-234m emits beta radiation 98.6% of the time when it changes to its ground state with a maximum energy of 2.28 MeV and an average energy of 0.825 MeV (Shleien, Slaback, and Birky 1998; ICRP 1973). An additional source of exposure in the Clarksville workplace was from bremsstrahlung produced in high-*Z* materials from interactions with higher energy beta particles. Beta particles emitted by ^{234m}Pa excite both bremsstrahlung and characteristic X-rays in DU or ^{238}U.

Beta radiation from DU could contribute to extremity and skin dose to workers unless precautions were taken to protect workers from the radiation. Protective clothing and gloves provide a protection factor of 2 or more, depending on the thickness. A bare slab source of natural uranium contributes an *Hp(0.07)* dose of approximately 230 mrad/hr at the surface compared to an *Hp(10)* dose at 1 ft of approximately 2 mrad/hr (Kathren 1975). However, significant beta exposures to Clarksville workers were rarely detected by film badges, based on a review of shallow and deep dosimetry data.

6.2.4.2 Photon Radiation

Photon radiation in the workplace could have been readily measured at Clarksville Modification Center with available dosimeter technology during all years of operation. It is assumed that all photons at Clarksville are within the 30-to-250-keV range, similar to data from the Pantex Plant.

6.2.4.3 Neutron Radiation

The in-flight-insertable design of nuclear weapons required a neutron initiator source. The first initiator sources were ^{210}Po mixed with beryllium (McConn 2006). The average energy of the neutrons was 4.2 MeV (Shleien, Slaback, and Birky 1998). The energies of the photons and neutrons were 0.8 and 4.45 MeV, respectively (Shleien and Terpilak 1984). Unfortunately, the half-life of ^{210}Po is only 138.4 d (Shleien, Slaback, and Birky 1998), so the initiator sources had to be exchanged frequently (McConn 2006).

Until 1957, the primary radiological task was periodically changing the Po-Be initiators. Between 1954 and 1956, Po-Be initiators were gradually replaced with a newer type of sealed neutron generator that did not require routine replacement. Maintenance activities were reduced to annual disassembly of capsules to verify the integrity of fissile materials, and radiation exposures to workers were reduced (Lamb Associates and Halliburton NUS 1996).

6.2.5 Dosimeter Response to Radiation Fields

6.2.5.1 Beta/Photon Film Dosimeter Response

The dosimeters used after 1957 contained an open window with little filtration, a lower energy window for allowing beta particles and lower energy photons to enter a film area with a plastic filter, and a film area with a metal (usually aluminum) filter. The open window enabled measurement of beta particles and lower energy photons. The plastic filter enabled measurement of intermediate energy photons and the metal filter enabled measurement of higher energy photons (1-cm depth).

Tracerlab provided commercial dosimetry services from October 1960 through 1965. The AEC tested film badges provided by Tracerlab with exposures to 40-, 70-, and 210-keV X-rays and ^{60}Co gamma rays, and mixed-energy exposures of all four radiations (AEC 1955). The film badges generally responded well “with a tendency to interpret most exposures too high.” The over-response (in the 100-to-200-keV region) tended to yield conservatively high results.

The film badge dosimetry reports provided by Tracerlab are less than adequate because no individual names are recorded in relation to specific film badge numbers. Radiation doses to workers were probably low during this period and many positive doses less than the minimum recordable dose would have been recorded as zero. The weekly film badge exchange frequency increased the probability that low doses were truncated to zero.

6.2.5.2 Neutron Dosimeter Response

The neutron doses of record at Clarksville are unreliable, and dose reconstructors should not use them.

6.2.5.3 Neutron-to-Photon Dose Ratios

Neutron-to-photon dose ratios were calculated from Pantex post-1993 dosimeter data because the work performed at Clarksville Modification Center and the Pantex Plant were similar. The Pantex data were analyzed by Strom (2004), and neutron-to-photon dose ratios were determined if the neutron and photon doses were greater than 50 mrem/yr. The 95th-percentile ratio from this distribution is 1.7 (ORAUT 2007c). These data represent radiation workers who were exposed to photons and neutrons emitted from nuclear weapon components, primarily bare pits.

Although the annual neutron-to-photon dose ratios have varied over the decades, the earlier annual neutron-to-photon dose ratio should be bounded by the 95th-percentile value of 1.7 derived from the analysis of data from dosimeters accredited by the DOE Laboratory Accreditation Program. Applying an annual neutron-to-photon dose ratio of 1.7 provides a method for reconstructing Clarksville worker neutron doses that is favorable to claimants.

Clarksville radiation workers accumulated photon doses from a variety of workplace sources, including full weapon assemblies, partially shielded pits, and bare pits. During the 1949–1956 period when Po-Be initiators were exchanged, the maximum neutron-to-photon dose ratio was 4 (Shleien, Slaback, and Birky 1998); use of this ratio is recommended.

Workplace records and measurements have shown that most neutron doses after 1957 were received during the handling of bare pits. A neutron-to-photon dose ratio of 1.7 should be applied to this period.

6.2.5.4 Neutron Dose Weighting Factor

The recommended neutron-to-photon ratios for Clarksville were based on Pantex dosimeter readings. At Pantex, thermoluminescent neutron dosimeters were calibrated with measurements based on fluence-to-dose conversion factors and quality factors similar to those from ICRP Publication 21 (ICRP 1973) and NCRP Report 38 (NCRP 1971). It is necessary to adjust the neutron dose to account for the change in neutron quality factors between historic and current scientific guidance, as discussed in NIOSH (2002). Table 6-3, excerpted from ORAUT (2007c), lists the correction factor to use.

Table 6-3. Neutron dose energies, percentages, and associated ICRP (1991) correction factors.

Process	Description	Neutron energy (MeV)	Default dose fraction[a] (%)	ICRP (1991)/ NCRP (1971) correction factor
Nuclear weapons component assembly	Neutron exposure associated with weapons assembly and disassembly activities	0.1-2	100	1.91

a. From Table 6-2; assuming all neutron energies are between 0.1 and 2 MeV is favorable to claimants.

6.3 RECOMMENDATIONS FOR CLARKSVILLE WORKER EXTERNAL DOSE RECONSTRUCTION – OPERATIVE YEARS

Dose reconstruction for Clarksville workers is based on the foregoing information, which requires assessment of dose to be added to the assumed photon dose from three primary causes:

- Adjustments to assumed photon dose for dosimeter uncertainty
- Calculated neutron dose using a neutron-to-photon dose ratio
- Multiplication of the calculated neutron dose by an ICRP (1991) neutron weighting factor adjustment of 1.91 for neutron energies between 0.1 and 2 MeV

6.3.1 Unmonitored External Dose

At Clarksville Modification Center, the concept of "unmonitored worker" will have to be expanded to include "monitored but records not found." Few dosimetry records have been found for Clarksville; those that have been found do not always identify the person receiving the radiation dose. Therefore, it was necessary to estimate the radiation doses Clarksville workers might have received. To perform these estimates, four exposure groups were identified (Table 6-4). Exposure Group 1 consists of individuals who worked with nuclear devices on a daily basis; these were considered full-time radiation workers who received the highest doses. Exposure Group 2 consists of individuals who routinely entered radiation work areas but were not in close contact with nuclear devices or were not exposed full time; they were assumed to have received half the dose received by Group 1. Exposure Group 3 consists of individuals who were only occasionally exposed and were not in close contact with nuclear components; they were assumed to have received one-quarter of the dose received by Group 1. Exposure Group 4 consists of individuals who did not enter radiation areas; they were assumed to have received only environmental dose.

Table 6-4. Worker job categories and exposure groups.

Exposure group	Conditions	Group members
1	Extensive work with pits; full-time exposure (2,000 hr/yr)	Production operator, operator, operator trainee, nuclear inspector, nuclear quality control inspector, nuclear quality control specialist
2	Entered radiation areas but did not handle pits; exposure equivalent to 500 hr/yr	Material handler, warehouseman, safety/ security inspector, fireman, inspectors not associated with nuclear components
3	Infrequent entry into radiation areas; exposure equivalent to 200 hr/yr	All job categories not explicitly listed in this table
4	Did not enter radiation areas; exposure from environmental sources only	Bus driver, grounds laborer, power plant operator, sewage disposal operator

Operations at Clarksville Modification Center between 1959 and 1965 were similar to those at the Pantex Plant, and MHSMC operated both facilities. Therefore, statistical information from the Pantex External Dosimetry TBD (ORAUT 2007c) was used to provide guidance for unmonitored workers at Clarksville for the MHSMC years. Table 6-5 summarizes the respective lognormal probability statistical parameters for the period from 1952 to 1965 for Pantex annual dose results that are equal to or exceed a gamma dose of 50 mrem. The statistics in Table 6-5 are based only on nonzero dose results; thus, they represent measured annual doses. What is not known is the number of zero badge readings that were included in the reported annual doses. The dose data reported at Pantex were reanalyzed with zero dose readings replaced by MDL/2 for the monthly period (see Table 6-6). For 1960 and later, the assumed photon dose received by Exposure Group 1 (Table 6-7) was equal to the median photon dose for the Pantex Plant for the year the worker was employed at Clarksville

Modification Center, where the median is assumed to be the greater of the measured 50th-percentile dose or the 50th-percentile dose including potential missed dose. The year 1960 was chosen because dose data from only four Pantex workers were available for 1959, and this population size was too small to form the basis of dose estimates for Clarksville Modification Center. For those same years, assumed Exposure Group 2 photon doses were one-half the median photon dose received at the Pantex Plant for the year the worker was employed at Clarksville Modification Center (Table 6-8); and one quarter of the median doses were assumed to apply to Exposure Group 3 (Table 6-9).

