ORAU Team **NIOSH Dose Reconstruction Project** Technical Basis Document for Atomic Energy Operations at the Iowa Army Ammunition Plant (IAAP)	Document Number: ORAUT-TKBS-0018 Effective Date: 04/16/2004 Revision No.: 00 Controlled Copy No.: _____ Page 1 of 58
Subject Experts: John A. Leonowich/Don Bihl/Jack Fix/Dillard Shipler/Bruce Napier Document Owner Approval: Signature on File Date: 04/16/2004 Donald Bihl, TBD Team Leader Approval: Signature on File Date: 04/19/2004 Judson L. Kenoyer, Task 3 Manager Concurrence: Signature on File Date: 04/19/2004 Richard E. Toohey, Project Director Approval: Signature on File Date: 04/16/2004 James W. Neton, OCAS Health Science Administrator	Supersedes: None

TABLE OF CONTENTS

Section Page

Record of Issue/Revisions 5

Acronyms and Abbreviations 6

1.0 Site Description, Operational History, and Process 7

2.0 Estimation of Internal Exposure 8
2.1 Tritium Exposure 9
2.2 Depleted Uranium 10
2.2.1 DU Intakes from Hydroshots 11
2.2.2 DU Intakes from Machining Baratols 13
2.2.3 DU Intakes by Operators at Burning Yard 14
2.2.4 DU Intakes from Disassembly of Weapons 15
2.3 Other Sources 16

3.0 Estimation of External Radiation Exposure 16
3.1 Introduction 16
3.2 Basis of Comparison 16
3.3 Workplace External Radiation Fields 17
3.3.1 Photon Radiation 17
3.3.2 Neutron Radiation 19
3.3.3 Depleted Uranium 20
3.4 External Radiation Dose Records 20
3.5 Dosimeter Technology 23
3.6 Dosimeter Performance Studies 24
3.6.1 Photon Radiation 24
3.6.2 Neutron Radiation 25

3.7 IAAP Worker External Dose Reconstruction 25
3.7.1 Photon Dose 26
3.7.2 Neutron Dose 27
3.7.3 Skin and Extremity Dose (Reserved) 29
3.7.4 IAAP Facilities 29
3.7.5 IAAP Nuclear Workers 29
3.7.6 Summary of Dose Reconstruction Recommendations 29
3.7.7 Radiation Dose Fraction 32
3.8 Uncertainty in Photon and Neutron Dose 32
3.9 Organ Dose 32

4.0 Occupationally Related Medical X-Rays 34

5.0 Occupational Environmental Dose 35
5.1 Introduction 35
5.2 Intakes from Onsite Atmospheric Radionuclide Concentrations 35
5.2.1 Intakes from Tritium Releases 36
5.2.2 Intakes from Release of DU from Burning Sites 37
5.3 External Dose 38
5.4 Uncertainty 38

6.0 Radon 38

7.0 Yearly Intakes 39

References 40

Glossary 44

Attachment A Position Titles and Tasks 49

Attachment B Occupational External Dose for IAAP Workers 50

B1.0 DOE IAAP Dose Records 50

B2.0 Dose Parameters 51
B2.1 Years of Exposure 52
B2.2 Rate 52
B2.3 Radiation Type 52
B2.4 Radiation Energy and Dose Fraction 52

B3.0 Distribution Parameters 53
B3.1 Type 53
B3.2 Parameter 1 53
B3.3 Parameter 2 56

