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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.

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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AEHA	(U.S. Army) Environmental Hygiene Agency
AFB	Air Force Base
AIRS	Aerometric Information Retrieval System
AP	anterior-posterior
CATI	Computer-Assisted Telephone Interview
CD	compact disk
Ci	curie
cm	centimeter
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
Hp(d)	personal dose equivalent at tissue depth *d* (*d* = 10 mm or 0.07 mm)
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
mCi	millicurie
MDL	minimum detection level

MeV	megaelectron-volt, 1 million electron volts
mGy	milligray
MHSMC	Mason and Hanger-Silas Mason Company, Inc.
min	minute
mL	milliliter
mm	millimeter
mo	month
MRD	minimum recordable dose
mrad	millirad
mrem	millirem
NCRP	National Council on Radiological Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
NTA	Eastman Kodak nuclear track emulsion, type A
NUREG	U.S. Nuclear Regulatory Commission Regulation
PA	posterior-anterior
PAEC	potential alpha energy concentration
PAEE	potential alpha energy exposure
pCi	picocurie
PM_{10}	particulate matter in the air with an aerodynamic diameter less than or equal to 10 micrometers
POC	probability of causation
ppm	parts per million
s	second
SI	small intestine
SNL	Sandia National Laboratories
ST	stomach
TBD	technical basis document
TLD	thermoluminescent dosimeter
TNT	trinitrotoluene
USAPMS	U.S. Army Preventive Medicine Service
U.S.C.	United States Code
UST	underground storage tank
WL	working level
WLM	working level-month
WSA	Weapons Storage Area
yr	year
Z	atomic number
µCi	microcurie
µg	microgram
µm	micrometer
§	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. The documents 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 POC guidelines (nor the dose reconstruction regulation) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work.

As noted above, the statute includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition contains an exclusion with respect to the Naval Nuclear Propulsion Program, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally derived radiation 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 dosimetry monitoring results are considered valid for use in dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived:

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

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

1.2 SCOPE

This Site Profile provides information about U.S. Atomic Energy Commission (AEC) operations at Clarksville Base 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 Weapons Storage Area (WSA) and Modification Center were similar in purpose and operation to Clarksville Base, Attachment A of this document contains information about Medina.

2.0 SITE DESCRIPTION AND OPERATIONAL HISTORY

2.1 SITE DESCRIPTION

Clarksville Base, at Fort Campbell, Kentucky/Tennessee, was one of 13 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 [later called Sandia National Laboratories (SNL)] for the AEC and the U.S. Navy. SNL, AEC, and the Navy were all active at Clarksville Base 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 Base for the AEC as a weapons modification and disassembly facility (Lamb Associates and Halliburton NUS 1996; McConn 2006; Mitchell 2003).

Clarksville Base 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 Base 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 Base 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 (CATIs) refer to the “Bird Cage.” This term was used officially to describe the criticality-safe framework built

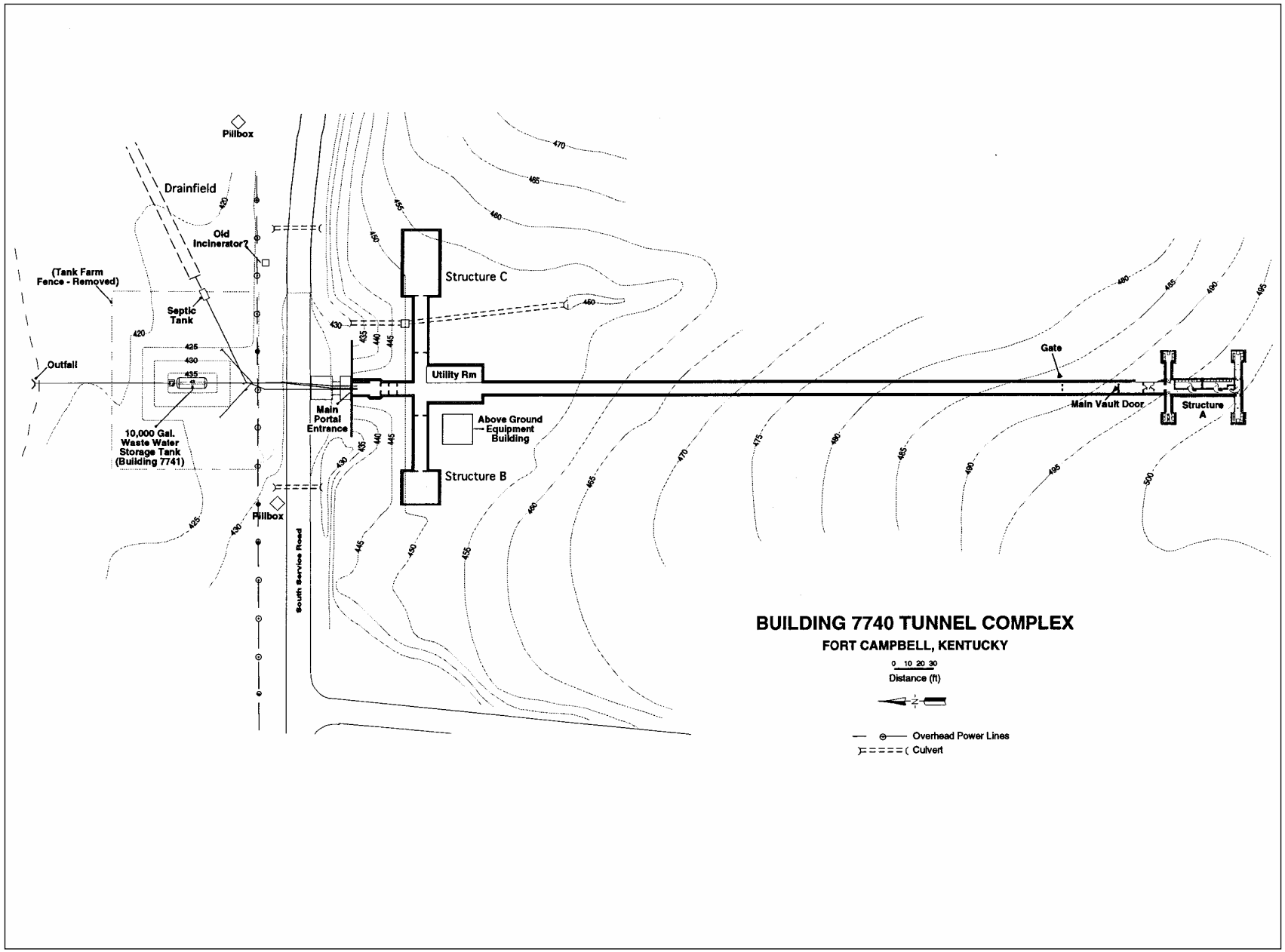

Figure 2-1. General plan view of ABC Structure.

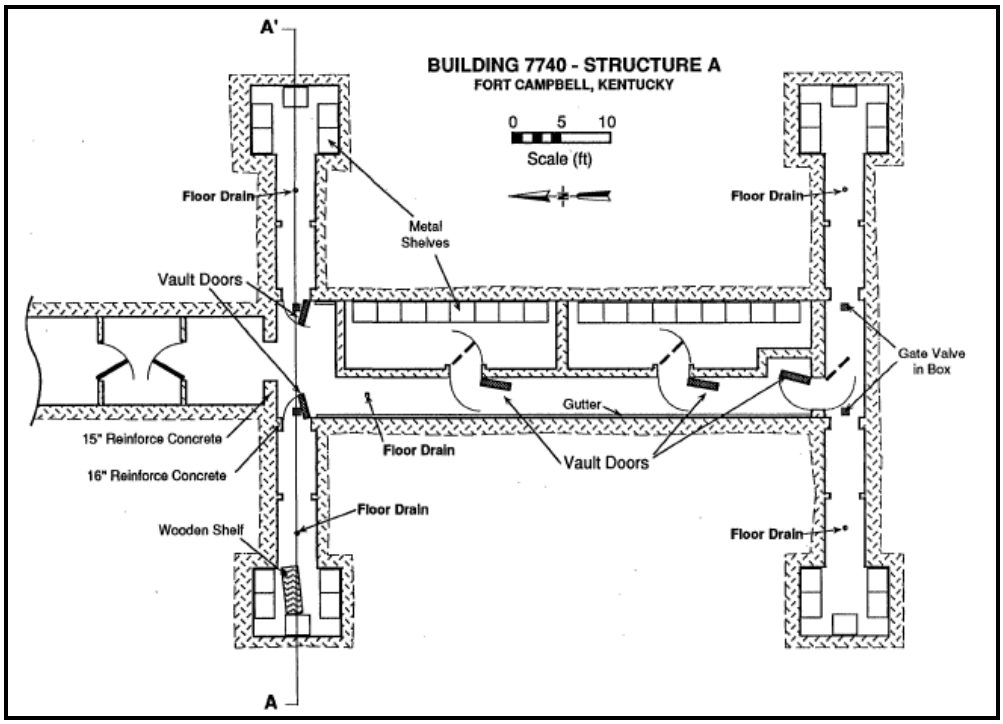

Figure 2-2. Plan view of the "A" Structure.

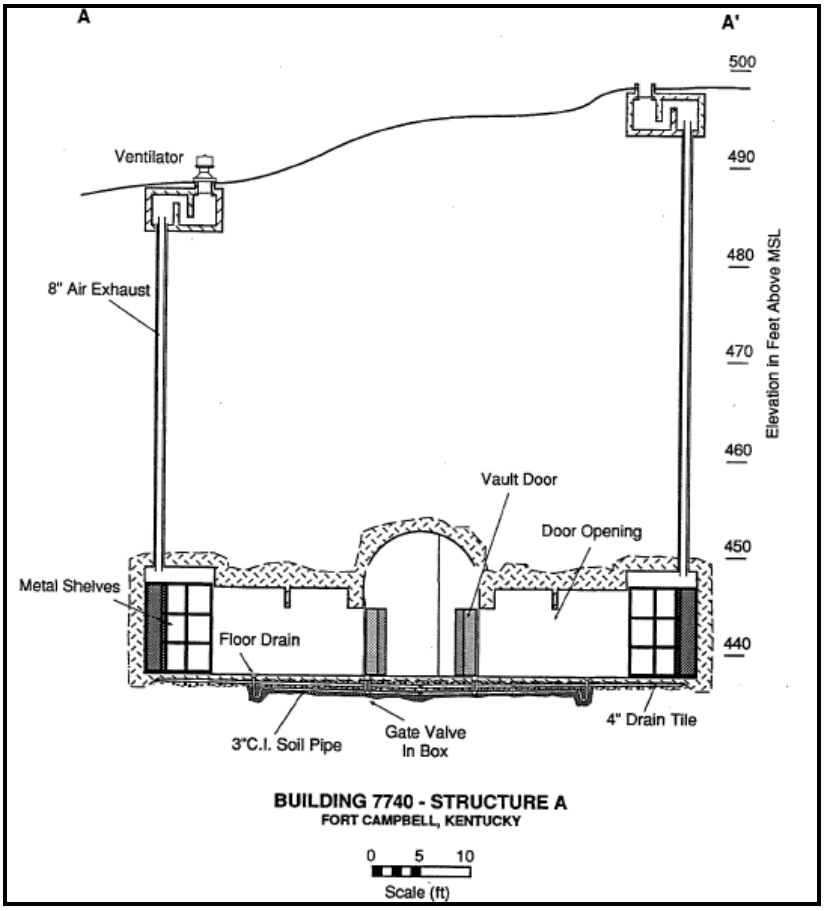

Figure 2-3. Cross-sectional view of the "A" Structure.