For the SNL years, 1949 to 1958, workers handled components rather than performing intimate handling of pits, so doses would be expected to be smaller than those for MHSMC operations. This is mostly consistent with [Name redacted] recollections in that he indicated that maximum doses of 1 rem occurred up to 1952 and that all doses were less than 100 mrem after that (McConn 2006). A small number of external dose data have been found for 1949 through 1957. Of those dose records, 28 worker-years of data have been found for SNL workers who did surveillance on nuclear capsules. There were no results for 1949, only two for 1950, and only one each for 1956 and 1957. The data are in the form of annual photon doses to the body and wrist. Dose units were not indicated on the data sheets but were assumed to be rem per year. Because there are insufficient data to perform a year-by-year analysis of the doses, the data for body and wrist were analyzed for all years. For the analysis, all zero dose values were replaced by 5 mrem, which was one-half of the lowest recorded dose.

Table 6-5. Pantex worker photon dose statistics.

	Annual recorded photon dose data[a]			Lognormal fit		
	No. of workers reported	Dose (mrem)		Dose (mrem)		
Year	photon dose >50 mrem	Mean	Maximum	Median	95%	GSD
1952–1958	(b)					
1959	4	36.3	40	36.0	45	1.15
1960	8	69.4	170	58.0	160	1.86
1961	33	55.7	190	50.1	103	1.55
1962	58	55.5	210	50.1	101	1.53
1963	186	65.7	513	49.6	141	1.88
1964	581	120.0	1,820	74.9	306	2.35
1965	380	101.0	2,950	64.3	231	2.18

a. Individual dosimeter records analyzed only if photon dose was equal to or greater than 50 mrem.
b. All recorded doses were less than 50 mrem.

Table 6-6. Pantex worker photon statistics for all dosimeters.

		Monthly and annual photon dose data (mrem)			
		Monthly		Annual	
Year	No. of dosimeters[a]	50th	95th	50th	95th
1952–1958	227	20	20	240	240
1959	246	86.7	86.7	1,040	1,040
1960	220	86.7	86.7	1,040	1,040
1961	614	20	35	240	420
1962	585	20	45	240	540
1963	919	20	60	240	720
1964	2,653	20	140	240	1680
1965	3,448	40	60	480	720

a. The dosimetry data contained no identifiers, so it was not possible to determine how many workers were represented.

Table 6-7. Dose recommendations for Clarksville Group 1 workers.

Period	Dose type	Records	Dose if no information
8/1949–1956	Photon	None	1,040 mrem/yr (constant upper bound)
1957–1960	Photon	None	1,040 mrem/yr (constant upper bound)
1961–1965	Photon	Missing	Median from Table 6-6, with GSD from Table 6-5
8/1949–1965	Neutron	Any	Neutron dose = 1.7 × photon dose
8/1949–1965	Neutron	Any	Multiply assigned neutron dose by 1.91[a]

a. ICRP (1991) weighting adjustments.

Table 6-8. Dose recommendations for Clarksville Group 2 workers.

Period	Dose type	Records	Dose if no information
8/1949–1956	Photon	None	520 mrem/yr (constant upper bound)
1957–1960	Photon	None	520 mrem/yr (constant upper bound)
1961–1965	Photon	Missing	½ median from Table 6-6, with GSD from Table 6-5
8/1949–1965	Neutron	Any	Neutron dose = 1.7 × photon dose
8/1949–1965	Neutron	Any	Multiply assigned neutron dose by 1.91[a]

a. ICRP (1991) weighting adjustments.

Table 6-9. Dose recommendations for Clarksville Group 3 workers.

Period	Dose type	Records	Dose if no information
8/1949–1956	Photon	None	260 mrem/yr (constant upper bound)
1957–1960	Photon	None	260 mrem/yr (constant upper bound)
1961–1965	Photon	None	¼ median from Table 6-6, with GSD from Table 6-5
8/1949–1965	Neutron	Any	Neutron dose = 1.7 × photon dose
8/1949–1965	Neutron	Any	Multiply assigned neutron dose by 1.91[a]

a. ICRP (1991) weighting adjustments.

Figure 6-2 shows the results for the body dose data. The data indicate that the 50th-percentile dose is 50 mrem and the 95th-percentile dose is 680 mrem. For the wrist, the measured doses are slightly smaller with a 50th-percentile dose of 50 mrem and a 95th-percentile dose of 560 mrem. The only item of note is that, for one case, the maximum body dose of 1,510 mrem exceeds the maximum dose recalled by [Name redacted] (McConn 2006). The data do not indicate how many dosimeter readings were zero, and this analysis does not include consideration of the number of exchange periods. However, the data do provide a measure of confidence that the Pantex and Clarksville doses for comparable years are compatible. Therefore, the highest 95th-percentile annual dose from Table 6-5 or 6-6 for 1959 to 1960 was judged to apply to Clarksville Modification Center for the SNL years, 1949 to 1958. This dose, 1,040 mrem, which is favorable to claimants, was assumed to be an upper bound and exceeds the 95th-percentile annual dose shown in Figure 6-2. Based on the above sources of information and assumptions, guidance on assigning photon doses to unmonitored or records-missing workers are listed in Tables 6-7, 6-8, and 6-9 for Groups 1, 2, and 3, respectively.

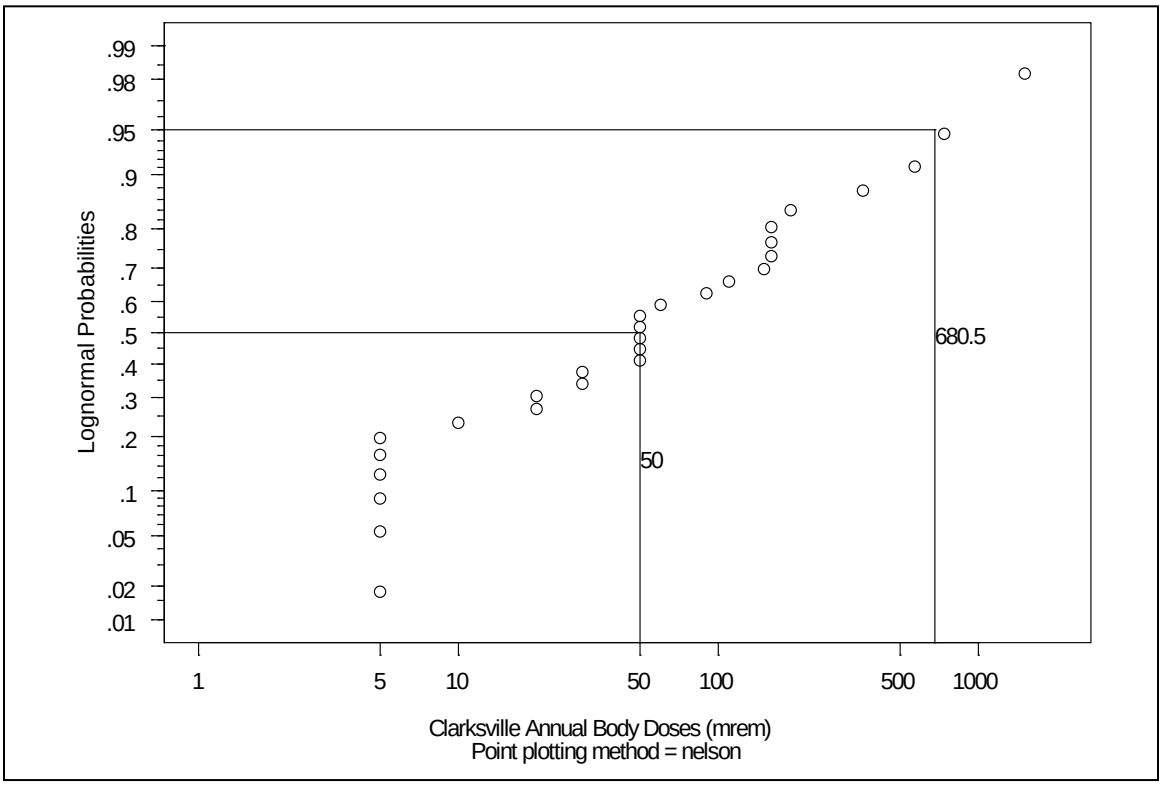

Figure 6-2. Log probability plot of annual doses received by monitored workers at Clarksville Modification Center, 1949 to 1958.