Attachment C Summary of Intakes and Details of Ingestion Calculations 60

C1.0 Intakes 57

C2.0 Ingestion Intake Calculation 57

LIST OF TABLES

Table — Page

1 Mass and radiological characteristics of depleted uranium 10
2 Measured DU air concentrations from hydroshots....11
3 Chronic DU intakes from hydroshots for test fire operators and drivers 13
4 Chronic DU intakes from hydroshots for other AEC personnel....13
5 Chronic DU ingestion intakes from hydroshots for cleanup crew 13
6 Summary of examination of IAAP worker dose records 21
7 IAAP worker recorded dose data statistics 22
8 IAAP Mason and Hanger monitored workers and reported whole-body doses 23
9 Summary of IAAP beta/photon dosimeters, MDL, exchange frequency and potential missed dose 24
10 IARC testing results for U.S. beta/photon dosimeters 25
11 Testing results for Hanford two-element and multielement film dosimeters for energy and angular response 25
12 Missed photon dose adjustments to recorded deep dose 27
13 Statistical parameters for lognormal probability distribution for neutron-to-photon dose ratios 29
14 IAAP neutron dose fractions and associated ICRP 60 correction factors....29
15 IAAP facilities handling radiation....30
16 IAAP total manpower and Division B workers, and AEC Form 190 reported nuclear and monitored workers 31
17 Summary of IAAP worker claimant-favorable dose reconstruction options 31
18 Beta, photon, and neutron radiation energies and percentages for IAAP external radiation exposures 32
19 Annual photon exposure to organ dose conversion factors....33
20 Annual neutron deep dose equivalent to organ dose conversion factors 33
21 Organ doses from lumbar spine X-rays at IAAP 35
22 Summary statistics of 1990 radon measurements at Pantex....39
B-1 IREP dose parameter input screen....51
B-2 Selection of radiation type, energies and percentages 52
B-3 Distribution parameters for IAAP worker measured photon dose....53
B-4 Missed photon dose adjustments to DOE reported gamma dose 54
B-5 Statistical parameters for lognormal probability distribution for neutron-to-photon dose ratios 54
B-6 IAAP neutron dose fractions, energies, percentages, and associated ICRP 60 correction factors 54
B-7 Annual photon exposure to organ dose conversion factors....55
B-8 Annual neutron deep dose equivalent to organ dose conversion factors 55
C-1 Summary of intakes by AEC workers at IAAP 57

LIST OF FIGURES

Figure — Page

1 Layout of the IAAP site with AEC facilities marked....7
2 MCNP calculated photon spectra emitted from ^{234m}Pa beta in ^{238}U spheres....18
3 Bremsstrahlung component of the calculated spectrum on a linear vertical axis....19
4 Characteristic X-ray component of calculated spectrum on a linear vertical axis....19
5 Trends in dosimeter measured IAAP worker deep, skin, neutron and extremity collective dose....22
6 Lognormal probability plot of measured annual IAAP worker deep (photon) dose....26
7 Lognormal plot of Pantex worker positive neutron 809/812 dosimeter data....28
8 Lognormal probability plot of Hanford plutonium facility worker measured neutron-to-photon dose ratio....28

RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
Draft	11/04/2003	00-A	New document to establish the technical basis for the development of a radiation exposure matrix for IAAP. Completed by Don Bihl, filling in for John A Leonowich while he was on travel.
Draft	11/12/2003	00-B	Resolved security issues and revised section on tritium and added an additional table to the external dosimetry section.
Draft	01/30/2004	00-C	Incorporated changes in response to OCAS review and comments on 00-B. Changes affected all sections.
Draft	03/03/2004	00-D	Incorporated changes in response to internal reviews. Changes affected all sections. Added Attachments A , B, and C.
Draft	03/19/2004	00-E	Incorporated changes in response to OCAS comments. New intake scenario in section 2.6. Numerous changes in section 3 and Attachment B incorporating statistical analyses of external doses.
Draft	04/14/2004	00-F	Improvements to section 3 incorporating statistical analyses of all the years measured doses and minor change to section 6 to make radon instructions more explicit. External skin doses reserved. External whole body doses prior to 1958 reserved.
Draft	04/16/2004	00-G	Adjustments made to DU ingestion intakes to be consistent with OTIB-009 per OCAS comments.
04/16/2004	04/16/2004	00	First approved issue. Initiated by Donald Bihl.

ACRONYMS AND ABBREVIATIONS

AEC	US Atomic Energy Commission
AMAD	Activity Median Aerodynamic Diameter
AP	Anterior-posterior (or front-to-back) irradiation of the body
BAECP	Burlington Atomic Energy Commission Plant
CF	conversion factor
CV	coefficient of variation
DCF	dose conversion factor
DOE	U.S. Department of Energy
DOELAP	DOE Laboratory Accreditation Program
dpm	disintegrations per minute
DU	depleted uranium
EDA	Explosives Disposal Area
EU	enriched uranium
FS	Firing Site
GSD	geometric standard deviation
HVL	half value layer
Hp(d)	personnel dose equivalent at depth d in tissue
IAAP	Iowa Army Ammunition Plant (also sometimes IAAAP)
IARC	International Agency for Research on Cancer
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
IMBA	Integrated Modules for Bioassay Analysis
IREP	Interactive RadioEpidemiological Program
ISO	International Standards Organization
ISO	isotropic
keV	kilo (thousand) electron volts, a unit of energy
LAT	lateral view X-ray
MED	Manhattan Engineer District
MeV	million electron volts, a unit of energy
MPC	maximum permissible concentration
MDL	minimum detectable level
NCRP	National Commission on Radiological Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
NTA	Eastman Kodak Nuclear Track Emulsion type A
OCAS	Office of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities