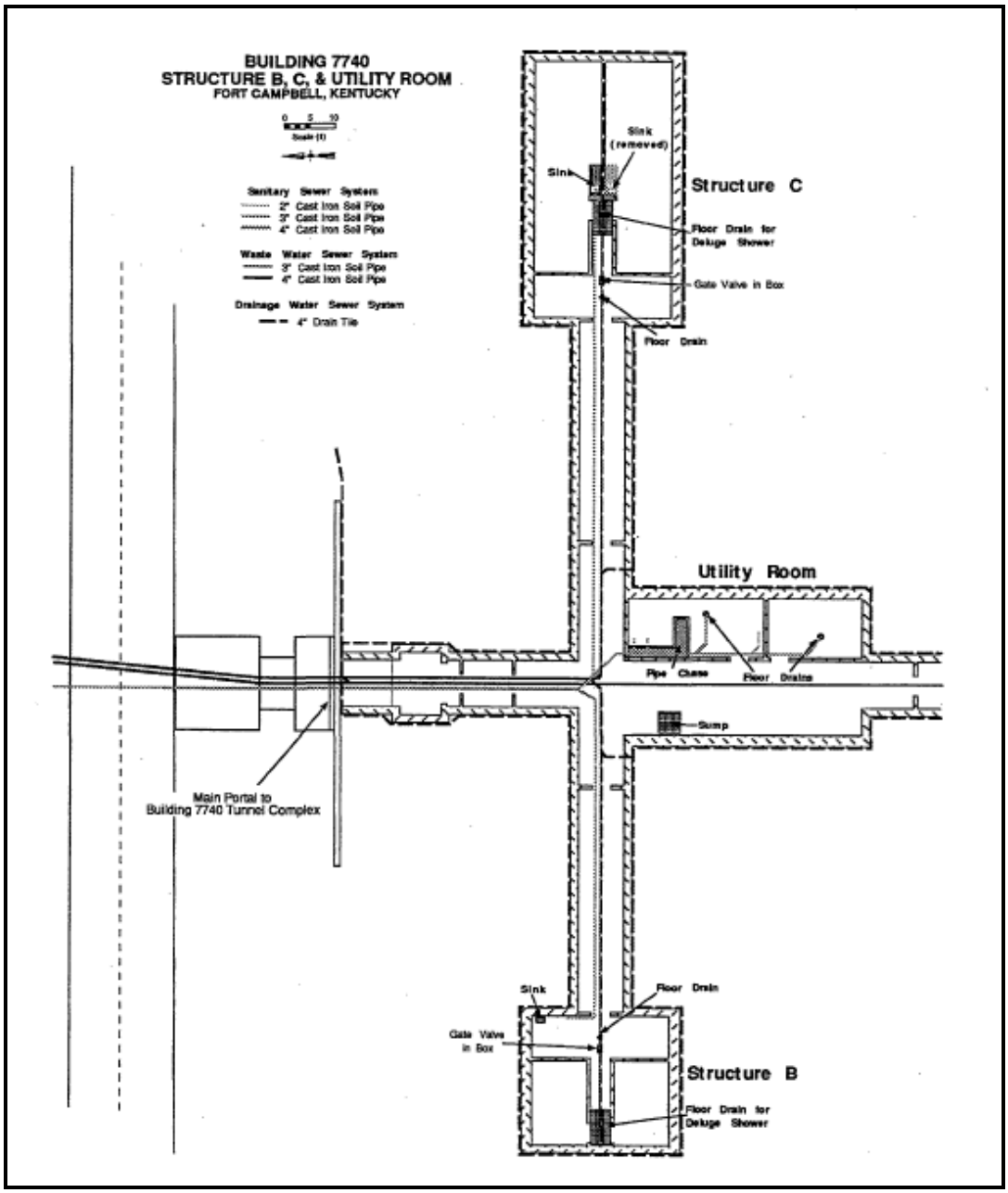

Figure 2-4. Plan view of the "B" and "C" Structures in the tunnel complex.

around a nuclear package (see Figure 2-5); however, the term appears to have been used unofficially 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 weapon, comprised of

Figure 2-5. Typical bird cage.

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.

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 Base are tritium as a gas, weapons-grade plutonium, HEU, depleted uranium (DU; also used in weapons construction), ^{210}Po in a Po-Be neutron generator, 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 Base 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 CATI stated about every 6 mo 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; CATI 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	CATI claims that fireman stood by with 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. Harold Rarrick, 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 Sandia was the principal AEC contractor (McConn 2006). Records on Clarksville workers from Pantex do not list any X-rays prior to 1960, even for workers who continued employment into the years 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 preemployment X-rays and who did not. For instance, the records for the two claims for clerk-typists 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 shots.) 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 prior to 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 described in *Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures* (ORAUT 2005a) 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

Guidance in ORAUT (2005a) was used to determine organ doses. For conventional chest X-rays, that document recommended a default entrance kerma of 0.2 rem for pre-1970 examinations (ORAUT 2005a, Table 3-4). In addition, Table 6-5 of ORAUT (2005a) provides factors for converting kerma to organ dose for pre-1970 machines that might have had limited collimation. Because nothing is known about the type of X-ray machine used, it is favorable to claimants to assume limited collimation. It is also assumed that the view is posterior-anterior (PA). The dose conversion factors and organ doses from ORAUT (2005a) are listed in Table 3-1. Dose reconstructors should use the most recent update of that document.

According to ORAUT (2005a), two anterior-posterior (AP) shots and two lateral (LAT) shots should be assumed for lumbar spine examinations; however, the doses in ORAUT (2005a) include both shots per view. The entrance skin exposure for AP was 4.00 rem and for LAT was 10 rem, and it was

Table 3-1. Organ doses from PA conventional chest X-rays[a].

Organ	PA dose conversion factor (mGy per Gy air kerma) HVL 2.5 mm Al minimum collimation	Organ dose (rem)
Thyroid	174	3.48E-2
Eye/brain	32	6.40E-3
Ovaries	NA[b]	2.5E-2
Liver/gall bladder/spleen	451	9.02E-2
Urinary bladder	NA	2.5E-2
Colon/rectum	NA	2.5E-2
Testes	NA	5.0E-3
Lungs (male)	419	8.38E-2
Lungs (female)	451	9.02E-2
Thymus	451	9.02E-2
Esophagus	451	9.02E-2
Stomach	451	9.02E-2
Bone surfaces	451	9.02E-2
Remainder	451	9.02E-2
Breast	49	9.80E-3
Uterus	NA	2.5E-2
Bone marrow (male)	92	1.84E-2
Bone marrow (female)	86	1.72E-2
Skin[c]	NA	2.70E-1

a. From ORAUT (2005a, Table 6-5, pre-1970).
b. NA: not available
c. Includes backscatter factor of 1.4.

assumed that the entrance skin exposure in rem is equal to the air kerma in rads. The entrance skin exposures were based on data applicable to 1950–1953 but, lacking any other information, are assumed to be applicable to the X-rays given at Clarksville Base in 1960–1965 as well. The organ doses for lumbar spine X-rays in ORAUT (2005a) per set of two shots are listed in Table 3-2. Dose reconstructors should use the most recent update of that document. Enter the values from ORAUT (2005a) 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%.

Table 3-2. Organ doses from lumbar spine X-rays.[a]

Organ	View	Organ dose (rem)
Thyroid	AP	8.00E-4
	LAT	1.00E-4
Eye/brain	AP	8.00E-4
	LAT	1.00E-4
Ovaries	AP	1.12[b]
	LAT	1.52[b]
Liver/gall bladder/spleen	AP	2.48E-1
	LAT	1.00E-1
Urinary bladder	AP	1.12[b]
	LAT	1.52[b]
Colon/rectum	AP	1.12[b]
	LAT	1.52[b]
Testes	AP	5.40E-2[b]
	LAT	1.12E-1[b]
Lungs	AP	2.48E-1
	LAT	1.00E-1
Thymus	AP	2.48E-1
	LAT	1.00E-1
Esophagus	AP	2.48E-1
	LAT	1.00E-1
Stomach	AP	2.48E-1
	LAT	1.00E-1
Bone surfaces	AP	2.48E-1
	LAT	1.00E-1
Remainder organs	AP	2.48E-1
	LAT	1.00E-1
Breast	AP	7.20E-2
	LAT	9.50E-2
Uterus	AP	8.68E-1
	LAT	2.00E-1
Bone marrow	AP	9.60E-2
	LAT	1.50E-1
Skin	AP	5.28[c]
	LAT	1.32E+1[c]

a. From ORAUT (2005a).
b. Based on actual measurements by Lincoln and Gupton (1957).
c. Includes backscatter factor of 1.32.

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 Base have been discovered. Prior to 1959, complete disassemblies were not performed at Clarksville Base, 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 Harold Rarrick, portable gloveboxes with HEPA-filtered exhausts were used to contain oxidized DU when weapons underwent inspections, maintenance, and refurbishment during the Sandia years (McConn 2006). The DU was cleaned from the nuclear components and deposited as solid waste on cleaning rags. Mr. Rarrick 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 Base.

After tritium reservoirs became part of the weapons, leaks of tritium into the disassembly cell and out the cell exhaust duct were possible. Mr. Rarrick 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 releases from similar work at the Iowa Army Ammunition Plant (IAAP) were documented for December 1965 through December 1970, averaging 26,000 µCi/yr (ORAUT 2005b). Lacking additional information, it was assumed that Clarksville Base had similar effluent rates of tritium. Tritium in the reservoirs was in the form of tritiated gas (HT), 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.

To estimate intakes to workers outside facilities if little or no atmospheric information is available, techniques recommended by the National Commission on Radiological Protection (NCRP) in Volume I of Report 123 (NCRP 1996) were used. The NCRP recommends a graded approach, with three screening levels. Level 1 is the most conservative (least dispersion) and requires the least amount of input information. The Level 1 method for determining an upper bound air concentration can be written as:

$$X\,(pCi/m^3) = \frac{F\,x\,Q\,(pCi/s)}{V\,(m^3/s)} \qquad (4\text{-}1)$$

where:
- X = annual average upper-bound air concentration
- F = assumed fraction of time the wind blows in the direction of the subject, assumed to be 0.25
- Q = release rate of the radionuclide from the source
- V = volumetric flow rate of the vent (the default value is 0.3 m^3/s, typical of hood ventilation rates)

The model essentially assumes that the subject breathes undiluted effluent from the vent or stack, modified by the fraction of time the wind blows in their direction (the factor of 0.25).

With the NCRP assumptions, the annual average air concentration near the release point should be less than:

$$26{,}000\ \mu\text{Ci/yr} \times (1 \times 10^6\ \text{pCi/}\mu\text{Ci}) \times 0.25 / (3.15 \times 10^7\ \text{s/yr} \times 0.3\ \text{m}^3\text{/s}) = 688\ \text{pCi/m}^3 \qquad (4\text{-}2)$$

Because tritium (as water) can be absorbed through the skin, the tritium inhalation intake is multiplied by a factor of 1.5 to obtain the total intake of tritium water. Assuming a breathing rate of 2,400 m^3/yr and assuming all the tritium is in the form of water results in an estimated annual intake of

$$688\ \text{pCi/m}^3 \times 1.5 \times 2{,}400\ \text{m}^3 = 2.5 \times 10^6\ \text{pCi or } 6{,}800\ \text{pCi/d} \qquad (4\text{-}3)$$

This intake rate results in a dose to any organ of less than 1 mrem, which can be ignored.

Robert Wells, a Clarksville material handler, described an accident involving a damaged weapon returned to Clarksville Base from the military (Bihl 2006a). The accident was corroborated in a claimant CATI. 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 CATI indicated that the accident occurred in 1962.

Because Mr. Wells 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 prior to its discovery. The reservoirs are under considerable pressure so most of the contents would have leaked prior to 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 CATI.

An accidental release of tritium during a disassembly occurred at the Pantex Plant in 1989 (ORAUT 2006a). This was a major release causing 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 1989 release. The Pantex Environmental Technical Basis Document (ORAUT 2004) assigns 15-mrem dose from the 1989 accident to all organs for that year. According the CATI, 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 incident at Pantex and that the environmental dose to workers was no greater than 15 mrem. All Clarksville workers should be given a 15-mrem dose from tritium to any organ for 1962 only. Because the Clarksville release was undoubtedly smaller than the Pantex release, the distribution is a constant upper bound.

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. 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 intake.

Period of application	Mode	Type	Radionuclide	Dose to any organ	Distribution
March 1962	Inhalation and skin absorption	Acute	Tritium	15 mrem	Constant

Table 4-2. 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

There is no available reference material that describes actual activities at Clarksville Base. One reference source describes "maintenance activities" conducted at Clarksville Base; these activities appear to have been primarily to replace Po-Be initiators (Lamb Associates and Halliburton NUS 1996). Po-Be initiators were replaced with another type of initiator from 1954 to 1957. Although there was little risk of intake from the Po-Be initiators themselves, the need to replace them presented the need to disassemble and reassemble the components, leading to the potential for uranium contamination.

Based on materials used to assemble weapons and considering that the fissile material was encapsulated (plated or sealed), the radionuclides most likely to result in an intake at Clarksville Base were DU (D38 or tuballoy) and tritium (^{3}H) starting in about 1954.

Maintenance activities took place in the "C" structures and never in the "A" structures. Therefore, workers who spent most of their time in the "A" structures can be considered to have little or no potential for intakes (other than radon) (Lamb Associates and Halliburton NUS 1996).