For all workers, neutron doses should be assigned as indicated in Table 6-7, 6-8, or 6-9. Figure 6-2 shows a plot of all data available for workers at Pantex for 1960; zero doses have been replaced by the MDL/2 dose. The data in Figure 6-3 show that worker dosimetry data do not follow a lognormal distribution; they also do not follow a normal distribution. For dose reconstruction, the geometric standard deviation (GSD) listed in Table 6-5 can be used.

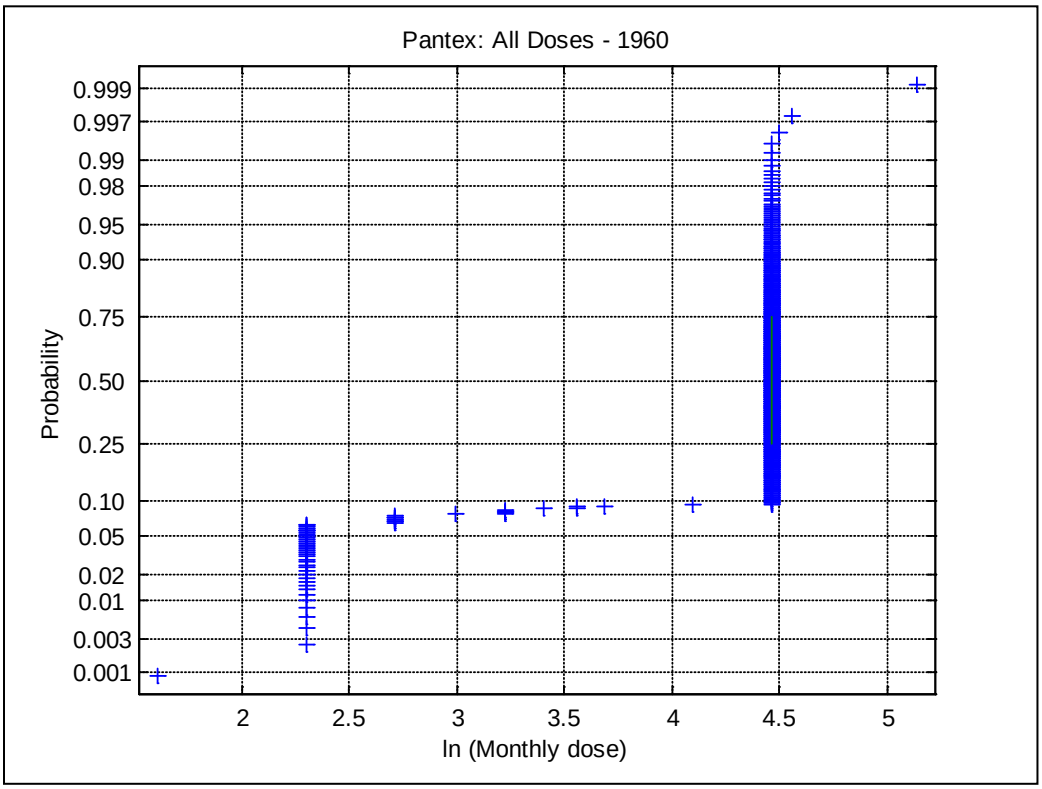

Figure 6-3. Log probability plot of Pantex dosimetry data that includes missed doses.

For all years, it appears that the 50th-percentile dose is equal to the MDL/2 times the number of exchange periods. In many years, the 95th-percentile dose is equal to the 50th-percentile dose. The dose reconstructor should use the dose data listed in Tables 6-7, 6-8, and 6-9.

6.3.2 Missed External Dose for Monitored Workers

If external dose data are found in a worker's file, the dose reconstructor should assign a missed photon dose based on the MDL/2 method and the number of exchange periods (NIOSH 2002) listed in Table 6-10 for the respective dosimetry systems.

Table 6-10. Potential missed dose for Clarksville workers.[a]

Dosimeter	Period	Exchange frequency[b]	MDL (mrem)			Missed annual mean dose (mrem)		
			Skin	Deep	Neutron	Skin	Deep	Neutron
βγ film–SNL	7/1949–1958	Monthly	40[c]	40[c]	(d)	240	240	
βγ film	1/1958–12/1959	Weekly	40[c]	40[c]	(d)	1,040	1,040	
βγ film–NTA film	1/1960–3/1961	Weekly	40	40	(d)	1,040	1,040	(e)
	4/1961–9/1964	Monthly	40	40	(d)	240	240	(e)
	10/1964–12/1965	2/month	40	40	(d)	520	520	(e)

a. Data for 1958 and later are assumed to be identical to Pantex data (ORAUT 2007c).
b. Exchange frequencies were established from dosimetry reports and the [Name redacted] interview (McConn 2006). The weekly exchange frequency was established with Tracerlab in October 1960 (Tracerlab 1965).
c. Estimated MDL typical of film dosimeter capabilities (Wilson 1960, 1987; NIOSH 1993; NRC 1989; Wilson et al. 1990).
d. The MDL for neutron doses was unreliable.
e. The reconstructed neutron dose is calculated using the adjusted photon dose and a neutron-to-photon dose ratio.

6.3.3 Radiation Dose Fraction

Table 6-2 summarizes the recommended fractions for Clarksville dose according to facilities, processes or activities, and energy categories required by IREP.

6.4 ORGAN DOSE – OPERATIVE YEARS

Once the *Hp(10)* adjusted doses have been calculated for each year, the values are used to calculate organ doses of interest using the external dose reconstruction implementation guidelines (NIOSH 2002). Consistent with NIOSH Division of Compensation Analysis and Support/Oak Ridge Associated Universities Team agreements, dose reconstructors should assume the use of the AP (front-to-back) geometry for the irradiation geometry and for conversion to organ dose. Multiply the calculated neutron doses by the neutron deep dose equivalent organ dose conversion factors for AP irradiation from Appendix B of NIOSH (2002). For photons applicable to Clarksville Modification Center (i.e., film badge era), use the conversion factor from exposure to organ dose.

Some workers at Clarksville Modification Center, generally production operators, operators, or operator trainees, might have handled unshielded pits with gloved hands. A maximizing dose rate estimate at the bare surface of plutonium metal is approximately 4 rem/hr for the total of photon and neutron radiation. This dose rate was based on calculations of the deep dose *Hp(10)* (Traub, Sherpelz, and Taulbee 2005) and modified at low photon energies to account for shallow dose, *Hp(0.07)*. The dose rate to the hands will decrease due to the use of protective clothing such as gloves. If the individual has skin cancer on the hands and handled unshielded pits, dose reconstructors should perform case-specific dose rate calculations to the hands. In likely compensable cases which include cancers on the extremities, a more realistic dose estimate should be performed using actual surface dose rates and/or the use of attenuation factors. Further, it is unlikely that individuals would have contact with the bare metal for extended periods of time.

6.5 ORGAN DOSE – POSTOPERATIVE YEARS

External dose might have been received by persons doing minor maintenance or surveillance of the site after the facility was shut down in 1966 and 1967, due to possible residual DU contamination on floors or surfaces. As mentioned in Section 5.2.2, a radiological survey in 1997 found no contamination above release criteria (Last, Gilmore, and Bronson 1998). The release criterion for combined fixed and removable contamination was 5,000 dpm/100 cm^2. Organ dose rates were calculated assuming the following:

- A geometry of standing on a contaminated floor
- 5,000 dpm/100 cm^2 of natural uranium, which would be favorable to claimants in relation to DU
- Progeny radionuclides after 5-year ingrowth

Calculations were based on dose factors provided in the compact disk (CD) supplement to Federal Guidance Report No. 13 (Eckerman et al. 1999). The dose rates to the skin are averages over the entire phantom used for the calculations; no credit for protective clothing or shoes was applied in the calculations. It was assumed that time spent in proximity to contaminated surfaces was limited to a few hours a month, so an occupancy factor of 0.02 was applied. The annual organ doses are listed in Table 6-11.

Because all measurements were reported as simply less than the release criterion, the above calculations are analogous with missed dose calculations; therefore, a triangular distribution should be applied with a minimum of zero, a mode based on the surface contamination at one-half of the release criterion, and a maximum based on the surface contamination at the release criterion. However, the doses are all less than 1 mrem/yr and can be ignored. They are provided in case a dose

reconstructor believes it appropriate to use a larger occupancy factor. No neutron doses should be applied.