PBX plastic-bonded explosive
PNL Pacific Northwest Laboratory [also PNNL – Pacific Northwest National Laboratory]
PA posterior-anterior
PAEC potential alpha energy concentration

R roentgen, unit of exposure to ionizing photons in air
REF radiation effectiveness factor
RGD radiation generating device
ROT rotational

SRS Savannah River Site

TBD technical basis document
TLD thermoluminescent dosimeter

WLM working level month

1.0 SITE DESCRIPTION, OPERATIONAL HISTORY, AND PROCESS

The Iowa Army Ammunition Plant (IAAP) is a load, assemble, and pack munitions facility that began production in 1941 and continues to operate as a Government-owned, contractor-operated installation. IAAP is in the southeastern part of Iowa, near the town of Middletown in Des Moines County. It is about 10 miles west of the Mississippi River and the town of Burlington (U.S. Army 1988). Less than a third of the IAAP's 19,015-acre (30-square-mile) property is occupied by active or formerly active production or storage facilities. The remaining land is evenly divided between leased agricultural acreage and woodlands (JAYCOR 1996).

Since operations began in 1941, IAAP has used explosives and lead-based initiating compounds to produce a wide variety of ordnance items. In 1947, the Line 1 area, portions of the Firing Site (FS) area, the Explosive Disposal Area (EDA) sites, and Yards C, G, and L came under the jurisdiction of the Atomic Energy Commission [AEC; now the U.S. Department of Energy (DOE)]. In addition, the Security Command Center, the Emergency Response Command Post, the Deactivation furnace, Line 3 Warehouse 301, and the North Burn Pads Landfill might have been utilized. This area, totaling around 1,630 acres, became known as the Burlington Atomic Energy Commission Plant (BAECP). The site was officially renamed the Iowa Army Ammunition Plant in 1965. The site has also been referred to as the Iowa Ordnance Plant.

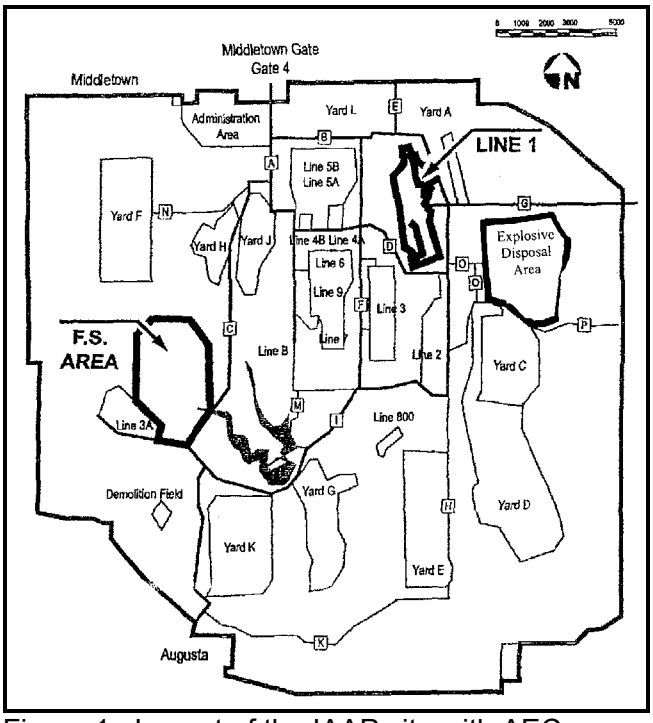

Figure 1. Layout of the IAAP site with AEC facilities marked.

The main function of the site was nuclear weapon fabrication and final assembly/ disassembly. Mason & Hanger-Silas Mason Co. assumed the contract for AEC functions at

BAECP in 1950. Mason & Hanger-Silas Mason Co. also operated the Pantex Plant, which had a similar mission, in Amarillo, Texas. Many of the health physics policies and practices were similar. For example, both IAAP and Pantex used film badges first provided by Tracerlab and then by Landauer, but Pantex had a short period when it procured its dosimetry from Eberline. AEC functions at BAECP ended in July 1975. Only AEC operations between 1947 and 1975 are applicable to the National Institute for Occupational Safety and Health (NIOSH) Dose Reconstruction Project. The exact start date for assembly of nuclear weapons is uncertain, but radiation exposures did not likely occur until after the modification of Line 1 in 1948. Production of explosives for use in nuclear weapons began in late 1948 (TN & Associated 2001). The date of first assembly of nuclear weapons has not been discovered except that it was after June 1949 (Poole and Harrison 1954). It is assumed that radiation exposures began in 1948.