"C" structures had a ventilation system designed to prevent release of uranium oxides to the atmosphere, indicating preparations for potential airborne hazards.

Procedures used for maintenance described steps during which there were checks for alpha contamination on the outside of containers, indicating knowledge of the potential for contamination. A procedure described the use of a Plexiglas glovebox, presumably to minimize or prohibit airborne contamination; other procedures described removing the oxidized DU during maintenance (Lamb Associates and Halliburton NUS 1996).

No records were found indicating bioassays were performed or internal dose was assessed for workers at Clarksville Base. Mr. Rarrick indicated that some in-house tritium urinalysis was performed during the Sandia years (McConn 2006). A letter dated March 22, 1961, indicated that there were procedures in place for air sampling in the assembly cell as well as procedures for a radiological urinalysis kit (Higgins 1961). However, no data were found for air samples or urinalyses.

5.1 TRITIUM EXPOSURE

Tritium intakes could have occurred and probably did occur to a certain extent during disassembly and maintenance of weapons at Clarksville Base. Review of CATI documents confirmed that tritium monitoring occurred, indicating the understanding that tritium intakes were possible. The actual date that tritium arrived at the site is unknown, but it appears to have been between 1954 and 1958. It is believed that the tritium reservoirs came from the Savannah River Site, which would make late 1955 the earliest date for tritium exposure at Clarksville Base (Bebbington 1990, page 52). However, in this Site Profile, a date of 1954, which is favorable to claimants, was assumed.

5.1.1 Operation Years (1949–1965)

The technology of tritium use in nuclear weapons is classified. No air sample or tritium bioassay results for Clarksville Base were found. Because MHSMC operated Clarksville Base (from around 1958 to closing in 1965), Pantex Plant, Medina Base, and IAAP, material and procedures at Clarksville are assumed to be similar to those at Pantex and IAAP, except Clarksville did not do original assemblies (ORAUT 2005b, 2006a). Hundreds of tritium bioassay results were obtained at Pantex in the 1970s and 1980s. The largest internal dose at Pantex from tritium recorded during any

year in this period, with the exception of a major accident, was 122 mrem. Using the standard calculation for tritium in the 1970s, which used a quality factor of 1.7 [based on International Commission on Radiological Protection (ICRP) Publication 10 (ICRP 1968) and explained in U.S. Nuclear Regulatory Commission Regulation (NUREG)-0938 (Brodsky 1983)] (1.5-mCi uptake resulted in 425 mrem), 122 mrem was indicative of a chronic annual uptake of 430 µCi of tritium. The uptake calculated using ICRP Publication 10 methodology accounts for tritium in body fluids from any intake mode.

The 122-mrem maximum dose at the Pantex Plant was recorded in the years when Pantex was performing more disassemblies. In only one other year was there a dose over 100 mrem for normal operations at Pantex (ORAUT 2006a). This can be assumed to imply that it is a bounding dose. Disassembly is similar to maintenance activities that were likely to occur at Clarksville Base. Lacking any information on tritium bioassay at Clarksville or additional information on activities at the site, 122 mrem can be considered a reasonable surrogate dose for production operators from 1954 through the closing of Clarksville operations in 1965.

Workers whose job categories were Production Operators, Inspectors, and Quality Control Specialists and who worked at Clarksville Base between 1954 and 1965 were the most likely people to receive the dose discussed above.

As discussed in Section 4.0, an accident involving a damaged weapon returned to Clarksville Base from the military apparently leaked tritium (Bihl 2006a). No documentation of the accident or any information about the amount of tritium that might have leaked has been found. The CATI indicated that the accident occurred in 1962.

For consistency with the assumptions made for environmental doses from the alleged accident, the accidental release of tritium during a disassembly in 1989 at the Pantex Plant was used as a basis for assigning doses to workers involved in the event at Clarksville Base (ORAUT 2006a). The event at Pantex was a major release that was unstopped causing severe contamination of a cell. It is unlikely that the leak at Clarksville could have been worse than the estimated release at Pantex of 40,000 Ci over 12 d. As noted in Section 4, the CATI indicated that the leak at Clarksville was stopped within half a day once the weapon was brought into a cell. The leak rate was probably much slower than that of the Pantex leak; otherwise, the tritium would have leaked out before the weapon was returned to Clarksville Base from the military.

Tritium urinalysis samples were collected from workers exposed to the Pantex accident. The maximally exposed worker had 460 µCi/L in a sample representing the first 24 hr after intake and 365.1 µCi/L in a spot sample taken 48 hr after the intake. [Other samples were taken but they were affected by medical treatment so were not used in this surrogate calculation.] Using the Integrated Modules for Bioassay Analysis (IMBA) software code Version 4.0.9, the acute intake was determined to be 1.8×10^{10} pCi and the resulting committed equivalent dose was determined to be 1,200 mrem, which is consistent with the Pantex assigned dose of 1,180 mrem. Because the maximally exposed worker was the person who loosened the nut that started the leak and had his face nearest the source, it is unlikely that anyone at Clarksville received as great an intake. Therefore, the distribution should be considered an upper bound. Because all the workers who came in contact with the damaged weapon before the leak was stopped are not known, the intake would apply to any production operator, quality specialist, or quality control inspector at the site in 1962.

One operator was sent back into the cell to stop the leak. The CATI indicated that this person was wearing protective clothing and respiratory protection appropriate for tritium (Scott air pack). Therefore, the above intake is considered an appropriate upper bound intake for that worker as well.

The material handler who picked up this weapon from the military airport and transported it to a storage area was told the next day that he had also been contaminated (Bihl 2006a). Although his exposure conditions were different than those in the cell – mostly outdoors with some time near the weapon in the storage igloo − the intake for the maximally exposed worker at Pantex is judged to be a sufficient upper bound to apply to the specific material handler as well. Do not apply this intake to all material handlers. The material handler involved has been identified (Bihl 2006a).

5.1.2 Postoperative Years (1966–1967)

Last, Gilmore, and Bronson (1998) performed radiological surveys of the 7740 tunnel complex in 1997, which included the sampling of water in floor drains and sumps. Tritium was detected at 2.4 pCi/mL in one sump under the central corridor. This concentration is at or maybe slightly above fallout levels in surface water in North America. Adjusting for physical decay to 1966 and making the gross overestimate of ingestion of 1 L/d at this concentration, the annual dose to any organ is less than 1 mrem. Intake by inhalation of water vapor around the sump would be much less, so tritium intake in 1966 and 1967 can be disregarded.

5.2 URANIUM EXPOSURE

DU oxide was known to be present, but apparently was not considered a significant enough internal hazard to warrant bioassay. No records were found indicating that bioassay was performed on workers to determine uptake of DU. However, according to Harold Rarrick, portable gloveboxes with HEPA-filtered exhausts were used to contain oxidized DU when weapons underwent inspections, maintenance, and refurbishment during the Sandia years (McConn 2006, Lamb Associates and Halliburton NUS 1996). The DU was cleaned from the nuclear components and deposited as solid waste on cleaning rags. Mr. Rarrick mentioned that the DU contamination came from spalling, which produced large unrespirable particles. Use of the glovebox indicates knowledge that DU might be in the environment and that containment was at least a good practice. Disassembly and maintenance activities at Clarksville Base during the MHSMC years were similar to those performed at the Pantex Plant and IAAP.

Intakes of DU might have occurred during disassembly and maintenance of weapons containing oxidized DU. DU emits less radiation per gram than natural uranium. By weight, DU is essentially pure ^{238}U. Isotopic abundances of ^{234}U and ^{235}U in DU can vary, but those isotopes generally contribute less than 10% of the alpha radioactivity. The dose reconstructor can use the isotopic abundance for DU in the IMBA computer program.

Concerning the inhalation absorption type, the *Pantex Internal Dosimetry Technical Basis and Quality Assurance Document* states that “the compounds of uranium at Pantex are pure metal or air-oxides; it is assumed that all forms encountered will exhibit class Y aerosol behavior” (BWXT Pantex 2001a, Section 13.2.1). Table 7.3 of that document indicates that ^{238}U should be considered 20% class D and 80% class Y. Uranium contamination at Clarksville Base is assumed to be similar to that at the Pantex Plant. The most likely form of uranium at Clarksville would be very insoluble, associated with lung absorption type S and a gastrointestinal-tract-to-blood uptake factor, f1, of 0.002. However, uranium oxides can exist in many states, and it might be too simplistic to assume a pure absorption type when the chemical form is not known for certain. Dose reconstructors should assume either type M or type S to maximize the dose to the organ of concern. Exposure to type F uranium at Clarksville is not credible.

5.2.1 Operation Years (1949–1965)

Experience at the Pantex Plant indicated that "about a half of a cup" (118 cm^3) of oxidized DU was available for resuspension (ORAUT 2006a). The density of UO_2 is 11 g/cm^3; thus, the estimated mass of UO_2 is approximately 1,300 g, of which about 1,140 g is DU [(238/270)(1,300g) = 1,140 g]. Interviews with people familiar with Clarksville Base never gave the impression that this much oxide was present, so using this value should provide an upper bound. No benefit is given for use of the glovebox that was mentioned in several interviews and in the site assessment (Lamb Associates and Halliburton NUS 1996).

The airborne release fraction and respirable fraction were obtained from a DOE handbook using the scenario described as the free fall spill of UO_2 powder from a height of 1 m (DOE 1994). The median value for the airborne release fraction was 0.00008, and the respirable fraction was 0.5. The assumed volume of air into which the contamination was suspended was 27 m^3, a volume judged to represent the immediate work area, not the volume of the entire cell. The material was assumed to be quickly dispersed into that volume. The immediate air concentration was then:

$$(1{,}140\ g)(0.00008)(0.5)/27\ m^3 = 1.689 \times 10^{-3}\ g/m^3 \qquad (5\text{-}1)$$

This air concentration was reduced over time by ventilation. The concentration as a function of time is given by:

$$C(t) = C_i e^{(-Qt/V)} \qquad (5\text{-}2)$$

where C_i is the initial room concentration and $C(t)$ is the concentration at any later time t, Q is the ventilation air flow rate, and V is the volume of the contaminated air (Caravanos ca.1990). The air exchange rate (a in Equation 5-3), is Q/V, so Equation 5-2 can be written as:

$$C(t) = C_i e^{(-at)} \qquad (5\text{-}3)$$

When this is integrated over an 8-hr work shift, the concentration-time exposure time is:

$$\textit{Concentration-time} = C_i[1-e^{(-8a)}]/a \qquad (5\text{-}4)$$

The air exchange rate is not known, but there was concern about control of the explosives, for both fire hazard and toxicology reasons. Ventilation standards are usually based on certain air flow rates per person of occupancy with additional considerations for reducing concentrations of hazardous materials. The 1989 standards range from 15 to 30 ft^3/min per person for places like bars or dry cleaners on the high end to reception areas, hotel lobbies, and supermarkets on the low end (ASHRAE 1989). Typical occupancy during disassemblies was 4-5 people[2], so the air flow was probably about 150 ft^3/min or 9,000 ft^3/hr, or maybe more because of the special concerns for the explosives. At Pantex the volume of the Gravel Gerties was about 14,000 ft^3 and volume of the various bays ranged from about 10,000 to 30,000 ft^3 (BWXT 2001b). Based on this information, an air exchange rate of 0.5/hr was assumed. (Note: the recommended air exchange rate for living areas of a house is 0.35/hr (ASHRAE 1989), so an air exchange rate of 0.5/hr for an industrial setting handling toxic material seems favorable to claimants.) Therefore, the concentration time for each work day is:

$$(0.001689\ g/m^3)(1-0.01832)/0.5 = 0.003316\ g\text{-}hr/m^3 \qquad (5\text{-}5)$$

[2] Personal communication, Jerry Martin, former manager of the Radiation Safety Department, 2006.

Applying the 1.2 m^3/hr breathing rate, the total intake was 3.99×10^{-3} g or 1,600 pCi. This applies to each weapon disassembled.

The resulting initial air concentration is an order of magnitude greater than the 1959 uranium air concentration limit. Although it is unlikely that the amount of oxidized DU estimated above was present in all cases, especially in the early years, the assumption was made that the potential for intake of this quantity did exist throughout the covered period at Clarksville Base (1949 to 1965). Not all weapon programs exhibited oxidized DU components. According to the Pantex Internal Dosimetry TBD, fewer than a third of the weapons disassembled at the Pantex Plant had noticeable oxide and only two had significant contamination (ORAUT 2006a). Because NIOSH cannot publicly identify programs that had significant DU oxidation, the intake assumption is applied to all maintenance and disassembly work over the operational period.