Table 6-11. Annual external dose to organs from natural uranium surface contamination 1966 to 1967.

Organ	Annual dose from surface contamination at or below release criterion (rem)	
	Mode	Maximum
Adrenals	7.28E-07	1.46E-06
Bladder wall	7.98E-07	1.60E-06
Bone surface	2.08E-06	4.16E-06
Brain	7.58E-07	1.52E-06
Breasts	1.06E-06	2.12E-06
Esophagus	6.73E-07	1.35E-06
ST wall	7.95E-07	1.59E-06
SI wall	7.46E-07	1.49E-06
ULI wall	7.68E-07	1.54E-06
LLI wall	7.74E-07	1.55E-06
Kidneys	8.07E-07	1.61E-06
Liver	7.96E-07	1.59E-06
Lungs	8.44E-07	1.69E-06
Muscle	1.00E-06	2.00E-06
Ovaries	7.41E-07	1.48E-06
Pancreas	7.10E-07	1.42E-06
Red marrow	8.27E-07	1.65E-06
Skin	2.80E-04	5.60E-04
Spleen	8.01E-07	1.60E-06
Testes	1.05E-06	2.10E-06
Thymus	7.86E-07	1.57E-06
Thyroid	8.78E-07	1.76E-06
Uterus	7.42E-07	1.48E-06

6.6 ATTRIBUTIONS AND ANNOTATIONS

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

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GLOSSARY

absorption
In external dosimetry, process in which radiation energy is imparted to material. In internal dosimetry, movement of material to blood regardless of mechanism.

absorption type
Categories for materials according to their rate of absorption from the respiratory tract to the blood, which replaced the earlier inhalation clearance classes. Defined by the International Commission on Radiological Protection, the absorption types are F: deposited materials that are readily absorbed into blood from the respiratory tract (fast solubilization), M: deposited materials that have intermediate rates of absorption into blood from the respiratory tract (moderate rate of solubilization), and S: deposited materials that are relatively insoluble in the respiratory tract (slow solubilization).

activity
Amount of radioactivity. The International System unit of activity is the becquerel (1 disintegration per second); the traditional unit is the curie [37 billion (3.7×10^{10}) becquerels].

acute exposure
Radiation exposure to the body delivered in a short period. See *chronic exposure*.

alpha particle (α)
See *alpha radiation*.

alpha radiation
Positively charged particle emitted from the nuclei of some radioactive elements. An alpha particle consists of two neutrons and two protons (a helium nucleus) and has an electrostatic charge of +2.

anterior–posterior (AP)
Physical orientation of the body relative to a penetrating directional radiation such that the radiation passes through the body from the front to the back. See *exposure geometry*.

background radiation
Radiation from cosmic sources, naturally occurring radioactive materials including naturally occurring radon, and global fallout from the testing of nuclear explosives. Background radiation does not include radiation from source, byproduct, or Special Nuclear Materials regulated by the U.S. Nuclear Regulatory Commission. The average individual exposure from background radiation is about 360 millirem per year.

beta particle (β)
See *beta radiation*.

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.

bird cage
(1) Criticality-safe framework around a nuclear capsule in the in-flight insertable design;
(2) common expression for Clarksville secured area.

bremsstrahlung

Electromagnetic radiation released as a result of inelastic scattering of a moving charged particle within the nucleus of an atom. X-rays produced in a typical medical X-ray tube frequently originate from inelastic scattering of accelerated electrons in the anode material.

chronic exposure

Radiation dose to the body delivered in small amounts over a long period (e.g., days or years). See *acute exposure*.

contamination

Radioactive material in an undesired location including air, soil, buildings, animals, and persons.

decay

(1) Disintegration of atomic nuclei from spontaneous radioactivity including alpha, beta, and neutron radiation, often accompanied by gamma radiation. (2) Decrease in the amount of radioactive material over time due to nuclear transformation. See *half-life*.

deep dose equivalent [$H_p(10)$]

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

depleted uranium (DU)

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

dose

In general, the specific amount of energy from ionizing radiation that is absorbed per unit of mass. Effective and equivalent doses are in units of rem or sievert; other types of dose are in units of roentgens, rads, reps, or grays.

dose equivalent

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*.

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* and *thermoluminescent dosimeter*.

dosimeter holder

Plastic holder for a dosimeter card, which typically includes one or more metallic filters that modify the response of the phosphor to radiation.

dosimetry

Measurement and calculation of internal and external radiation doses.

enriched uranium (EU)

Uranium in which processing has increased the proportion of ^{235}U to ^{238}U to above the natural level of 0.7% by mass. Reactor-grade uranium is usually about 3.5% ^{235}U; weapons-grade uranium contains greater than 90% ^{235}U.

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

exposure geometry
Orientation (physical positioning) of a person or object in relation to a radiation source. This geometry is a factor in the radiation dose to various parts of the body. See *anterior-posterior*, *posterior-anterior*, and *lateral*.

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 badge
See *film dosimeter*.

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.

filter
Material used (1) in a dosimeter to adjust radiation response to provide an improved tissue equivalent or dose response and (2) in an X-ray machine to selectively absorb photons from the beam to reduce unnecessary exposure of individuals or to improve radiographic quality.

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.

gamma ray, particle, or photon (γ)
See *gamma radiation*.

geometric standard deviation (GSD)
In probability theory and statistics, the geometric standard deviation describes the spread of a set of numbers whose preferred average is the geometric mean.

Gravel Gertie
Facility with the distinguishing characteristic of having blow-out roof panels overlain with gravel to dissipate the pressure surge and energy of a conventional high-explosive detonation. This design was developed to allow the energy of the blast to be dissipated while minimizing the spread of contamination of any radioactive material present.

half-life
Time in which half of a given quantity of a particular radionuclide disintegrates (decays) into another nuclear form. During one half-life, the number of atoms of a particular radionuclide decreases by one half. Each radionuclide has a unique half-life ranging from millionths of a second to billions of years.

high-efficiency particulate air (HEPA) filter

Dense filter that removes contaminants from air flows before return to the working environment or discharge to the outside air (exhaust).

highly enriched uranium (HEU)

Uranium enriched to at least 20% ^{235}U for use as fissile material in nuclear weapons components and some reactor fuels.

igloo

Earth-covered storage area for items that might explode, such as ammunition, high explosives, bombs, or bomb parts.

in-flight insertable

Historical weapons design in which final assembly of the nuclear and nonnuclear components of an air-drop weapon did not occur until just before use. Military technicians completed the assembly en route to the target by inserting the nuclear materials capsule into the mechanical assembly.

lateral (LAT)

Orientation of the body during an X-ray procedure in which the X-rays pass from one side of the body to the other. See *exposure geometry*.

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.*

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.

neutron radiation

Radiation that consists of free neutrons unattached to other subatomic particles emitted from a decaying radionuclide. Neutron radiation can cause further fission in fissionable material such as the chain reactions in nuclear reactors, and nonradioactive nuclides can become radioactive by absorbing free neutrons. See *neutron*.

neutron-to-photon dose ratio

Ratio applied to the photon fraction to estimate the unmeasured neutron dose based on knowledge and measurements in a specified location.

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 sensitive to fast neutrons made by the Eastman Kodak. The developed image has tracks caused by neutrons that become visible under oil immersion with about 1,000-power magnification.

open window

Area of a film dosimeter that has little to no radiation shielding (e.g., only a holder and visible light protection). See *film dosimeter*.

operational years

The period of AEC responsibility during which the site had an active mission that involved handling or storing radioactive materials.

personal dose equivalent [$H_p(d)$]

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 millimeter (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 $H_p(0.07)$ and $H_p(10)$, respectively. The International Commission on Radiological Measurement and Units recommended $H_p(d)$ in 1993 as dose quantity for radiological protection.

PM_{10}

Particles less than 10 micrometers in aerodynamic median diameter that include both fine and coarse dust particles; essentially particles of respirable size.

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 radiation

Electromagnetic radiation that consists of quanta of energy (photons) from radiofrequency waves to gamma rays.

posterior-anterior (PA)

Physical orientation of the body relative to a penetrating directional radiation field such that the radiation passes through the body from the back to the front. See *exposure geometry*.

postoperative years

The period of AEC responsibility during which no active functions were performed that involved handling or storing radioactive materials. The period after the site was shut down and major radioactive materials were removed, but the site was still under AEC jurisdiction.

probability of causation (POC)

For purposes of dose reconstruction for the Energy Employees Occupational Illness Compensation Program Act, the percent likelihood, at the 99th percentile, that a worker incurred a particular cancer from occupational exposure to radiation.

progeny

Nuclides that result from decay of other nuclides. Also called decay products and formerly called daughter products.

radiograph

Static images produced on radiographic film by gamma rays or X-rays after passing through matter. In the context of EEOICPA, radiographs are X-ray images of the various parts of the body used to screen for disease.

radiography

The process of producing images on film (or other media) with radiation.

radon (Rn)

Radioactive gaseous element with atomic number 86. Radon is a decay product (progeny) of other radioactive elements such as thorium and radium.

shallow dose equivalent [$H_p(0.07)$]

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

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 (WB) 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.