Radiation sources at IAAP included depleted uranium (DU), enriched uranium (EU), plutonium, tritium, ^{210}Po, and radium, ^{60}Co, and x-ray generating devices for radiography. Additionally, work-required medical screening x-ray examinations were included in the IAAP program.

IAAP worker titles and tasks are summarized in Attachment A.

Technical basis documents are general working documents that provide guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist the National Institute of Occupational Safety and Health (NIOSH) 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 IAAP. It does not necessarily connote an “atomic weapons employer facility” or a “Department of Energy facility” as defined in the Energy Employee Occupational Illness Compensation Program Act of 2000 (42 U.S.C. § 7384l (5) and (12)).

2.0 ESTIMATION OF INTERNAL EXPOSURE

A 1969 Health Protection Appraisal (Shaykin 1969) indicated that swipe counting and direct surveys routinely monitored removable and nonremovable radioactive contamination at IAAP. A personal interview with Joe Shannan, long-time (1958-1985) employee in the Safety Department and eventually Radiation Safety Manager, confirmed that shipments of radiological materials were swipe tested on entry and before being sent to the assembly facilities (Fix and Bihl 2003). The contents of the containers were swipe tested when the containers were opened. Mr. Shannan said that during his employment at the BAECP, contamination outside or inside the incoming containers was rare.

Based on materials used to assemble weapons, the radionuclides most likely to result in an intake at IAAP were DU and tritium (^{3}H). A radiological survey of the plant conducted in 2001, years after radiological work had ceased, found only DU and ^{137}Cs. The document providing the results of the survey states, “Radioactive materials used at the line were received in a sealed configuration and were swipe tested before use. Known radioactive materials include DU, enriched uranium, plutonium, tritium gas, and ^{210}Po.” The source of the ^{137}Cs on the swipes is unknown but seems inconsistent with the nature of the work. When questioned specifically on the source of the ^{137}Cs, Mr. Shannan said he was not aware of any ^{137}Cs used at IAAP other than small sealed sources at µCi levels as instrument check sources.

Selected employees were given bioassays to detect intakes of radioactive material. However, no bioassay or swipe records were discovered during the records search. Based on experience at

Pantex, there was no potential for intakes during assembly. The canisters of tritium gas arrived sealed and assembly did not involve breaking seals or release of the gas. The plutonium and EU were also sealed and not available for intakes, even during disassembly. Pantex did some plutonium bioassay, but no intakes were ever recorded, with the exception of one well-documented accident. No reports of similar accidents at IAAP were found in the literature. The ^{210}Po arrived sealed and was not disassembled at IAAP.

Note: Intakes discussed below and in Sections 5 and 6 are summarized by year and work task in Table C-1 in Attachment C.

2.1 TRITIUM EXPOSURE

Tritium intakes could have occurred and probably did occur to a certain extent during weapons disassembly procedures.

Concerning estimation of intakes of tritium, the technology of tritium usage in nuclear weapons is classified. Therefore, information is not available on source terms for tritium at IAAP. No tritium bioassay results or tritium air sampling results for IAAP have been located. However, material and procedures at IAAP were almost certainly the same as those at Pantex because the same company operated both plants and the materials and tasks were the same. (This assumption was confirmed in a telephone interview with Mr. Herman Phillips, who was a safety engineer at Pantex but also worked for some time at IAAP.) 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 NUREG-0938 (NRC 1983)][1.5 mCi = 425 mrem], 122 mrem was indicative of a chronic annual uptake of 430 µCi of tritium. Allowing for possible different circumstances between Pantex in the 1970-80s and IAAP from the early 1950s, a reasonable upper bound for tritium uptake would be 800 µCi per year of exposure. The uptake as calculated using ICRP 10 methodology accounted for tritium in body fluids from any and all intake modes.

In all AEC Form 191s generated at IAAP from 1962 to 1973 (AEC 1962-1973a), the site reported “no internal deposition during the period.” In a health protection appraisal and report in September 1969, C.E. Davis, from the AEC Albuquerque Office, stated, “Routine internal exposure monitoring is provided only for tritium. Two urine samples are analyzed biweekly for various selected individuals who work in areas where there is potential for exposure. To date, there has never been a positive result. If air samples, radiation survey results, or unusual conditions should indicate the possibility of internal exposure to any radioisotope, special bioassays would be necessary. There has been no occasion for such tests to date” (Davis 1969). Although the criteria for IAAP tritium monitoring, reporting levels and positive results have not be found; historical reviews of detection capabilities at other AEC programs indicate the calculated upper bound for the IAAP annual uptake of 800 µCi should have been readily detectable, with the possible exception of the later 1940s and first few years of the 1950s.