For dose reconstruction, it was assumed that during the Sandia years, which involved some training, inspection, and replacement of Po-Be initiators, on average 50 surveillance/disassembly operations might be conducted by a single worker per year with the potential for internal exposures to the quantity of DU estimated above. To account for an increased rate of disassembly and modification during the MHSMC years, it was assumed that any production operator might have been involved in 100 operations per year with potential for significant contamination. The intake should be modeled as a chronic annual inhalation of 80,000 pCi of DU (219 pCi/d), as a constant upper bound for 1949 through 1957, and twice that rate for 1958 through 1965.

Ingestion of DU settling out of the air on drinks or foodstuffs or transfer from hands to cigarettes or food cannot be ruled out. Guidance for determining ingestion intakes from air concentration is provided in *Estimation of Ingestion Intakes* (NIOSH 2004). The estimated ingestion intake from air concentration is:

$$\textit{ingestion daily intake} = (0.2)(\textit{air concentration in pCi/m}^3) \qquad (5\text{-}6)$$

where the air concentration is intended to be the average concentration, not the initial concentration. Dividing the concentration-time value in Equation 5-5 by an 8-hr shift gives an average air concentration of 4.14×10^{-4} g/m^3. Then:

$$\text{ingestion daily intake} = (0.2)(4.14 \times 10^{-4}\ \text{g/m}^3)(4.02 \times 10^5\ \text{pCi/g}) = 33\ \text{pCi} \qquad (5\text{-}7)$$

where 4.02×10^5 is the specific activity of DU. The material would have been insoluble (f1 = 0.002). As for inhalation intakes, the 33 pCi is per weapon. For 1949 to 1957, the daily intake from 50 weapons per year would have been 4.6 pCi/d; for 1958 to 1965, the intake is 9.1 pCi/d.

5.2.2 Postoperative Years (1966–1967)

Casual exposure to residual DU contamination after operations ceased is possible. According to Last, Gilmore, and Bronson (1998), "[t]he Defense Nuclear Security Agency conducted a closeout radiological survey in July 1970 to determine if Clarksville Base had any radioactive contamination. The study found elevated levels of indoor radon, but concluded that no radiological health hazards existed in Building 318 [numbered 7740 in the Last survey]." The surveys conducted for the Last, Gilmore, and Bronson study found no contamination above release criteria. For removable contamination of natural uranium, ^{235}U, or ^{238}U, the criterion was less than 1,000 dpm/100 cm^2. Assuming a passive resuspension factor of 10^{-6}/m, and given that:

$$1{,}000\ \text{dpm/100 cm}^2 = 10^5\ \text{dpm/m}^2 \qquad (5\text{-}8)$$

the air concentration of uranium above a surface contaminated just at the release criterion would be:

$$(10^5 \text{ dpm/m}^2)(10^{-6}\text{/m})/2.22 \text{ dpm/pCi} = 4.5 \times 10^{-2} \text{ pCi/m}^3 \quad (5\text{-}9)$$

After weapons and nuclear material were removed from the site, it is unlikely that workers entered potentially contaminated areas more than a few hours a month for minor maintenance or general surveillance. An occupancy factor for exposure to airborne contamination of 0.02 was assumed. Therefore, a chronic intake of uranium if all surfaces were contaminated just at the release criterion would be:

$$\text{intake} = (4.5 \times 10^{-2} \text{ pCi/m}^3)(1.2 \text{ m}^3\text{/hr})(2{,}000 \text{ hr/yr})(0.02)/365 \text{ d/yr}) = 0.0059 \text{ pCi/d} \quad (5\text{-}10)$$

Because all measurements were reported as simply less than the release criterion, the above calculation is analogous with a missed dose calculation; therefore, the intake distribution should be considered a triangular distribution with a minimum of zero, a mode of 0.0030 pCi/d, and a maximum of 0.0059 pCi/d.

5.2.3 DU from Burning Grounds

The 1996 site assessment states that during the years that Clarksville performed modifications and disassemblies:

> *The high explosive portion of the weapon was a casting that contained paper and felt materials. Toluene was used to partially dissolve the high explosive to separate it from the paper and felt during the disassembly process. The solvent and explosives mixture was burned at a site outside of Clarksville Base.* (Lamb Associates and Halliburton NUS Corporation 1996)

It is not known if MHSMC employees performed the burns; however, two interviews with claimants imply that MHSMC employees did perform the burns, and site operator employees performed the burns at IAAP, Pantex, and Medina (ORAUT 2005b, 2006a; Bihl 2006c). Therefore, it is assumed that this task was performed by MHSMC employees.

Usually there was some DU contamination associated with the high explosives. Air sample measurements were made for a similar operation at Pantex (ORAUT 2006a). There is no information concerning the amount of high explosives or DU contamination burned at Clarksville; therefore, it was assumed that the air concentrations and intakes by the burning ground operators were represented by the Pantex operation. The assessment of the Pantex operation indicated that the highest exposure occurred during the cleanup of the contaminated ash. The estimated intake at Pantex was 130 pCi/d of DU based on the 95th-percentile air concentration for the cleanup activities. It is assumed this intake rate applies as well to Clarksville workers involved in burning high explosives. The intake is an upper-bound estimate so the distribution is a constant. Because incomplete oxidation of the DU can occur during these operations, dose reconstructors should assume either absorption type M or S (ORAUT 2006a). The intake would apply only to 1958 through 1965 and only to workers who burned high explosives (not a common task).

(Because the burn did not occur at Clarksville, no environmental dose to Clarksville workers was assigned.)

5.3 PLUTONIUM OR POLONIUM EXPOSURE

Mr. Rarrick believes that during the Sandia years no significant spread of contamination of plutonium occurred based on reports from the Sandia safety inspectors from the various WSAs (Rarrick 2006; Lamb Associates and Halliburton NUS Corporation 1995). The plutonium was plated and nothing was purposely done to compromise the barrier between the plutonium and the workspace. During the process of removing the Po-Be initiators, the parts were smeared and counted for alpha contamination. In general, the alpha contamination was less than 100 dpm with a few leaks in the early days slightly exceeding 100 dpm, but not significantly (Rarrick 2006). Mr. Phillips indicated that at Medina and Pantex during the MHSMC years, the incoming nuclear component was promptly surveyed for alpha contamination and cleaned before being placed into storage or the cells (Bihl 2006c). The procedure at Clarksville during the MHSMC years has not been discovered but was likely to be similar to the procedure at Medina and Pantex. An assumption was made that workers were possibly exposed for a short time to plutonium contamination on the internal parts during disassembly. Assuming 100 dpm alpha/100 cm^2 (100 cm^2 is the industry standard area for smears) and a resuspension factor for indoor work of 5×10^{-5}/m (IAEA 1970), the air concentration is calculated as:

$$100 \text{ dpm}/100 \text{ cm}^2 = 1 \text{ dpm/cm}^2 \qquad (5\text{-}11)$$

$$\text{air concentration} = (1 \text{ dpm/cm}^2)(10^4 \text{ cm}^2/\text{m}^2)(5 \times 10^{-5}/\text{m}) = 0.5 \text{ dpm/m}^3 = 0.225 \text{ pCi/m}^3 \qquad (5\text{-}12)$$

The above calculation works for general room concentration from large contaminated surfaces or for small volumes of air immediately above small surfaces. Neither condition would have applied to the disassembly workers for the whole shift; however, contamination levels might have exceeded 100 dpm on occasion. On balance, and to be favorable to claimants, the above air concentration was assumed to exist for all work hours. The daily inhalation intake was, therefore:

$$\text{intake} = (0.225 \text{ pCi/m}^3)(1.2 \text{ m}^3\text{/hr breathing rate})(2{,}000 \text{ hr/yr})/365 \text{ d/yr} = 1.5 \text{ pCi/d} \qquad (5\text{-}13)$$

Ingestion intakes resulting from contaminated surfaces and airborne contamination cannot be ruled out. For estimating ingestion resulting from contamination inside buildings, NIOSH recommends a daily ingestion of 0.2 times the air activity per cubic meter (NIOSH 2004). Therefore, the daily ingestion would have been:

$$\text{ingestion intake} = (0.2)(0.225 \text{ pCi/m}^3) = 0.045 \text{ pCi/d} \qquad (5\text{-}14)$$

These intakes should be applied to production operators and nuclear component inspectors for the operative years for in-flight insertable designs (1949 to 1958). Because the calculations ignore the prompt cleanup of components upon disassembly and the use of gloveboxes during cleaning (Lamb Associates and Halliburton NUS Corporation 1996, Martin 2006a), these intakes should be considered constant upper bounds.

The alpha contamination could have been either plutonium or ^{210}Po. The dose reconstructor should use whatever radionuclide is most favorable to the claimant. The plutonium mixture would have been weapons grade. The age since original separation from the ^{241}Am would have varied, but an assumption of 10-yr-old mixture is reasonable. The plutonium would have been oxidized, so inhalation type S and an f_1 of 1×10^{-5} should be used (ICRP 1994).

If the contamination is assumed to be ^{210}Po, because the chemical form is classified, the dose reconstructor should use inhalation type F or M, whichever is favorable to the claimant. For polonium the only f_1 listed is 0.10 (ICRP 1994).

No plutonium or ^{210}Po intakes should be assigned during the period of sealed pits or during the postoperative years.

5.4 ASSESSING OCCUPATIONAL INTERNAL DOSE FROM ELEVATED RADON CONCENTRATIONS

Uranium occurs naturally in virtually all soils, with average levels of about 1 ppm. Radium-226 is typically in secular equilibrium with ^{234}U and decays to ^{222}Rn with a half-life of 1,600 yr. Therefore, the noble gas ^{222}Rn is continuously produced in soil where it can be trapped in the crystalline structure of minerals or released to the interstices between solid materials and eventually diffuse out of the soil and into the airspace.

In general, structures that exhaust air to the environment without adequately engineered replacement air have higher indoor radon levels than structures that do not do this, and structures that have exposed soil (dirt floors, sumps) or exposed minerals (e.g., gravel) tend to have higher radon levels. Underground structures have a higher ratio of soil surface to building volume. All other factors being equal, an underground building would be likely to have a higher radon concentration than an above-ground building.

5.4.1 Radon Concentrations

Radon concentrations were measured at Clarksville Base on several occasions from 1971 through 1986. A listing of all radon measurements up to March 1984 is provided in a memorandum from the Chief of the Fort Campbell Preventive Medicine Service to the Deputy Post Commander (Vaeth 1984). The radon levels in the underground tunnel building (7740) are listed in Table 5-1.

Table 5-1. Radon concentrations in the 7740 Building[a].

Date sampled	Agency performing sampling	Sample results (pCi/L)
June 7–17, 1971	AEHA	152.48
April 5–6, 1976	USAPMS	14.6 43.4
November 20, 1981	USAPMS	21.4 33.4

a. From Last, Gilmore, and Bronson (1998).

Another set of radon measurements was made by the U.S. Army Environmental Hygiene Agency (AEHA) in 1986 (AEHA 1986). A summary discussion of these measurements is provided in *Relative Risk Site Evaluation for Buildings 7740 and 7741 Fort Campbell, Kentucky* (Last, Gilmore, and Bronson 1998). Building 7740 was not sampled in the 1986 study; it was unoccupied and sealed at the time of the sampling. Neither how the sampling was conducted nor the time of day of the sampling was mentioned in the Vaeth memorandum. However, with the tunnel complex sealed and unventilated, it is probable that diurnal fluctuations were dampened. The three sets of sampling were conducted in different seasons (November, April, June). Table 5-2 lists results of sampling in other Clarksville structures. The AEHA sampling technique in 1986 was a 1-L grab sample of air obtained about 1 m above the floor with laboratory analysis of the sample at the Aberdeen Proving Ground. Table 5-3 lists statistical parameters from the radon concentration measurements. There is a distinct difference between concentrations in the tunnel complex and those in other structures expected to have high radon concentrations. The statistics for the tunnel complex are strongly influenced by the

Table 5-2. Radon concentrations in Clarksville structures.

Type of structure	Number	Date sampled	Sample results (pCi/L)
Igloo	7704	June 7–17, 1971	8.60[a]
		November 20, 1981	3.90[a]
Igloo	7708	June 7–17, 1971	4.53[a]
		October 30, 1981	3.20[a]
Igloo	7726	June 7–17, 1971	15.86[a]
		October 30, 1981	9.70[a]
Igloo	7728	February 26-27, 1979	0.60, 0.50, 0.20, 0.10[a]
Above-ground, concrete ceiling, and 10-ft thick concrete walls	7724	September 29, 1981	3.30[a]
Hallway outside Gravel Gertie	7811	March 3, 1986	8.9 ± 0.3[b]
Inside Gravel Gertie	7811	March 3, 1986	10 ± 0.4[b]

a. From Vaeth (1984).
b. From AEHA (1986).