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A.1 SPECIAL EXPOSURE COHORT

On August 23, 2012, as provided for under 42 U.S.C 7384 q(b), the Secretary of Health and Human Services designated the following class of employees as an addition to the SEC (Sebelius 2012b):

> *All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Medina Modification Center in San Antonio, Texas, from January 1, 1958 through December 31, 1966, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort.*

In its evaluation (NIOSH 2012b), NIOSH found that it lacks sufficient information to reconstruct internal radiation doses adequately for all Medina Modification Site employees for all potential radiation exposures. Specifically, this includes internal personnel monitoring data, air monitoring data, process data, and radiological source term information to allow NIOSH to estimate with sufficient accuracy potential internal exposures to uranium, plutonium, and tritium to which the proposed class may have been subjected. However, NIOSH has decided that the occupational medical dose and external exposures can be reconstructed based on available data. Based on the occupational medical and external data available, and the available dose reconstruction methods, NIOSH believes it is possible to either: (1) estimate the maximum external dose for every type of cancer for which radiation doses are reconstructed that could have been incurred under plausible circumstances by any member of the class; or (2) estimate the external doses to members of the class more precisely than a maximum dose estimate. Although NIOSH found that it is not possible to reconstruct internal radiation doses completely for the proposed class, NIOSH intends to use any internal monitoring data that might become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Therefore, dose reconstructions for individuals employed at Medina Modification Center, San Antonio, Texas, during the period from January 1, 1958, through December 31, 1966, but who do not qualify for inclusion in the SEC, can be performed using these data as appropriate to support a partial dose reconstruction.

A.2 SITE DESCRIPTION AND FUNCTIONS

Medina Base, located on about 3,700 acres of Lackland Air Force Base southwest of San Antonio, was one of 13 WSAs created under the Armed Forces Special Weapons Project. Medina Base was constructed by the U.S. Air Force and the AEC between 1953 and 1955, with the first weapons components arriving in 1955. It was supported by SNL for the AEC and the Air Force. SNL, AEC, and the Air Force were all active at Medina from 1955 until early 1959, performing maintenance and quality assurance on nuclear components of weapons (Mitchell 2003).

The approved dates for applicability under EEOICPA for this site are 1958 through 1966 only.

During the AEC tenure, nuclear weapons and weapon components were stored by the AEC and maintained by SNL and Air Force personnel at the Medina WSA. WSAs were comprised of storage buildings that housed nuclear capsules, maintenance structures, waste burial sites, and bunkers used for storage of weapons casings. SNL personnel worked at Medina under contract to the AEC until early 1959 (Martin 2006a).

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In 1958, MHSMC was chosen by the AEC to manage Medina Base, and construction of new facilities was undertaken. Three Gravel Gertie cells were constructed along with other specialized facilities that comprised the Medina Modification Center (Mitchell 2003). From April 1959 until 1966, MHSMC operated Medina for the AEC as a weapons modification and disassembly facility. The mission was to perform stockpile surveillance, modifications, retrofits, and weapon retirements (Carr ca. 1992). This work included inspections for corrosion and replacement of tritium reservoirs. Medina was operated by MHSMC until January 1966, when its mission was transferred to the Pantex Plant, and Medina Base was transferred back to the Air Force.

A.2.1 Site Description

Lackland Air Force Base (AFB) is in the San Antonio metropolitan area in Bexar County, Texas (Figure A-1). Commercial and residential developments border Lackland AFB on the north, west, and south sides, and Kelly AFB borders it on the east. The western portion of Lackland AFB was the Medina Base, which is now designated the Lackland Training Annex. The Medina Base was comprised of four main areas designated as the 200 Area (general shops and stores), 300 Area (operations and storage), 400 Area (Plants 1 and 2, main production operations), and 500 Area (igloos and storage facilities). Two additional areas were the Burning Ground and the Railhead (Figure A-2) (Lamb Associates and Halliburton NUS 1995).

There were seven main types of structures at the Medina Base, including A Structures, C Structure, Base Spares Warehouse, assembly/maintenance buildings, S Structure, storage igloos, and the modification/disassembly plants (Lamb Associates and Halliburton NUS 1995). The site also included low-level radioactive waste (LLRW) disposal areas and emergency underground holding (or storage) tanks (USTs). Each of these structures is described in the following paragraphs.

A Structures included Buildings 301, 402, 403, 404, 552, 556, 562, 571, and 585 in the 300, 400, and 500 Areas. A Structures were used to store nuclear capsules for weapon systems (Lamb Associates and Halliburton NUS 1995). The buildings, though massive concrete structures, had only four small storage rooms, each approximately 10 ft wide, 13 ft deep, and 9 ft high. Each room had a capacity for approximately 30 nuclear capsules that were stored in criticality safe bird cage containers (Figure 2-5). Each room had a bank-vault type door equipped with dual combination locks. The 10-ft-thick walls and massive berms around the rooms were designed to protect the nuclear capsules from external attacks, rather than as containment of possible accidental detonations in the buildings. Maintenance activities always took place in the C Structure, never in the vault where the capsules were stored. Therefore, no nuclear material was ever exposed in an A Structure and there was little or no potential for a release of radioactive material with these buildings. Activities in the A Structures ended in 1960 (Lamb Associates and Halliburton NUS 1995).

Building 307, a C Structure, was used as a nuclear materials inspection laboratory and maintenance building for the nuclear weapons stored at Medina Base. The C Structure provided bench space to perform required maintenance operations, storage for neutron calibration and assay sources, and support facilities that included a change room and storage areas. Nuclear capsules destined for maintenance were transported in their bird cages to the C Structure; when maintenance was completed, the capsules were placed back in their bird cages, sealed, and returned to one of the A Structure buildings (Lamb Associates and Halliburton NUS 1995).

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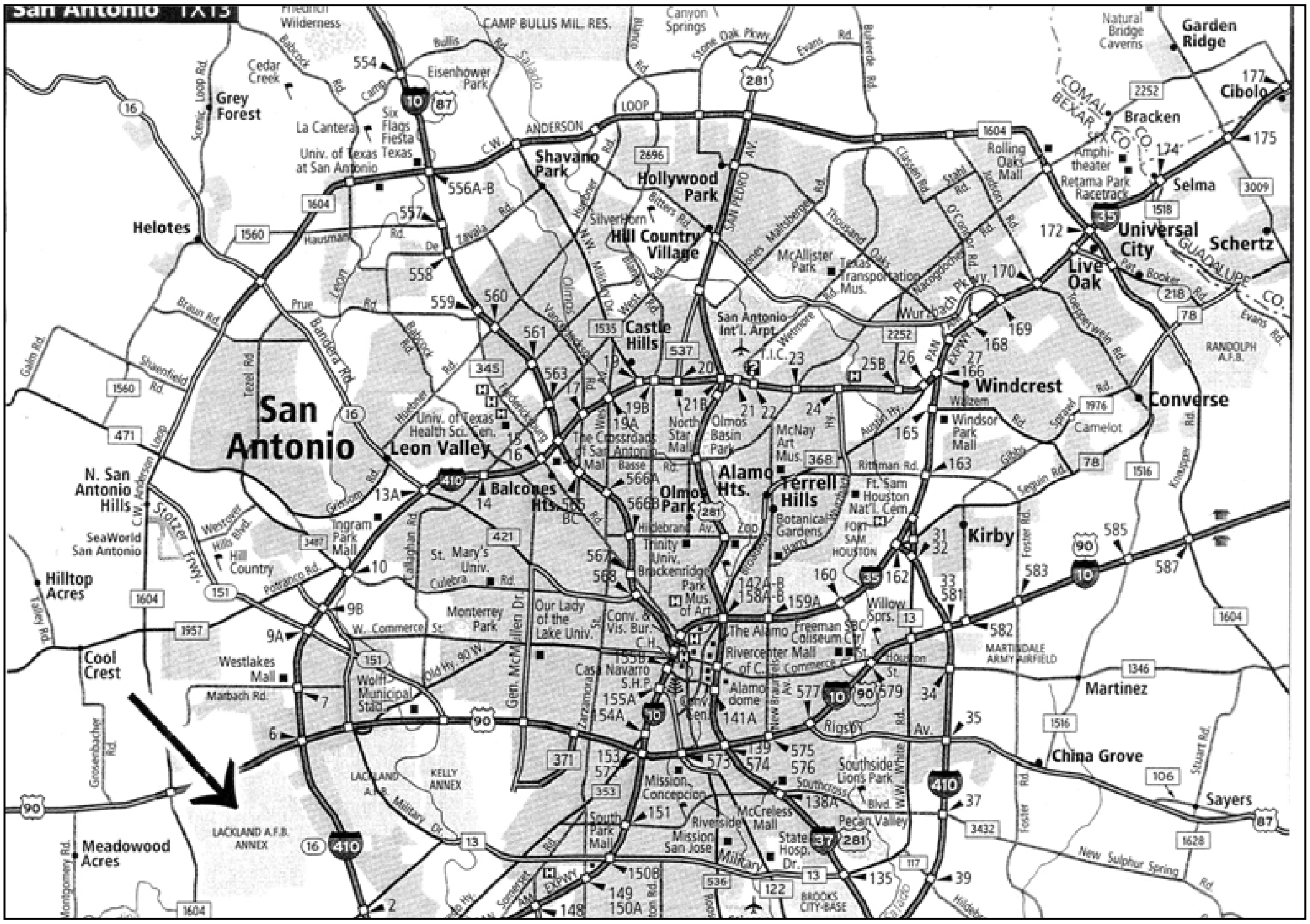

Figure A-1. San Antonio, Texas, area showing location of Lackland Training Annex (previously called Medina Base). Source: Rand McNally Road Atlas 2006.