Another approach for estimating intakes of tritium uses tritium effluent values. There was some information regarding the release of tritium from the site. The University of Iowa Needs Assessment for IAAP (Fuortes 2001) quotes an annual release of 0.006 curie (6,000 µCi) of tritium from the site. But another 2001 report (TN & Associates 2001) quotes an effluent summary that indicates annual releases of about 0.026 Ci in the latter half of the 1960s. Either way, in comparison to other sites that handled tritium, this release level is very small and provides some indication that not much tritium ever

escaped containment. Most of the tritium released from the stack was probably tritium gas, whereas the worker dose comes from tritiated water. The 800-µCi annual uptake estimated in the paragraph above is about 3% of the total airborne effluent for a typical year in the 1960s and greater than 10% of the effluent for other years. It is improbable that any single worker had an annual uptake approaching 3% of the effluent, especially not of tritiated water.

As discussed in the preceding two paragraphs, the 800-µCi uptake is an overestimate, especially when applied to all years of employment, and, therefore, for IREP input the distribution type is constant. Because of the way IMBA handles tritium intakes, even inhalation intakes, uptake equals intake (personal communication Anthony James 2003), so the 800-µCi uptake can be modeled as an 800-µCi injection or inhalation. The tritium reservoirs came from the Savannah River Site (SRS), so the earliest possible date for tritium exposure at IAAP would be 1954. Intakes of tritium would have occurred only during disassembly, but it is not known when the first disassembly occurred. It is claimant-favorable to assume tritium intakes occurred for each year a worker was at the assembly/disassembly line from 1954 to 1975.

2.2 DEPLETED URANIUM

Intakes of DU might have occurred during disassembly of old, oxidized DU bomb parts, during hydrotesting, or during machining of baratols (spherical-shaped, explosive charges that surround the nuclear weapons core). 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. Typical weight percents and activity fractions of uranium isotopes are listed in Table 1. These activity fractions are slightly different from the default values in IMBA, compiled by the NIOSH Office of Compensation Analysis and Support (OCAS), but within the variability of batches of DU. Either the values in Table 1 or the IMBA values can be used.

Table 1. Mass and radiological characteristics of depleted uranium.

Weight percentage[a]	**DU**
^{234}U	0.0005
^{235}U	0.2500
^{236}U	Negligible
^{238}U	99.7500
Specific constituent activity in mixture (µCi/g, nCi/mg, or pCi/µg[b]	
^{234}U	0.0313
^{235}U	0.0054
^{236}U	Negligible
^{238}U	0.3352
Total	0.3718
Specific constituent activity in mixture (dpm/µg)[b]	
^{234}U	0.0694
^{235}U	0.0120
^{236}U	Negligible
^{238}U	0.7441
Total	0.8254

a. From Carbaugh 2003.
b. Can be used to represent specific alpha activity as well.

The chemical and radiological risks of DU were acknowledged at IAAP, but they were generally considered insignificant in relation to other chemical hazards (such as beryllium); therefore, limited air

sampling data were taken during DU operations. 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" (Pantex 2001, Section 13.2.1). The same document lists in Table 7.3 that ^{238}U should be considered 20% class D and 80% class Y. Uranium contamination at IAAP would be similar to that at Pantex with the exception of material detonated in hydroshots. The most likely form of uranium at IAAP 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. The dose reconstructor should assume either type M or type S to maximize the dose to the organ of concern. Exposure to type F uranium at IAAP is not considered credible.