Table 5-3. Statistical parameters of radon concentrations.

Type of structure	Parameter	Concentration (pCi/L)
7740 tunnel complex	Average	53
	Standard deviation	57
	Geometric mean	37
	GSD	2.4 (unitless)
Igloos, Gravel Gertie, 7724 Bldg	Average	5.3
	Standard deviation	4.9
	Geometric mean	2.5
	GSD	5.2 (unitless)

measurement taken in 1971. However, even if that one result is ignored, the median concentration for the tunnel complex would be notably higher than the median for the igloos and Gravel Gertie.

5.4.2 Dose from Radon-222 Progeny

Radon itself produces far less dose to the bronchial epithelium than its progeny. Because radon progeny measurements are more difficult to obtain, measurements of radon are often used as a surrogate for progeny measurements. Radon progeny concentrations are expressed as the quantity *potential alpha energy concentration* (PAEC), traditionally measured in working levels (WLs). One WL is equivalent to 100 pCi/L of radon in equilibrium with its short-lived decay products. Time-integrated exposures to radon progeny are expressed in the quantity *potential alpha energy exposure* (PAEE), which is traditionally measured in working level-months (WLMs) and defined as exposure to 1 WL for 170 hr or any equivalent concentration and time product.

The Clarksville measured radon concentrations were converted to equilibrium-equivalent concentrations by multiplying the radon concentration by the equilibrium factor *F*. A value of 0.4 is recommended by the ICRP (1981) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1993) for homes and buildings. However, a higher equilibrium factor might be appropriate for poorly ventilated underground rooms or tunnels. Therefore, an equilibrium factor of 0.7 was applied to the igloos and the tunnel complex [e.g., see Table XVIII in the *DOE Standard – Internal Dosimetry* (DOE 2003)]. The equilibrium equivalent concentration was divided by 100 pCi/L/WL to arrive at the PAEC. These operations were combined to create:

$$PAEC = C \times F/100 \text{ pCi/L/WL} \qquad (5\text{-}15)$$

where *C* is the radon concentration in picocuries per liter and *PAEC* is in WLs. To determine WLM for input to IREP, WLs are multiplied by an occupancy time in terms of hours per month/170 and the number of months of exposure per year. In general, material handlers were in and out of igloos and similar storage areas for less than a couple of hours per workday, so an occupancy factor of 0.4 was used. It was assumed that inspectors and production operators were in the tunnel complex or Gravel Gertie full-time, so an occupancy factor of 1.0 was used. For other nonadministrative job categories (e.g., crafts, security), some time in the igloos or tunnel complex could not be ruled out, so an occupancy factor of 0.1 was used. From claimant interviews, it appears that even administrative personnel occasionally entered the tunnel complex or other storage sites; for instance, an accountant claimed to spend 1 week a year in the storage areas. For administrative personnel, an occupancy factor of 0.02 was assumed. For instance, the WLM for a production operator in the tunnel complex would be

$$(37\ \text{pCi/L})(0.7)(1.0)(12\ \text{mo})/100\ \text{pCi/L/WL} = 3.1\ \text{WLM/yr} \qquad (5\text{-}16)$$

Table 5-4 lists WLMs for job categories.

Table 5-4. Working level-months for Clarksville workers.

Job description	Assumed location	Years	Assumed occupancy factor	Working level mo/yr[a] (GSD)
Production operator, any inspector, quality control specialist	7740 tunnel complex	1949–1958	1.0	3.1 (3)
Production operator, any inspector, quality control specialist	Gravel Gertie	1959–1965[b]	1.0	0.21 (5)
Material handler	7740 tunnel complex	1949–1958	0.4	1.2 (3)
Material handler	Igloos, Gravel Gertie	1959–1965	0.4	0.084 (5)
Other nonadministrative	7740 tunnel complex	1949–1958	0.1	0.31 (3)
Other nonadministrative	Igloos, Gravel Gertie	1959–1965	0.1	0.021 (5)
Administrative	7740 tunnel complex	1949–1958	0.02	0.062 (3)
Administrative	Igloos, Gravel Gertie	1959–1965	0.02	0.0042 (5)
Facility surveillance, minor maintenance after shutdown	Igloos, Gravel Gertie	1966–1967	0.02	0.0042 (5)

a. Can prorate for partial year by multiplying by x/12 where x is the number of months exposed in a year.
b. The change in dates approximately coincides with the construction and use of the Gravel Gertie.

5.5 SUMMARY OF INTAKES

Table 5-5 summarizes occupational intakes (not including environmental).

Table 5-5. Occupational intakes.

Job category or task	Dose calculation parameters					IREP input parameters		
	Period	Material	Mode	Absorption type	pCi/d	Distribution type	1	2
Production operator, nuclear components inspector, quality control specialist	1954–1965	Tritium	Chronic inhalation and skin absorption (model as injection)	NA	1.3E7	Constant	Dose	
Production operator, nuclear components inspector, quality control specialist	March 1962	Tritium	Acute inhalation and skin absorption (model as injection)	NA	1.8E10 pCi	Constant	Dose	
Production operator, nuclear components inspector, quality control specialist	1949–1958	DU	Chronic inhalation, Ingestion	M, S Insoluble	2.2E2 4.6	Constant Constant	Dose Dose	
Production operator, nuclear components inspector, quality control specialist	1959–1965	DU	Chronic inhalation, ingestion	M, S Insoluble	4.4E2 9.1	Constant Constant	Dose Dose	
Production operator, nuclear components inspector, quality control specialist	1949-58	Pu weapons grade, 10 yr; or Po-210	Chronic inhalation ingestion	Pu: S Po: F or M Pu: insoluble	1.5 0.045	Constant Constant	Dose Dose	
Production operator, **any** inspector, quality control specialist	1949–1958	Radon	Chronic inhalation	NA	NA	Lognormal	3.1 WLM/ 12 mo	3
Production operator, **any** inspector, quality control specialist	1959–1965	Radon	Chronic inhalation	NA	NA	Lognormal	0.21 WLM/ 12 mo	5
Material handler	1949–1958	Radon	Chronic inhalation	NA	NA	Lognormal	1.2 WLM/ 12 mo	3
Material handler	1959–1965	Radon	Chronic inhalation	NA	NA	Lognormal	0.084	5
Individual material handler involved in 1962 damaged weapon	March 1962	Tritium	Acute inhalation and skin absorption	NA	1.8E10 pCi	Constant	Dose	
Burning of high explosives	1959-1965	DU	Chronic	M or S	130	Constant	Dose	
Other nonadministrative	1949–1958	Radon	Chronic inhalation	NA	NA	Lognormal	0.31	3
Other nonadministrative	1959–1965	Radon	Chronic inhalation	NA	NA	Lognormal	0.021	5
Administrative	1949–1958	Radon	Chronic inhalation	NA	NA	Lognormal	0.062	3
Administrative	1959–1965	Radon	Chronic inhalation	NA	NA	Lognormal	0.0042	5
Surveillance after shutdown	1966-67	DU	Chronic inhalation	M, S	0, 3.0E-3, 5.9E-3	Triangular	(a)	(a)
Surveillance after shutdown	1966-67	Radon	Chronic inhalation	NA	NA	Lognormal	0.0042	5

a. Parameter 1 is zero dose; parameter 2 is the mode dose based on the 0.003-pCi/d intake; parameter 3 is the maximum dose based on the 0.0059-pCi/d intake.

6.0 OCCUPATIONAL EXTERNAL DOSE

6.1 INTRODUCTION

Workers at Clarksville Base 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 Base 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 (BWXT Pantex 2001c).

There were three major groupings of workers at Clarksville. AEC employees served primarily in oversight positions and generally did not perform hands-on work. Sandia, 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 Sandia or MHSMC employees; the military primarily loaded the weapons onto airplanes and performed any in-flight operations that were necessary.

6.2 EXTERNAL RADIATION DOSIMETERS AND RECORDS

External dosimetry records for Clarksville Base 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 Sandia personnel 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 Base, containing weekly dose information for a few workers from October 1960 to 1965. Although MHSMC began its management of Clarksville Base 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 that NTA film was used for neutron dosimetry has not been determined. Mr. Rarrick 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 out of nearly 3,900 individual weekly film badges (Tracerlab 1965).

6.2.1 Historical Administrative Practices

Clarksville Base 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; and 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.

Table 6-1. Dosimeter type, period of use, exchange frequency, MRD, and MDL (Martin 2005).

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 though 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.

The routine practice at Clarksville Base 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 later in this Site Profile.

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). Mr. Rarrick 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 Mr. Rarrick.

The first commercial dosimeter used by MHSMC at Clarksville Base 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 to 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.

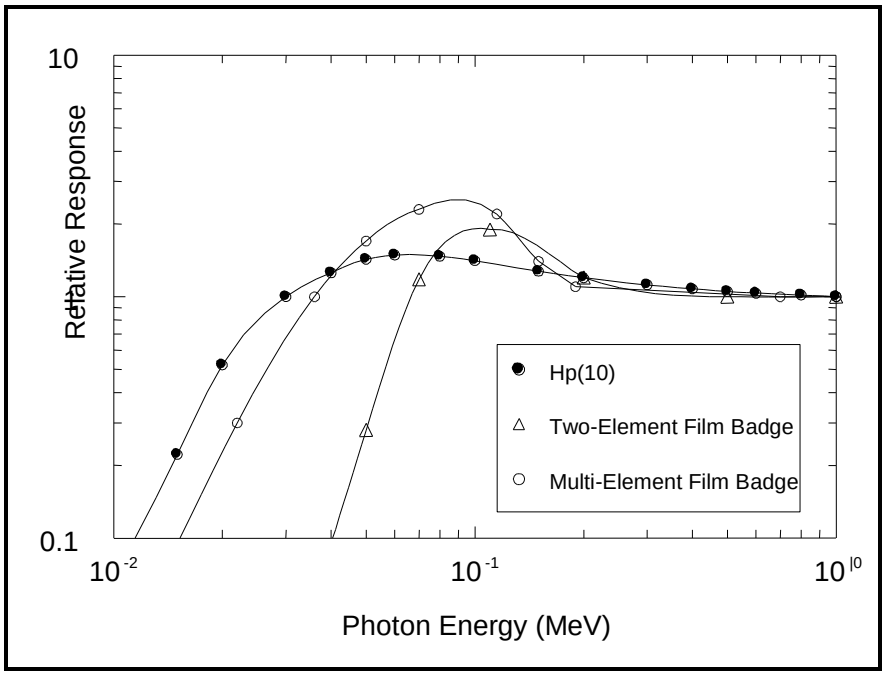

Figure 6-1. Comparison of *Hp(10)* for photons with energy responses for sensitive DuPont 502 emulsion in two-element film badge (Pardue, Goldstein, and Wollan 1944) and sensitive DuPont 555 emulsion in multielement film badge (Thornton, Davis, and Gupton 1961).

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; ORAUT 2006b). 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 made 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 concerning 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 Base 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.

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 d. 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, Slayback, 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

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.

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 (ORAUT 2005c). 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 Base 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, Slayback, and Birky 1998). The ratio of neutron dose to photon dose produced by the α/n reaction was approximately 4 (Shleien, Slayback, 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, Slayback, 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 Base and the Pantex Plant were similar. The Pantex data were analyzed by Strom (2004), and neutron-to-photon dose ratios were determined where the neutron and photon doses were greater than 50 mrem/yr. The median ratio is 0.7915 (rounded to 0.8) and the 95th-percentile ratio from this distribution is 1.603 (rounded to 1.6). 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 1.6 derived from the analysis of data from dosimeters accredited by the DOE Laboratory Accreditation Program. Applying an annual neutron-to-photon dose ratio of 1.6 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, Slayback, 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 1.6 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, from ORAUT (2006c), 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 Base, 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 that 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 of 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 Base 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 2006c) 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 Base, 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 Base. For those same years, assumed Exposure Group 2 photon doses were one-half of the median photon dose received at the Pantex Plant for the year the worker was employed at Clarksville Base (Table 6-8); and one quarter of the median doses were assumed to apply to Exposure Group 3 (Table 6-9).

Table 6-5. Pantex worker photon dose statistics.