Workrooms in the C Structure were constructed with floor drains that were connected to an emergency UST in the building. If there had been an accident, the UST would have collected the decontamination washwater and any plutonium released. No accidental releases of plutonium are known to have occurred at Medina Base during the 1955–1966 period (Lamb Associates and Halliburton NUS 1995).

The C Structure had an extensive ventilation system that prevented the release of uranium oxides to the atmosphere. Based on information reviewed from environmental reports, there are no indications that any spills or releases of radioactive material occurred in the C Structure during its operational lifetime (Lamb Associates and Halliburton NUS 1995).

The Base Spares Warehouse was used to store spare weapon components for maintenance purposes (Lamb Associates and Halliburton NUS 1995).

The Assembly/Maintenance Buildings were also called Plants 1 and 2; each plant consisted of two buildings used for maintaining non-nuclear components of weapons stored at Medina. The buildings contained several bays, and activities included inspection, testing, and assembly of non-nuclear mechanical and electrical systems. The buildings featured heavy blast doors and earthworks that

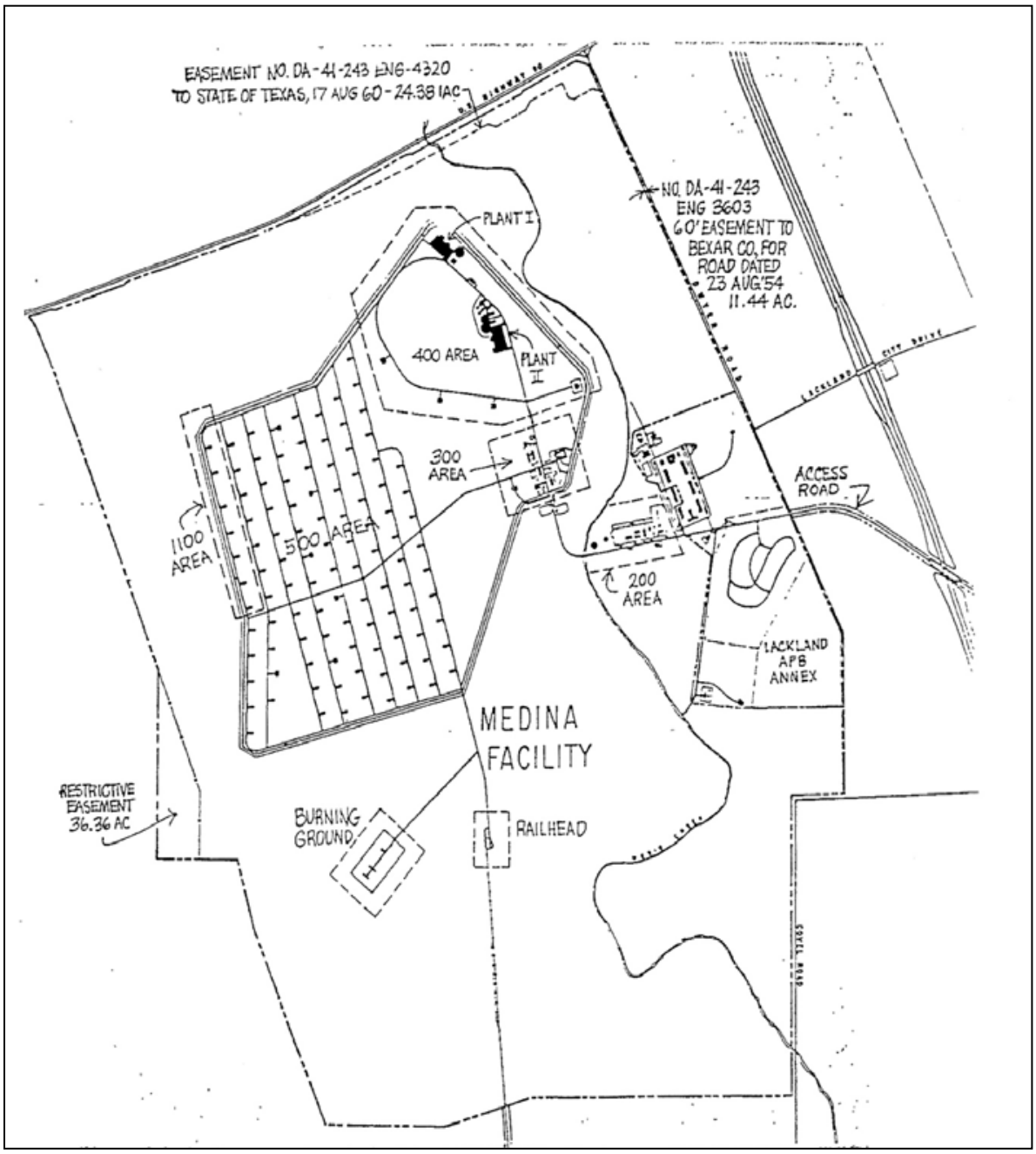

Figure A-2. Medina Base. Source: Lamb Associates and Halliburton NUS 1995.

would have deflected the effects of an accidental explosion upward. The design is typical for facilities in which large amounts of high explosives are handled (Lamb Associates and Halliburton NUS 1995).

An S, or Surveillance, Structure (Building 444) was used for inspections and testing of weapons in the stockpile. The S Structure separated quality assurance activities from the routine maintenance and assembly functions performed at Plants 1 and 2. Building 444 contained electrical and mechanical bays and a calibration room, but did not have a floor drain connected to a UST. The building was

modified in 1959 for the modification/disassembly mission managed by MHSMC (Lamb Associates and Halliburton NUS 1995).

One hundred igloos were constructed in the 500 Area for the storage of weapon components, assembled weapons, and weapon casings. All nuclear materials stored in the igloos were sealed in the weapons. No maintenance activities took place in the igloos and, therefore, there was little or no potential for a release of radioactive or hazardous materials (Lamb Associates and Halliburton NUS 1995).

In 1959, three Gravel Gertie cells were built for modifying and disassembling weapons. High-explosive shells were removed from nuclear assemblies in these structures. Several tons of gravel were above the ceiling of each structure for containment of fissile material in the event of an accidental detonation of the high-explosive system. The Gravel Gerties were used between 1959 and 1965 (Lamb Associates and Halliburton NUS 1995).

Three sites at Medina (RW-15, RW-17, and RW-19) were designed for the collection of dry and liquid LLRW. RW-15 was a landfill for the disposal of LLRW, and is suspected of having received classified limited-life components disposed of during weapons modification and disassembly operations between 1959 and 1965. The LLRW was excavated in 1965 and transferred in container express (CONEX) containers to the Pantex Plant. The RW-15 site was cleared by the AEC as decontaminated when the site was closed in 1965 (Lamb Associates and Halliburton NUS 1995). Dry LLRW generated in the C Structure was packed in cardboard boxes and disposed of in the RW-17 site. RW-17 was an unlined pit that was fenced and considered a classified waste landfill. RW-19 was a small gravel leaching area behind Building 444. The site reportedly received intermittent LLRW wastewater discharges from Building 444. Gravel and soil from the area were excavated in 1965 and transferred in CONEX containers to the Pantex Plant (Lamb Associates and Halliburton NUS 1995).

Three emergency USTs were designated RW-16, RW-18, and RW-20. The USTs were intended for the collection of liquid LLRW in the event of an accidental release; however, no evidence has been found that any of the USTs were ever used (Lamb Associates and Halliburton NUS 1995). RW-16 and RW-18 are 1,000-gal steel tanks; RW-20 is a 5,000-gal steel tank.