2.2.1 DU Intakes from Hydroshots

From 1965 to 1973, there was a potential for workers to be exposed to DU oxide-bearing dust in proximity to the North Firing Site 12 (FS-12) immediately following the detonation of a hydroshot. In addition, there might have been a few DU tests at the South Firing Site 6 (FS-6), though the number there was small in comparison to FS-12. A hydroshot was a diagnostic operation that used DU as a surrogate for weapons-grade material, and was a quality control technique for measuring the performance of plastic-bonded explosives (PBX) produced at IAAP. Mr. Shannan described the hydroshot operation (Fix and Bihl 2003). Hydroshots were conducted outdoors. One or two persons occupied the test fire control bunker, which was next to ground zero. All other site employees were kept outside a fenced area with the closest proximity about 1 mile from ground zero. A cable tunnel ran underground from the test fire control bunker to ground zero. A driver was at the fence gate. Within minutes of the explosion, the driver would enter the restricted area, pick up the workers in the bunker, and drive to the blast area to retrieve instruments. Then the workers would leave the fenced area. Neither the driver nor the control bunker operators wore respirators. According to Mr. Shannan, exposure to a plume would have been for a few minutes at most. Records indicate that 701 hydroshots occurred between 1965 and 1973 at FS-12, reportedly involving approximately 4,000 kg of DU (ATSDR 2003). Mr. Shannan said that shots were infrequent but could have been bunched, including more than one on a given day. Records list 530 hydroshots between December 2, 1965, and March 3, 1969, 3 hydroshots under a different program presumably between March 4 and July 14, 1969, and 168 hydroshots between July 15, 1969, and December 31, 1973.

A limited amount of air sampling was performed after hydroshots in 1971 and 1972 (Meek and Shahan 1972), summarized in Table 2. The data were plotted on log-probability paper to determine the geometric mean (or median) and geometric standard deviation (GSD) air concentration values. Only a few samples were taken at the control bunker, and the results were less than the 100-yard concentrations. Nevertheless, the data from the FS-12 tunnel were more robust, were more claimant-favorable, and compensate for the trip to the blast area after the dust had settled. Assuming an exposure of about 30 minutes for the operators and driver for each shot, the intake of DU for each of the periods listed in the above paragraph would be

(air concentration $\mu g/m^3$)(1.2 m^3/hr breathing rate)(0.5 hr)(no. of shots in the period).

Table 2. Measured DU air concentrations from hydroshots.

Location	DU concentrations ($\mu g/m^3$)[a]	Geometric mean air concentration ($\mu g/m^3$)[b]
FS-12 tunnel	0.0 – 21.82	2.8
100 yards from shot[c]	0.0 – 9.12	0.9

1 mile from shot[d]	0.0 – 2.47	0.24

a. Air sampling data from Meek and Shahan (1972).
b. Taken directly from log-probability plot of air concentrations
c. Includes three data at 150 yards.
d. Includes one datum at 0.75 mile

No particle size distribution information for the hydroshots was available so, the default of 5-µm Activity Median Aerodynamic Diameter (AMAD) particle size should be assumed. The intakes are assumed to be chronic, and lognormally distributed. For the drivers and test fire operators, the geometric mean of 2.8 µg/m^3 was used and the GSD was 4.6. Intakes for the three periods are provided in Tables 3 and C-1 (Table C-1 also has results in pCi/d). For input into IMBA, the intake per calendar day is needed, which was determined by dividing the total intake for the period by the calendar days in the period.

Table 3. Chronic DU intakes from hydroshots for test fire operators and drivers.

Period of exposure	Total intake (mg)	Calendar days	Daily chronic intake (mg)
December 2, 1965 through March 3, 1969	0.890	1187	7.5E-4
March 4, 1969 through July 14, 1969	0.00504	132	3.8E-5
July 15, 1969 through December 31, 1973	0.282	1630	1.7E-4

Everyone at the site might have been exposed to a small degree to the plumes from hydroshots. It is unlikely that the plumes always drifted in the same direction, and the decrease in air concentration as the plume moved across the site is not known. But because the nearest AEC facilities were about equally distant from the fence as was ground zero to the fence, an assumption of a factor-of-4 decrease from the mean of the 1-mile air concentration is claimant-favorable for an annual intake, especially considering the high density of DU in relation to dust or nearly all other types of airborne effluents, and variable plume directions when averaged over a year. The assumed period of exposure at this distance was 2 hr (assumes turbulence type A at 4000 m and 1 m/s drift speed then doubled for conservativism); other assumptions are the same as for the operators.

$$\text{Intake} = (0.24\ \mu g/m^3)(1.2\ m^3/\text{hr breathing rate})(2.0\ \text{hr})(\text{no. of shots in the period})/4.$$

Intakes for all other personnel from the hydroshots are provided in Table 4 and C-1. The intakes are chronic, lognormally distributed, with a GSD of 4.0, obtained from the probability plot.

Table 4. Chronic DU intakes from hydroshots for other AEC personnel.