Year	Annual recorded photon dose data[a]			Lognormal fit		
	No. of workers reported photon dose >50 mrem	Dose (mrem)		Dose (mrem)		GSD
		Mean	Maximum	Median	95%	
1952–58	(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.

Year	No. of dosimeters[a]	Monthly and annual photon dose data (mrem)			
		Monthly		Annual	
		50th	95th	50th	95th
1952-58	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
7/1949–1956	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
7/1949–1956	Neutron	Any	Neutron dose = 4 × photon dose
1957–1965	Neutron	Any	Neutron dose = 1.6 × photon dose
7/1949–1965	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
7/1949–1956	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
7/1949–1956	Neutron	Any	Neutron dose = 4 × photon dose
1957–1965	Neutron	Any	Neutron dose = 1.6 × photon dose
7/1949–1965	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
7/1949–1956	Photon	None	260 mrem/yr (constant upper bound)
1957–1960	Photon	None	260 mrem/yr (constant upper bound)
1961–1965	Photon	None	1/4 median from Table 6-6, with GSD from Table 6-5
7/1949–1956	Neutron	Any	Neutron dose = 4 × photon dose
1957–1965	Neutron	Any	Neutron dose = 1.6 × photon dose
7/1949–1965	Neutron	Any	Multiply assigned neutron dose by 1.91[a]

a. ICRP (1991) weighting adjustments

For the Sandia 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 Mr. Rarrick's 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 nine Sandia 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.

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 Mr. Rarrick (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 Base for the Sandia 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.

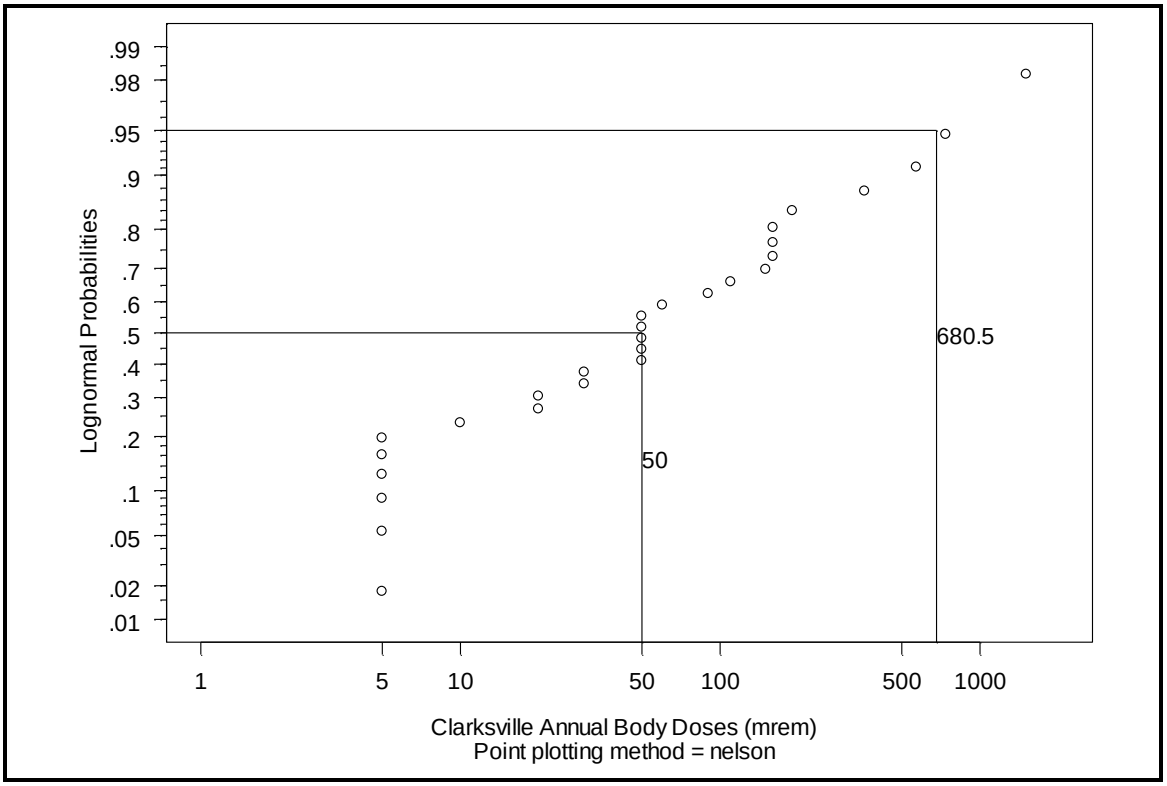

Figure 6-2. Log probability plot of annual doses received by monitored workers at Clarksville Base, 1949 to 1958.

For all workers, neutron doses should be assigned as indicated in Tables 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 GSD listed in Table 6-5 can be used.

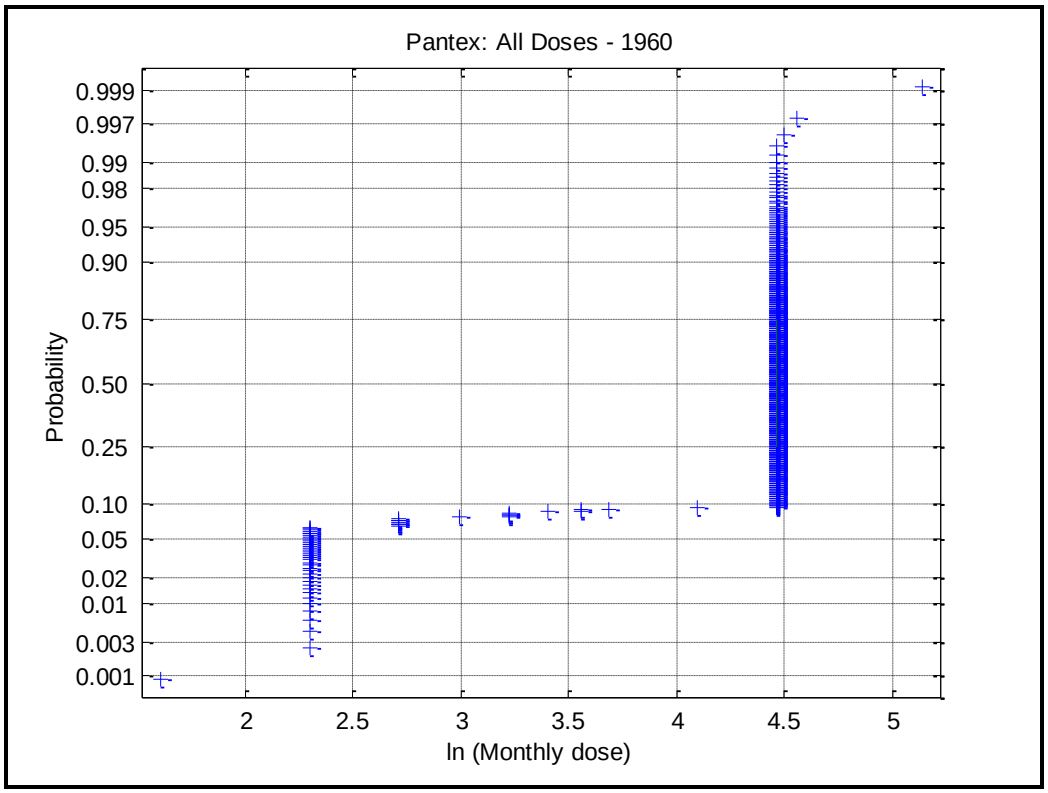

Figure 6-3. Log probability plot of Pantex dosimetry data that includes missed doses.

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 identical to Pantex data (ORAUT 2006c).
b. Exchange frequencies were established from dosimetry reports and the Rarrick 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 Office 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 Base (i.e., film badge era), use the conversion factor from exposure to organ dose.

Some workers at Clarksville Base, generally production operators, operators, or operator trainees, might have handled unshielded pits with gloved hands. The dose rate at the bare surface of plutonium metal is approximately 4 rem/hr for the total of both 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.

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 1966–1967, 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-yr 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

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

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

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GLOSSARY

U.S. Atomic Energy Commission (AEC)
Original agency established for nuclear weapons and power production; a predecessor to the U.S. Department of Energy.

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

bremsstrahlung
Secondary photon radiation emitted by a charged particle under acceleration such as X-rays emitted by an electron that is scattered by a nucleus. From German meaning *brake radiation*.

depleted uranium (DU)
Uranium with a percentage of ^{235}U lower than the 0.7% found in natural uranium. As examples, spent (used) fuel elements, byproduct tails, residues from uranium isotope separation, and some weapons materials contain DU. DU can be blended with highly enriched uranium to make reactor fuel or used as a raw material to produce plutonium.

equilibrium factor (*F*)
In relation to the potential alpha energy of radon and its progeny in air, the ratio of the equilibrium equivalent concentration to the actual activity concentration of radon. See *potential alpha energy concentration*.

Gravel Gertie
Facility covered with crushed gravel to contain radioactive contamination from the potential accidental explosion of a nuclear weapon during assembly or disassembly, characterized by a cable-supported roof of wire mesh and a thick gravel overburden. Also called *Gertie*.

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

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

nuclear track emulsion, type A (NTA)
Film made by Eastman Kodak sensitive to fast neutrons. The developed image has tracks caused by neutrons that are visible under oil immersion with about 1,000-power magnification.

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

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

postoperative years

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

potential alpha energy concentration (PAEC)

Kinetic energy in units of working levels potentially released in a unit volume of air by alpha particles emitted by the short-lived radioactive progeny of ^{222}Rn (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po) and ^{220}Rn (^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po). See *potential alpha energy exposure* and *working level*.

potential alpha energy exposure (PAEE)

Average potential alpha energy concentration to which a worker is exposed multiplied by the time of exposure in working months of 170 hours (units of working level months). PAEE is the potential alpha energy concentration multiplied by time. See *potential alpha energy concentration* and *working level-month*.

progeny

Nuclides that result from decay of other nuclides. In the case of ^{226}Ra, for example, nine successive radioactive progeny occur in a decay chain. The chain ends with ^{206}Pb (lead), which is a stable nuclide. Also called *decay products* and formerly called *daughter products*.

radon (Rn)

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

working level (WL)

Unit of concentration in air of the short-lived decay products of ^{222}Rn (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po) and ^{220}Rn (^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po) defined as any combination of the short-lived radioactive progeny of radon or thoron in 1 liter of air, without regard to the degree of equilibrium, that results in the ultimate emission of 130,000 MeV of alpha energy; 1 WL equals 2.083×10^{-5} joules per cubic meter. See *potential alpha energy concentration*.

working level-month (WLM)

Unit of exposure to radon progeny defined as exposure for 1 working month (170 working hours) to a potential alpha energy concentration from of 1 WL; 1 WLM equals 1 WL times 170 hours, which is 0.00354 joule-hours per cubic meter. See *potential alpha energy exposure* and *working level*.

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A.1 SITE DESCRIPTION AND FUNCTIONS

Medina Base, located on about 3,700 acres of Lackland Air Force Base southwest of San Antonio, Texas, was one of 13 former 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 Sandia Corporation (later 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 the 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).

In 1958, MHSMC was chosen by 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.1.1 Site Description

Lackland Air Force Base (AFB) is within 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 briefly described in the following paragraphs.