A.2.2 Operational History as a Weapons Storage Area

The early nuclear weapons used Po-Be initiators to generate neutrons during the explosion sequence. Because ^{210}Po has a half-life of only 138 days, the initiators had to be replaced periodically. According to former SNL personnel (Martin 2006a), these devices were maintained following precise quality control methods that required maintenance personnel to:

1. Release pressure from the bird cage container through a filter and check the filter for alpha activity. If no activity was found, remove the capsule from the container using a handling tool.

2. Place the capsule on a table top with an alpha probe at one end. (The table was covered with a large piece of butcher paper to contain any spalling of uranium oxides.)

3. Place a Plexiglas glovebox over the capsule.

4. Disassemble the capsule parts and check the integrity of the coatings.

5. Remove the glovebox.

6. Remove uranium oxide deposits from the threads using a small cloth or paper swipe and trichloroethylene. Wipe the threads with ethyl alcohol to dry the components.

7. Use acetone to remove previous markings made with blue machinist's dye and make new markings. (Later components had serial numbers etched on their surfaces.)

8. Check the activity of the fissile material using beta and gamma radiation measurements.

9. Assay the nuclear material by accurately weighing it and perform subcritical multiplication measurements using external neutron sources.

10. Replace the Po-Be initiators. (These were later replaced with nonradioactive initiators.)

11. Reassemble the capsule.

12. Place the capsule and a sack of desiccant in the bird cage container.

13. Screw on the bird cage container top. Repressurize and wire seal the bird cage container (positive pressure was maintained to ensure dryness and keep O-rings in place) (Lamb Associates and Halliburton NUS 1995). [Later designs used a vacuum rather than overpressure (Bihl 2006c).]

Contaminants generated in the maintenance process were chemicals mentioned above and uranium oxides. Polonium-210 waste was not generated (Lamb Associates and Halliburton NUS 1995). Used (decayed) initiators were sent to Los Alamos National Laboratory for storage, regeneration, or disposal. The spalled uranium oxides, swipes contaminated with solvents, lead-wire seals, and gloves were wrapped in butcher paper and placed in 18-by-18-by-24-in. cardboard boxes for disposal in the dry LLRW disposal area (currently designated RW-17) (Lamb Associates and Halliburton NUS 1995).

A source safe (a cylindrical apparatus below the floor surface with a polyethylene neutron absorber at the top) was in a corner of the laboratory room in the C Structure. Below the neutron absorber, the source safe had a tray for storing check sources used to verify the activity of the fissile material in the weapons (Lamb Associates and Halliburton NUS 1995).

Between 1954 and 1957, the Po-Be initiators and plated pits used in the in-flight-insertable design were phased out and replaced with sealed pits and a newer type of sealed neutron generator that did not require routine replacement (Lamb Associates and Halliburton NUS 1995, Mitchell 2003). Thus, some SNL workers handled Po-Be initiators and plated pits before 1957, but no MHSMC workers were exposed to the initiators or plated pits. After 1957, maintenance activities were reduced to annual disassembly of capsules to determine their condition and to verify the integrity of the fissile materials. Maintenance of the newer capsules generated the same types of waste, but in smaller quantities because of the less frequent maintenance schedule. By 1960, nuclear capsules had been phased out of the stockpile and maintenance activities no longer involved exposed nuclear material (Lamb Associates and Halliburton NUS 1995).

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A.2.3 Operation as a Modification/Disassembly Center

Between 1959 and 1966, the mission of MHSMC workers was to perform stockpile surveillance, modifications, retrofits, and weapon retirements (Carr ca. 1992). Typical modifications involved disassembly and reassembly with some modified components and replacement of tritium reservoirs. Weapon retirements involved complete disassembly and return of nuclear components to other DOE sites. Some damaged weapons were returned to Medina during these years. Their ultimate disposition has not been determined, but they were no longer at Medina after shutdown. During this period, the MHSMC workers at Medina were exposed to the same types of radiation and levels of contamination as Pantex workers because their work activities were nearly identical (except there were no hydroshot operations at Medina) (Mitchell 2003).

A.3 OCCUPATIONAL MEDICAL DOSE

Similar to Clarksville Modification Center, the Pantex Plant has the X-ray histories of Medina workers during the MHSMC years. Only written histories, not film, are available. Because essentially the same work was done by the same contractor, it is assumed that the X-ray guidance for Clarksville Modification Center should be applied to Medina workers for the MHSMC years, 1958 to 1966. (There is evidence in the claims files that MHSMC gave some preemployment X-rays in October 1958.) See Section 3.0, Occupational Medical Dose.

A.4 ENVIRONMENTAL DOSE

A.4.1 Routine Doses

Insufficient information has been obtained about Medina Base to develop site-specific considerations for environmental releases. The only environmental doses assigned for the Pantex Plant are from radon and a large accidental release of tritium. Similarly, environmental doses at Clarksville Modification Center resulted from a tritium accident modeled after the Pantex accident and from direct radiation from use of radiography sources. Throughputs, in terms of number of disassemblies, for instance, of the four assembly/disassembly sites (Pantex, IAAP, Clarksville, and Medina) are classified, so comparison of effluents by relationships to throughput is not possible. Medina had three Gravel Gerties compared with one at Clarksville.

The average tritium release from the Pantex Plant from 1981 through 1988, when a large number of disassemblies was performed, was 70,000 µCi/yr. Assuming that Medina Base operations were commensurate with those of the Clarksville Modification Center and Pantex, the annual doses resulting from tritium intakes are also less than 0.001 rem. Thus, the annual dose to any organ from tritium intakes at the Medina Base are less than 0.001 rem and can be ignored.

There is no reason not to believe that Medina Base had the same radiography sources as Clarksville Modification Center. Dose reconstructors should assign Medina workers the same 4-mrem external dose from radiography as that for Clarksville workers (Section 4.0 and Table 4-1.). The 4-mrem annual dose is applied as a lognormal distribution with a GSD of 2.0 with a photon energy range of 100% 30 to 250 keV.

A.4.2 November 13, 1963, Explosion

A.4.2.1 Background

On November 13, 1963, an explosion involving 50,500 kg (123,000 lb) of chemical high-explosive components of nuclear weapons occurred at the Medina site. Workers were placing subassemblies from dismantled atomic bombs into storage Igloo 572. The subassemblies, which were being stored for further processing and disposal, contained chemical high explosives, natural uranium, and DU. They were handled by a three-man crew – two forklift operators who moved them from a straddle carrier into the igloo and one man on the carrier.

Most of the load was in the igloo when, at about 10:24 a.m., the explosive in one of the subassemblies ignited. Seeing the flash, the drivers sprinted for cover, alerting the workers outside. For about 45 seconds the explosive burned, then it detonated with a force of more than 60 tons of TNT. The first explosion set off other subassemblies in the igloo and those still on the carrier. The igloo disappeared in a cloud of smoke and dust, leaving a crater some 20 ft deep. A large cloud of dust was seen near the ground moving downwind of the event.

In the 45 seconds between ignition and detonation, the three workers got away. Their injuries were minor. Adjacent igloos were not disturbed. The only known radioactive material involved was a mixture of DU and natural uranium. Fissile materials (enriched uranium or plutonium) were not involved in the accident.

A.4.2.2 Direct Radiation

Assuming an infinite plane source and the distribution of natural uranium (which has a higher compounded dose rate than DU) in equilibrium with its short-lived progeny, external doses can be calculated. Dose rates can be calculated for each organ using organ-specific, dose-rate conversion factors such as those in Federal Guidance Report No. 12 (Eckerman and Ryman 1993) or the CD supporting Federal Guidance Report No. 13 (Eckerman et al. 1999).

Using the factors from Federal Guidance Report No. 13 CD (Eckerman et al. 1999), the rate of effective dose per $\mu Ci/m^2$ would be

$^{238}U + {}^{234}Th + {}^{234m}Pa$ $\quad (0.489)(49.5 + 876 + 12{,}600) \times 10^{-6}$ rem/yr per $\mu Ci/m^2$

$^{235}U + {}^{231}Th$ $\quad (0.0225)(16{,}400 + 1{,}720) \times 10^{-6}$ rem/yr per $\mu Ci/m^2$

^{234}U $\quad (0.489)(68.4) \times 10^{-6}$ rem/yr per $\mu Ci/m^2$

$= 0.025$ rem/yr $= 25$ mrem/yr per $\mu Ci/m^2$ for full-time occupancy (A-5)

However, this value is somewhat misleading; Federal Guidance Report No. 13 (Eckerman et al. 1999) factors include a tissue-weighting factor for skin dose. Using Federal Guidance Report No. 13 factors but omitting the contribution from the weighted skin dose, the gamma dose rate, which more closely approximates the average organ dose, is

$^{238}U + {}^{234}Th + {}^{234m}Pa$ $\quad (0.489)(40.7 + 856 + 1{,}600) \times 10^{-6}$ rem/yr per $\mu Ci/m^2$

$^{235}U + {}^{231}Th$ $\quad (0.0225)(16{,}200 + 1{,}820) \times 10^{-6}$ rem/yr per $\mu Ci/m^2$

^{234}U $(0.489)(57.8) \times 10^{-6}$ rem/yr per μCi/m^2

= 0.0017 rem/yr = 1.7 mrem/yr per μCi/m^2 for full-time occupancy (A-6)

For an occupational exposure of 2,000 hr/yr, this would be 0.39 mrem/yr per μCi/m^2. The highest onsite location, 60 μCi/m^2, might have resulted in 23 mrem/yr. For regularly occupied areas downwind, a value of one-tenth of that, or 2.3 mrem/yr, would be appropriate. Most of the site is upwind of the footprint left by the plume, so the external dose from uranium in the soil would be negligible. However, at present there is no way to discriminate between workers in offices upwind versus downwind of the plume footprint. Therefore, dose reconstructors should apply a 2.3-mrem/yr external dose (photon 30–250 keV).