Period of exposure	Total intake (mg)	Calendar days	Daily chronic intake (mg)
December 2, 1965 through March 3, 1969	7.63E-2	1187	6.4E-5
March 4, 1969 through July 14, 1969	4.32E-4	132	3.3E-6
July 15, 1969 through December 31, 1973	2.42E-2	1630	1.5E-5

An unsigned undated record in the IAAP files (file locator 000916) indicates that FS-12 employees picked up pieces of exploded baratols lying around ground zero by hand without gloves to bag them as waste. If so, a potential for ingestion of DU existed. Assuming 76 mg of DU contamination on hands, of which about 10% is ingested (assuming hands are not washed before eating), results in ingestion of about 7.6 mg of DU per cleanup task. (Details of the calculation are provided in Attachment C.) There is no record of how many times cleanup of baratol pieces occurred; a claimant-favorable assumption is after each hydroshot. Results of the calculations are provided in Tables 5 and C-1. This should be modeled as chronic ingestion, insoluble material, constant upper bound.

Table 5. Chronic DU ingestion intakes from hydroshots for cleanup crew.

Period of exposure	Total intake (mg)	Calendar days	Daily chronic intake (mg)
December 2, 1965 through March 3, 1969	4.0E3	1187	3.3
March 4, 1969 through July 14, 1969	2.3E1	132	0.17
July 15, 1969 through December 31, 1973	1.3E3	1630	0.78

2.2.2 DU Intakes from Machining Baratols

On Line 1, from 1948 through about 1962 (TN & Associates 2001), the first step of the production process was the casting of baratols. Both baratols and hydroshot explosive charges might have contained a thin shell of DU. Machining or grinding these components might have released small quantities of DU to the machining room environment. DU was not machined directly but unintentional "nicking" of the DU occasionally occurred during machining on the explosive charges. DU-contaminated explosive waste was reportedly taken to the Explosives Disposal Area burn pads for burning. Beginning in about 1962, the process of casting baratols was replaced by a new process

that involved pressing explosives in a plastic state into molds. Thus, the need for machining was eliminated (ATSDR 2003).

Mr. Shannan confirmed that machining directly on DU was not done because it produces hot, smoldering filings that would have been extremely hazardous because of the intimate proximity to explosives (Fix and Bihl 2003). Machining on contaminated metals might have produced some airborne contamination and cleanup operations around the machines might have created low, temporary airborne concentrations of DU. An assumption of some intake of DU by the machinists is reasonable, although not comparable to sites where actual machining on uranium occurred. Airborne DU contamination was probably intermittent and did not exist for the full 40 workhours every week, and it is unlikely that any worker was exposed for the full 40 hours each week. An exposure at 2% of the maximum permissible air concentration (MPC) for 20 hours per week is assumed as an upper bound for machining or cleaning around the machines. This assumes concentration of airborne contamination is consistent with values measured at the Hanford Site from machining of uranium and cleanup of machinery at a fuel fabrication plant (Wilson 1958), and is believed to be claimant-favorable because the source term at IAAP was much smaller. The MPC for insoluble ^{238}U (which would apply to DU as well) established by the National Commission on Radiological Protection and Measurements (NCRP) in 1959 was 1×10^{-10} µCi/cm^3 (NBS 1959). Assuming a breathing rate of 9.6 m^3 per workday (light work) results in a chronic intake of DU of about 2.4×10^{-3} µCi per year (6.6 pCi/day for input into IMBA).

In addition, the machinists might have ingested DU by transfer from contaminated hands to food or cigarettes. For estimating ingestion resulting from contamination inside buildings, OCAS recommends a daily ingestion of 0.2 times the air activity per m^3 (NIOSH 2004a). This approach includes ingestion from transfer from hands and settling of contamination onto open sources of drink, such as a coffee mug. The approach assumes continuous settling of material from the air onto surfaces for 24 hours per day, 7 days per week. The air concentration discussed in the preceding paragraph (2% MPC) was assumed to apply only about half the time, so the average continuous air concentration would have been 1% MPC or 1×10^{-12} µCi/cm^3. The daily ingestion intake would have been

$$(0.2)(1 \times 10^{-12}\ \mu Ci/cm^3)(10^6\ pCi/\mu Ci)(10^6\ cm^3/m^3) = 0.2\ pCi/d.$$

0.2 pCi/d should be the mode of a triangular distribution with the minimum at 0.1 pCi/d (no open drinks) and the maximum at 0.4 pCi/d (to account for the possibility that some contamination on the hands may have come from handling a baratol that was contaminated on the surface as opposed to touching general work surfaces (infrequent but possible when the DU was “nicked”). .