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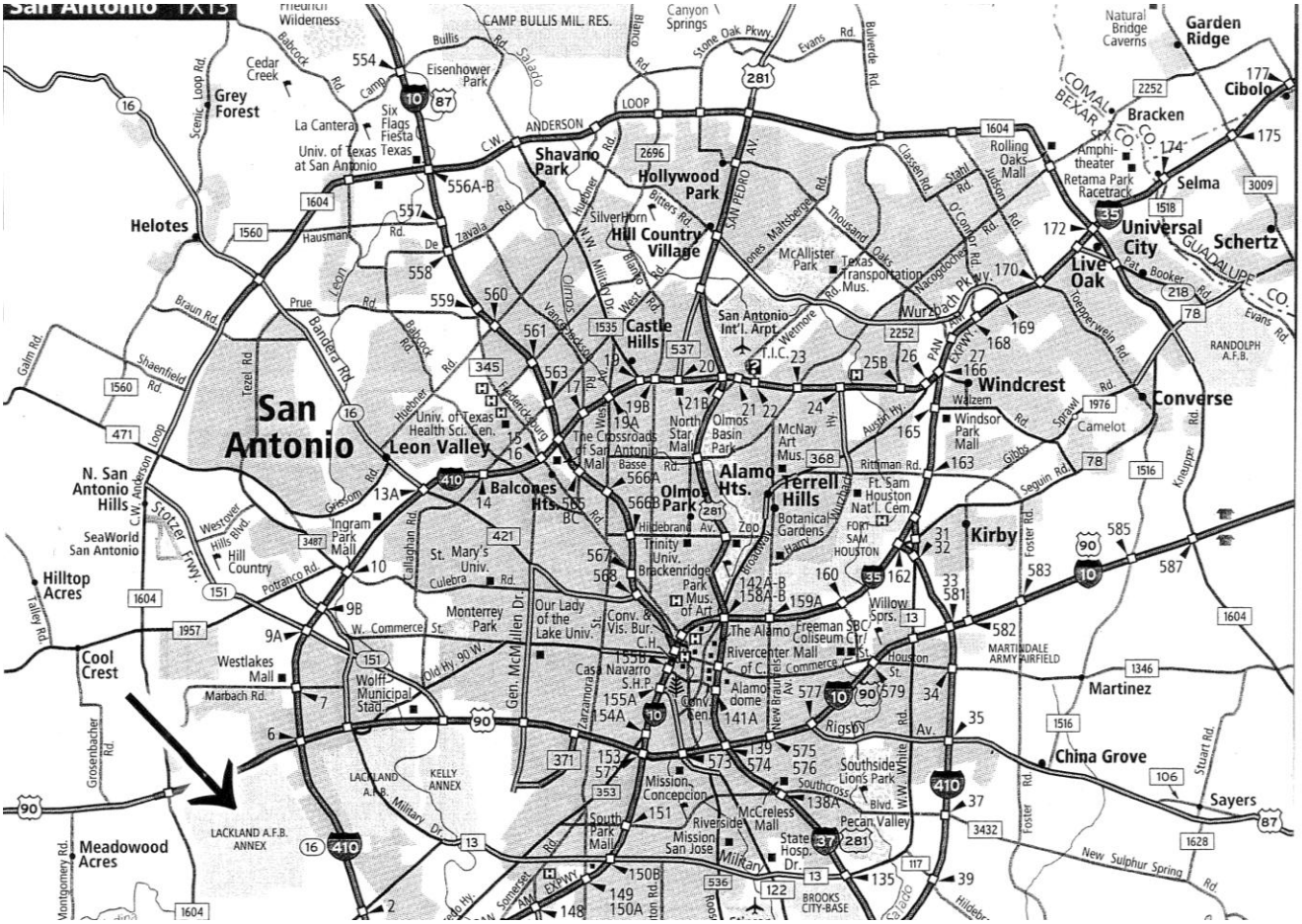

Figure A-1. San Antonio, Texas, area showing location of Lackland Training Annex (previously called Medina Base). Source: Rand McNally Road Atlas 2006.

"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 critically 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 within 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).

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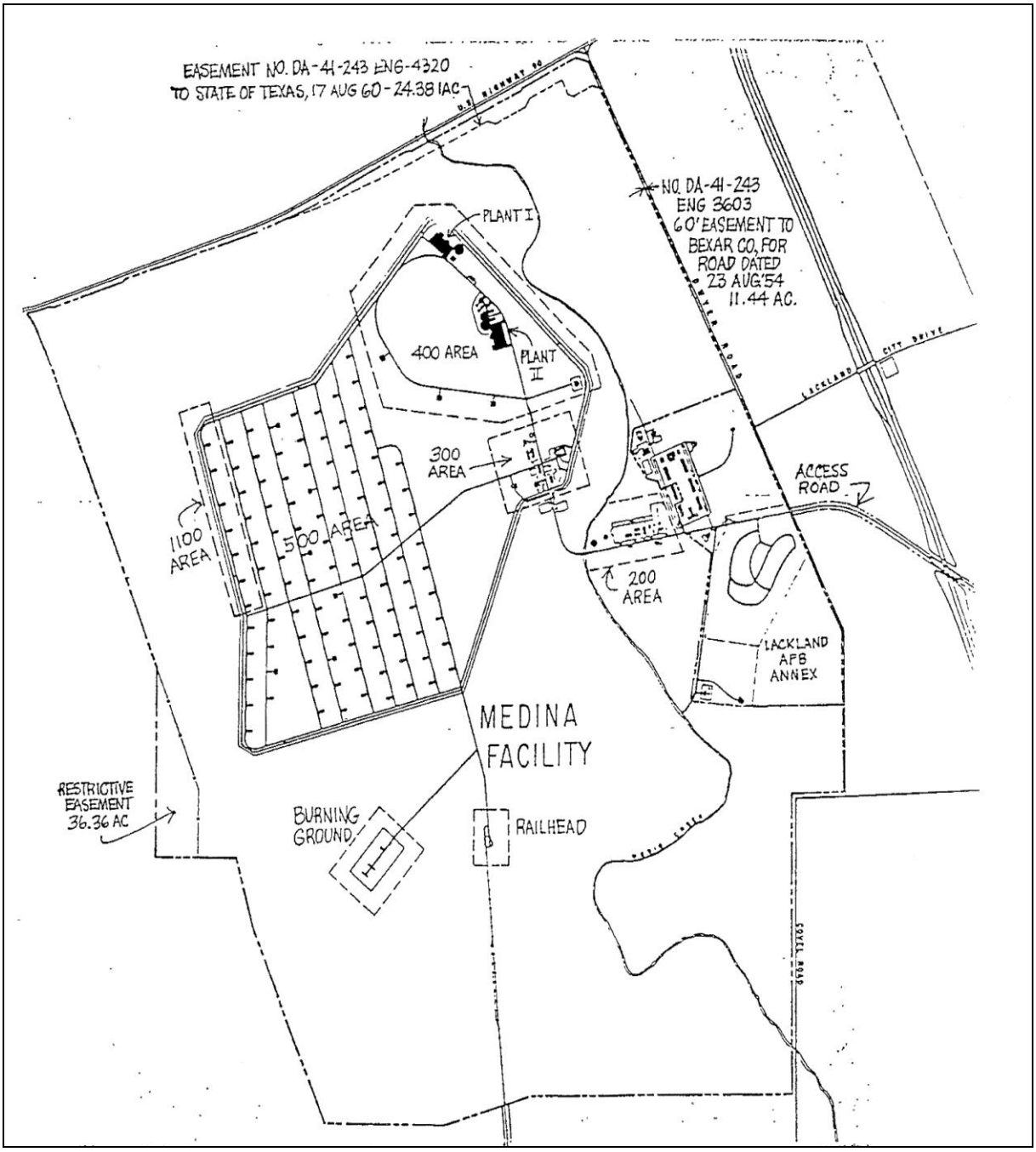

Figure A-2. Medina Base. Source: Lamb Associates and Halliburton NUS 1995.

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).

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 other environmental reports, there were 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 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 tied 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 storage 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 any 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 located 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 used 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 CONEX containers to Pantex. The RW-15 site was cleared by AEC as being 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 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 Pantex (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 exists 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.1.2 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 d, 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). (However, intakes of ^{210}Po are modeled; see Section 5.3.) 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 located below the floor surface with a polyethylene neutron absorber at the top) was located 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 prior to 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 any exposed nuclear material (Lamb Associates and Halliburton NUS 1995).

A.1.3 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.2 OCCUPATIONAL MEDICAL DOSE

Similar to Clarksville Base, 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 Base 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). No X-rays should be assigned for the Sandia years (i.e., prior to October 1958) unless there is clear evidence in the claim files.

A.3 ENVIRONMENTAL DOSE

A.3.1 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 Base 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, Medina) are classified, so comparison of effluents by relationships to throughput is not possible. Medina had three Gravel Gerties compared to 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. This compares to a range of 6,000 to 26,000 µCi during a few years at IAAP (ORAUT 2005b). Assuming that Medina Base was a larger operation than Clarksville Base and approximated Pantex operations, and using the same formulas as those for the Clarksville tritium releases, an annual environmental tritium intake of 18,300 pCi/d is estimated [(70,000/26,000)(6,800 pCi/d)]. The annual dose to any organ from this intake is less than 1 mrem and can be ignored.

There is no reason not to believe that Medina Base had the same radiography sources as Clarksville Base. Dose reconstructors should assign Medina workers the same 4-mrem external dose from radiography as that for Clarksville workers (Section 4.0 and Table 4-2.)

A.3.2 November 13, 1963, Explosion

A.3.2.1 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, aluminum, 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 sec the explosive burned, then it detonated with a force of over 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 sec 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. Amounts involved are not available. Fissile materials (enriched uranium or plutonium) were not involved in the accident.

Radiation surveys on the Base and downwind were performed immediately after the accident. No metallic fragments were identified. Soil samples were collected and analyzed for uranium content, reported as ^{238}U in micrograms uranium per gram of soil. Concentrations elevated above background were found in the downwind direction, west-southwest of the site of the explosion; no areas of elevated concentration were found off the Base. It is not known if areas of higher contamination were removed.

Based on the historical description, the only radionuclides of concern are natural uranium and DU. The isotopic mixtures of these in terms of activity are listed in Table A-1.

Table A-1. Assumed isotopic mixtures of uranium, % activity.[a]

Type of uranium	U-234	U-235	U-238
Natural	48.9	2.25	48.9
Depleted	15.4	1.06	83.6

a. From Rademacher (2000).

Because the initial masses of uranium in the igloo are not reported, and only soil concentrations of ^{238}U are reported (it is hypothesized that total uranium activities were reported as ^{238}U), it is favorable to claimants for external dose rate analyses to assume the mixture is natural uranium and, for inhalation analyses, that the activity is all ^{234}U.

A.3.2.2 Intake Calculation

The available historical soil measurements, circa November – December 1963, are listed in Table A-2 (from Rademacher 2000). The basis for the coordinate system is unknown; however, assuming that it is a Cartesian grid in feet, the area of elevated concentration is an ellipse larger than 4,000 ft by 2,000 ft. The highest concentrations approach 2,400 µg ^{238}U/g of soil, equivalent to about 800 pCi/g.

It is assumed that all the uranium is reported as ^{238}U. The depth of soil sampled in these measurements is not known. If it is assumed that a relatively shallow sample (conservative because it assumes little mixing into deeper soil) of 5 cm was taken, with a soil density of 1.5 g/cm^3, this enables the calculation of an areal contamination of:

$$800 \text{ pCi/g} \times 10^4 \text{ cm}^2/\text{m}^2 \times 5 \text{ cm} \times 1.5 \text{ g/cm}^3 \times 10^{-6} \text{ µCi/pCi} = 60 \text{ µCi/m}^2 \qquad \text{(A-1)}$$

[To get an estimate of the total amount of uranium involved in the explosion, if we assume from the tabulated measurements that the major contaminated area is about 4,500 ft by 600 ft (1,500 m by 200 m) at an average concentration of about 400 pCi/g, the total deposition would be about

$$400 \text{ pCi/g} \times (60 \text{ µCi/m}^2/800 \text{ pCi/g}) \times 1{,}500 \text{ m} \times 200 \text{ m} = 9{,}000{,}000 \text{ µCi} \qquad \text{(A-2)}$$

or, with a specific activity of 0.33 µCi/g for ^{238}U, around 30 tons of uranium. This is somewhat comparable to the amount of high explosive involved, so it seems reasonable.]

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Table A-2. Uranium soil measurements after explosion, circa November-December 1963.

Sample Number	Coordinate Locations		Net ^{238}U in Soil*	
	(East)	(West)	$\mu g\ g^{-1}$	$pCi\ g^{-1}$
1	2102600	557600	780	260
2	2102600	557200	1112	370
3	2102600	556800	1875	620
4	2101100	556500	2398	790
5	2103000	557300	284	94
6	2103800	557400	242	80
7	2103900	557000	823	270
8	2104000	556700	706	230
9	2104300	557400	7	2.3
10	2104400	557000	336	110
11	2103400	556900	1188	390
12	2102000	558000	ND	ND
13	2102000	557000	4	1.3
14	2102000	556000	26	8.6
15	2103000	556000	5	1.7
16	2104000	556000	65	21
17	2101000	558200	ND	ND
18	2101300	557200	1	0.3
19	2101500	556100	2	0.7

* Assumed Background of 2 $\mu g\ g^{-1}$ ^{238}U
ND = None Detected

The areal concentration enables direct estimation of the external dose rate and indirect estimation of the total time-integrated atmospheric concentration. It is assumed that the uranium was in particulate form, either as tiny fragments of material or condensed or agglomerated onto dust from the explosion. Ten-µm (respirable size) particles with density of about 10 g/cm^3 have a deposition velocity of about 0.03 m/sec (Sehmel 1984). Models (HOTSPOT, GENII) indicate that particles of this size, for the energetic event described and for a source of this magnitude, would result in a deposition pattern approximately the same as that seen in the measurements. Using a deposition velocity of 0.03 m/sec, and the maximum measured deposition level of about 60 µCi/m^2, the time-integrated air concentration is

$$(6.0 \times 10^7\ pCi/m^2) \div 0.03\ m/s = 2.0 \times 10^9\ pCi\text{-}s/m^3 \qquad \text{(A-3)}$$

This can be assumed to represent the maximum likely exposure. The plume drifted to the west-southwest of Igloo 572. There appear to be no regularly occupied facilities or structures in this direction from the point of the explosion for about 10,000 ft (3,000 m), at which point dispersion modeling indicates that the concentration would be less than one-tenth of this value.