A.5 INTERNAL DOSE

NIOSH has concluded that is not possible to reconstruct internal doses completely during the operational period of the Medina Modification Site. Therefore, in the absence of monitoring data for an individual claim, no occupational internal doses are assigned. For claims in which individual internal monitoring data are available, the internal dose will be reconstructed based on interpretation of the monitoring data using existing NIOSH dose reconstruction processes and procedures.

A.6 EXTERNAL DOSIMETRY

The MHSMC dosimetry records for Medina began on April 27, 1959, and extended through January 24, 1966 (Pantex Plant 1959–1966). It is possible that some earlier dosimetry records exist for SNL personnel, but none have been found to date. Exposures to the few (less than 10) SNL personnel between 1955 and 1959 did not involve exchange of Po-Be initiators, and [Name redacted] estimated maximum exposures at 100 mrem/yr (Martin 2006a). However, the approved EEOICPA dates for this site are 1958 through 1966 only. MHSMC utilized weekly dosimetry services provided by Tracerlab from April 1959 until July 1964 (Tracerlab 1965). Weekly dosimeters were provided by Nuclear Service Laboratories of Knoxville, Tennessee, from July 1964 until January 1966 (NSL 1964–1966). Work at Medina was completed in January 1966, and dosimetry services were terminated on January 24, 1966. Most of the MHSMC workers left the site in January and February 1966. Many of the workers transferred to the Pantex Plant in Amarillo, Texas.

The clerical maintenance of the dosimetry records was not rigorous. For example, individual names were consistently assigned to only 11 film badge numbers, and some numbers were reused when an individual left the program. More than 100 other film badges were assigned to different people each week and the individual names, for nonzero results only, were recorded on the film badge dose report after it was received. In some weeks, the task of recording names associated with nonzero dose results was not completed, so it is impossible to reconstruct who received nonzero doses. Because more than one individual was assigned to a given film badge number, the quarterly and annual totals maintained by the film badge processor were not useful.

Therefore, the dose records from Pantex were carefully examined, corrected, and summarized in a letter to the Project file, “Medina Dose Records, 1959-1966” (Martin 2006b). Dose reconstructors should disregard any incomplete dose records provided with the claims and use Martin (2006b).

Figure A-3 shows a log probability plot of all recorded annual doses received by monitored workers at Medina Base for 1959 to 1966. This plot can be compared with the plot in Figure 6-2 for Clarksville

Modification Center. The 50th- and 95th-percentile doses shown in Figure A-3 are slightly higher than the same percentile doses for the Clarksville data.

Because the doses received by Medina and Clarksville workers appear similar in magnitude within the uncertainties in how annual doses were calculated, the recommendations for Medina are the same as those for Clarksville. The exception is that it appears the exchange frequency at Medina was weekly for all years of operation. Because the work performed at Medina was similar to that performed at Clarksville, and the distribution of annual doses received at Medina, as seen in Figure A-3, is similar to that for Clarksville, it is reasonable to use the same dose assignment recommendations for Medina as those described for Clarksville Modification Center. A summary of dose recommendations for Medina is listed in Table A-1.

Radiation Incident at Medina on September 7, 1959

On September 7, 1959, there was a radiation exposure incident at Medina that involved a radiography source (Pantex Plant 1959–1966). The details were provided in Computer Assisted Telephone Interviews, the most detailed one associated with claim number [claim number redacted]. A vendor came to the site to demonstrate a new type of portable radiography source/shield that was air operated (apparently referred to as a Puff camera). The device could pneumatically transfer a source from the safe shielded position, through a 30-ft tube, to a radiography exposure location. The end of the tube was located such that it could take an X-ray of an electronic part. The vendor representative first performed the transfer of the capsule out to the end of the tube and back into the lead shield using a dummy (nonradioactive) capsule. The transfer was successfully demonstrated several times and the Medina radiography staff successfully used the equipment with the dummy capsule in a training exercise. While the vendor representative was leaving the site, he realized he did not have the dummy capsule with him and there could be a problem. An investigation revealed that the dummy capsule was still in the lead shield and when the air flow was reversed, the 30-Ci ^{192}Ir source could not enter the shield because the dummy capsule was in it. When the air flow stopped, the ^{192}Ir source fell back down the tube to an area where personnel were present. As a result of this incident, three individuals received unusually high radiation exposures, as follows: Individual A – 6,600 mrem gamma, Individual B – 3,000 mrem gamma, and Individual C – 2,370 mrem gamma. These exposures are included in the summarized records (Martin 2006b).

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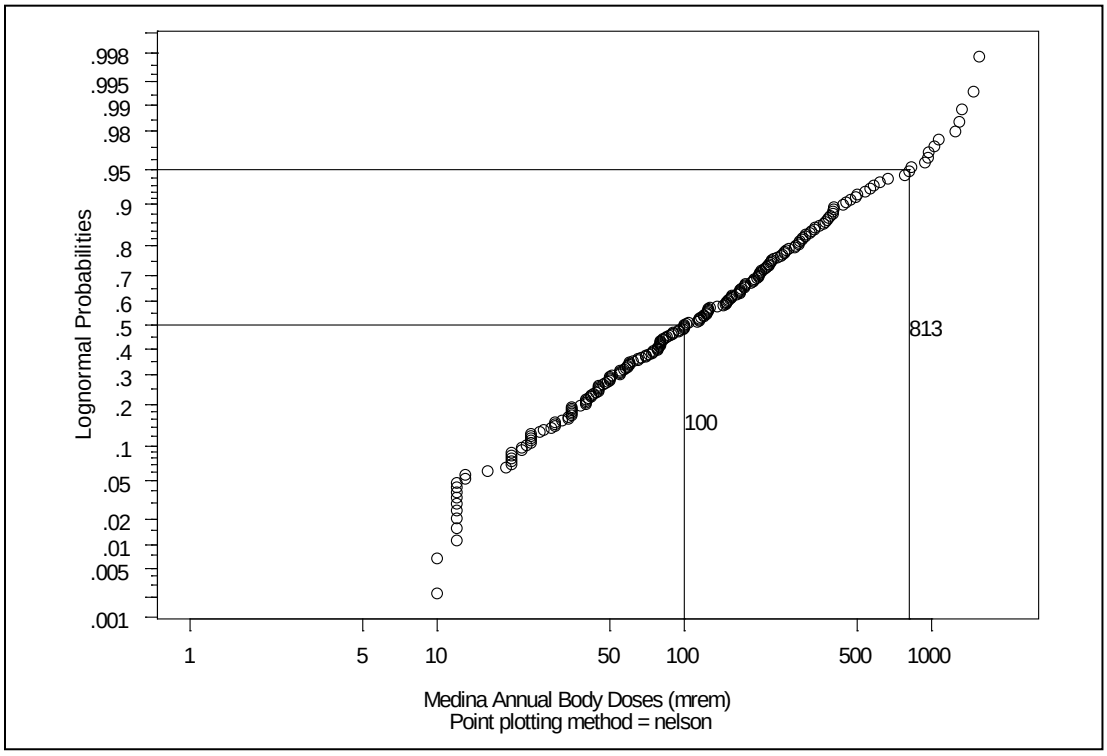

Figure A-3. Log probability plot of recorded annual doses received by monitored workers at Medina, 1959 to 1966 (Pantex 1959–1966).

Table A-1. Dose recommendations for Medina workers.

Monitored status	Dose type	Recommendation
Monitored	Photon	Maximum of recorded annual dose or 20 mrem × number of weeks worked during year
	Neutron	Neutron dose = 1.7 × photon dose
	Neutron	Multiply assigned neutron dose by 1.91[a]
Not monitored	Exposure categories	As listed in Table 6-4
	Photon	As listed in Tables 6-7 to 6-9
	Neutron	Neutron dose = 1.7 × photon dose
	Neutron	Multiply assigned neutron dose by 1.91[a]

a. ICRP (1991) weighting adjustments.