A person breathing at a rate of 1.2 m^3/hr at the maximum point would inhale

$$(2 \times 10^9 \text{ pCi-s/m}^3)(1.2 \text{ m}^3\text{/hr}) \div 3{,}600 \text{ sec/hr} = 6.7 \times 10^5 \text{ pCi } ^{238}\text{U or } 1.4 \times 10^6 \text{ pCi U nat} \quad \text{(A-4)}$$

Because the material was a mixture of DU and natural uranium, assuming 100% natural uranium is favorable to claimants. This would be an acute inhalation of type S material for the three workers who were closest to the explosion or to anyone who reported having been in the plume immediately following the explosion. For general workers at Medina in the nearest occupied area, the maximum intake was 1.4×10^5 pCi. Use 10-µm particle size. The geometric standard deviation for 10-µm particles is 2.499526 (to be used in IMBA when changing the particle size; not to be confused with a GSD of 3 for dose for input into IREP). A spreadsheet (intake doses Medina explosion.xls) providing annual doses to organs from this acute intake has been developed for use by dose reconstructors.

Following the accident, there were two potential sources of dose: the external dose rate from direct radiation from the soil and inhalation of resuspended radioactive materials.

A.3.2.3 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 µCi/m^2 would be

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

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

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

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

However, this value is somewhat misleading; Federal Guidance Report No. 13 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 µCi/m^2

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

^{234}U $\quad (0.489)(57.8) \times 10^{-6}$ 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) for all organs except skin.

The skin dose, using Federal Guidance Report No. 13 values (Eckerman et al. 1999), could be as high as:

$^{238}U + ^{234}Th + ^{234m}Pa$ (0.489)(867 + 2,010 + 1,100,000) × 10^{-6} rem/yr per μCi/m^2

$^{235}U + ^{231}Th$ (0.0225)(22,700 + 10,000) × 10^{-6} rem/yr per μCi/m^2

^{234}U (0.489) (1,060) × 10^{-6} rem/yr per μCi/m^2

= 0.54 rem/year = 540 mrem/year per μCi/m^2 for full-time occupancy (A-7)

For an occupational exposure of 2,000 hr/year, this would be 123 mrem/yr per μCi/m^2. The highest onsite location, 60 μCi/m^2, might have resulted in a skin dose of 7,400 mrem/yr. For regularly occupied areas downwind, a value of one-tenth of that, or 740 mrem/yr, would be appropriate. For areas upwind (most of the site), a negligible value would apply; however, dose reconstructors should use the 740-mrem/yr value if it is not possible to tell if the work location was outside the plume.

A.3.2.4 Inhalation from Resuspension

Material deposited on the ground can be resuspended by wind or mechanical stresses. If it is assumed that the annual average concentration of dust in the air is 50 μg/m^3 and that it is all generated locally, an upper bound on the amount inhaled can be developed. [The RESRAD manual (Yu et al. 2000) presents a distribution from the Environmental Protection Agency's Aerometric Information Retrieval System (AIRS). The RESRAD distribution, verified by download from the AIRS Web site (http://www.epa.gov/airs/airs.html), indicates that the average U.S. concentration of PM_{10} is only about 23 μg/m^3. Recent data from a particulate sampler in the Hanford 200 Area for February 2001 through June 2002 is available (Napier and Snyder 2002, Appendix C). The mean air concentration of PM_{10} in the 200 Areas, in an outdoor area influenced by the Hanford 24 Command wildfire in 2000, was 21 μg/m^3. The 95th-percentile daily value was 36.5 μg/m^3. These data show that 50 μg/m^3 is an upper bound value.] For continuous occupancy in the most contaminated location, about 2,400 μg ^{238}U per g soil, the amount inhaled per calendar day would be approximated as:

(50 μg soil/m^3 air)(1.2 m^3/hr)(2,000 hr/yr)(2,400 μg ^{238}U/g soil)(1 × 10^{-6} g soil/μg soil)/365 cal d/yr
= 0.79 μg ^{238}U/d (A-8)

For natural or depleted uranium, the ^{238}U accounts for essentially all of the mass (more than 99%), so the total uranium mass is also 0.79 μg/d. If a specific activity of 0.7 pCi/μg natural uranium is used, the daily intake is 0.55 pCi/d. However, because there are only igloos in the vicinity, it is unlikely that a worker would have continuously occupied the area around the most contaminated soil. Therefore, an occupancy factor of 0.1 was assumed. The resulting daily intake from resuspension is 0.055 pCi/d of natural uranium (modeled as ^{234}U.) The absorption type is S; the distribution is a constant.

Tables A-3 and A-4 summarize environmental intakes and external doses, respectively.

Table A-3. Environmental intakes.

Period of application	Applied to	Mode	Type	Radionuclide	Intake	Distribution
November 1963	In plume close to Igloo 572	Inhalation	Acute	U-234 type S[a]	1.4E6 pCi	Constant
November 1963	In plume at nearest occupied facility	Inhalation	Acute	U-234 type S[a]	1.4E5 pCi	Constant
November 1963	Facilities not in plume				No intake	
November 1963–1967	In plume footprint at nearest occupied facility or working outdoors near crater	Inhalation	Chronic	U-234 type S[b]	5.5E-2 pCi/d	Constant

a. Use 10-µm particle size and GSD of 2.499526 (IMBA only, not IREP).
b. Use standard 5-µm particle size.

Table A-4. Environmental external dose.

Period of application	Applied to	Annual whole-body dose	Photon energy category	Distribution
1958–1966	All	4 mrem	30-250 keV	Lognormal GSD = 2
1964–1966	All	2.3 mrem	30-250 keV	Lognormal GSD = 2
1964–1966	All	Skin dose: 740	Beta	Lognormal GDS = 2

A.4 INTERNAL DOSE

Occupational intakes of tritium and DU by Medina workers are assumed to be the same as those for Clarksville workers during the MHSMC years, with the exception of the accidental tritium release at Clarksville Base. See Table A-5.

Table A-5. Occupational intakes.

	Dose calculation parameters					IREP input parameters		
Job category	Period	Material	Mode	Absorption type	pCi/d	Distribution type	1	2
Production operator, nuclear components inspector, quality control specialist	1958–Jan. 1966	Tritium	Chronic inhalation and skin absorption	NA	1.3E7	Constant	Dose	
Production operator, nuclear components inspector, quality control specialist	1958–Jan. 1966	DU	Chronic inhalation, Ingestion	M, S Insoluble	4.4E2 9.1	Constant Constant	Dose Dose	
Production operator, **any** inspector, quality control specialist	1958–1966	Radon	Chronic inhalation	NA	NA	Lognormal	0.072 WLM/ 12 mo.	3
Material handler	1958–1966	Radon	Chronic inhalation	NA	NA	Lognormal	0.029	5
Other nonadministrative	1958–1966	Radon	Chronic inhalation	NA	NA	Lognormal	0.0072	3
Burning of high explosives	1958-1966	DU	Chronic inhalation	M or S	130	Constant	Dose	

No information about radon levels in Medina facilities has been found. Mr. Rarrick indicated that radon was an issue at Medina (Martin 2006a). The Pantex Plant is in an area rated moderate for radon by the U.S. Geological Survey, whereas Medina is in an area rated low and Clarksville is in a boundary area between low and moderate. However, radon levels at Medina would probably be more similar to those at Pantex than to those at Clarksville because the covered structures were similar.

Therefore, workers who spent essentially full time in covered buildings such as Gravel Gerties should be assigned 0.072 WLM per 12-mo exposure. Material handlers, who often entered igloos or other storage areas, should be assigned an occupancy factor of 0.4, and workers who occasionally entered Gravel Gerties, cells, or igloos (e.g., security or crafts staff) should be assigned an occupancy factor of 0.1 (ORAUT 2006a).

A.5 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 Sandia personnel, but none has been found to date. Exposures to the few (less than 10) Sandia personnel between 1955 and 1959 did not involve exchange of Po-Be initiators, and Mr. Rarrick estimated maximum exposures at 100 mrem per year (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 that were retrieved 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 Base. 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 Base. A summary of dose recommendations for Medina is listed in Table A-6.

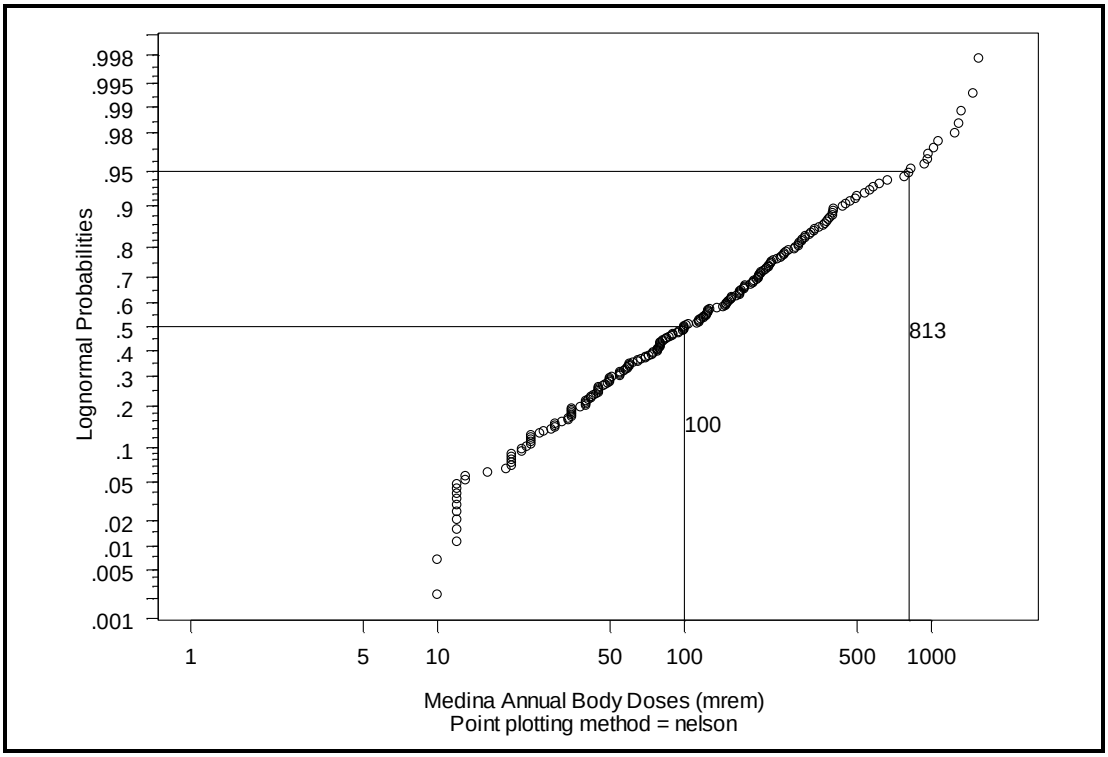

Figure A-3. Log probability plot of recorded annual doses received by monitored workers at Medina, 1959 to 1966 (Pantex 1959–1966).

Table A-6. 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 = 1.6 × photon dose
	Neutron	Multiply assigned neutron dose by 1.91
Not monitored	Exposure categories	As listed in Table 6-4
	Photon	As listed in Tables 6-7 to 6-9
	Neutron	Neutron dose = 1.6 × photon dose
	Neutron	Multiply assigned neutron dose by 1.91

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 CATIs, the most detailed one associated with claim number 5800. 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 so 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 also 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 the shield. When the air flow stopped, the ^{192}Ir source fell back down the tube to an area where the radiographers were present. As a result of this incident, three individuals received unusually high radiation exposures, as follows: Radiographer A – 6,600 mrem gamma, Radiographer B – 3,000 mrem gamma, and Radiographer C – 2,370 mrem gamma. These exposures are included in the summarized records (Martin 2006b).