2.2.3 DU Intakes by Operators at Burning Yard

About 2,000 g/yr of DU as contamination on scrap explosive components was burned at the Explosive Disposal Area (TN & Associates 2001). Section 5.2.2 addresses inhalation by general plant workers from the effluent of the burning. The ash was bagged and shipped off the site. Intakes might have occurred during the bagging of the ash. Probably more than 99% of the DU remained in the ash, so 100% was assumed (airborne release fractions from burning DU are generally 10^{-3} or 10^{-4} [DOE 1994]). This means about 10 g/workday was bagged. Even when mixed with nonradioactive ash from the explosives, the total amount of ash bagged per day was small and should have taken only a few minutes to sweep up and dispose of in a bag or drum. Airborne release fractions and respirable fractions of radioactive materials, including uranium, under many different scenarios have been compiled by DOE (DOE 1994, page 4-9). The scenario considered most appropriate for bagging ash was described as “free-fall spill of cohensionless powders: free-fall <3 m, air velocity normal to

powder flow, general forced enclosure ventilation or low-wind outside conditions." The median airborne release fraction was 3×10^{-4} and the median respirable fraction was 0.5; the upper bound values for the same parameters were 2×10^{-3} and 0.3. The upper bound values might apply to an acute event, but for daily intakes the median values were considered more appropriate. It was assumed that the dust produced from this process was dispersed in 1 m^3 of air. Because of the small amount of ash, 5 min. was assumed as the time for gathering the ash and disposing of it in a bag or drum. The DU air concentration from this activity was

(source µg/d)(airborne release fraction)(respirable fraction)/(air vol. m^3)

or $(10{,}000{,}000\ \mu g/d)(3 \times 10^{-4})(0.5)/1\ m^3 = 1{,}500\ \mu g/m^3$.

The DU inhaled was

(airborne concentration)(breathing rate)(time)

$(1{,}500\ \mu g/m^3)(1.2\ m^3/hr)(0.0833\ hr) = 150\ \mu g/workday$.

The inhalation per workday is equal to 100 µg/calendar day or 38 pCi/calendar day. This is assumed to be the median value of a lognormal distribution with a GSD of 3.

This intake would apply to the period from 1948 through 1975. Exposure to the plume from burning was considered for burning yard workers using the same approach applied to workers outside the burning yard, except 100 m was assumed for the source-to-worker distance. Section 5.2.2 describes the calculation of intakes from the plume. This source of intake was calculated to be < 1 µg/work day, and was considered negligible compared to the intake from the cleanup of the ash, which would apply to the same workers.

2.2.4 DU Intakes from Disassembly of Weapons

Disassembly of nuclear weapons might be another source of intake of DU. Evidence gathered at Pantex indicates that the DU material in the disassembled weapons was clean metal with no reasonable chance of airborne contamination until about 1980 (oxidized parts were encountered after that date). Mr. Shannan indicated that contaminated internal parts were rare, and, when necessary, decontamination was performed before work on the weapons was started (Fix and Bihl 2003). However, there is a possibility that the situation was different from 1949 to 1957, prior to when Mr. Shannan was employed at IAAP. Experience at Pantex indicated that "about a half of a cup" of oxidized DU was available for resuspension.

$½\ cup = 118\ cm^3$

The density of UO_2 is 11 g/cm^3, so the mass of UO_2 is

$(118 cm^3)(11\ g/cm^3) = 1{,}300\ g$

of which about (238/270)(1,300g) = 1,140 g is DU.

The airborne release fraction and respirable fraction were obtained from the DOE handbook (1994) using the scenario described as release of pressurized gases over a solid surface contaminated with loose oxide where the gas does not significantly pressurize the confinement in which the contamination exists. Only upper bound values were presented in the handbook for this scenario; the airborne release fraction was 0.005, and respirable fraction was 0.3. The volume of air into which the

contamination was suspended was assumed to be 27 m^3, and the exposure time was 1 hr. These latter two assumptions assume quick work and no dilution by ventilation. Conversely, it could have been assumed that the work pace was slower but the concentration was decreased by ventilation, which would have produced about the same result. The estimated intake of DU per disassembly is then

$$(1{,}140g)(0.005)(.3)(1.2\ m^3/hr)(1\ hr)(10^6\ \mu g/g)/27m^3 = 7.63 \times 10^4\ \mu g \text{ or } 2.84 \times 10^4\ pCi.$$

The frequency of disassembly of old weapons is not known but should have been rare considering that the primary mission at BAECP was assembly. An assumption was made that no single worker was involved in more that two disassemblies per year. The intake should be modeled as an acute intake of DU at the start of each year of 5.7×10^4 pCi total alpha activity, constant upper bound. Because assembly of weapons did not occur until some time after June 1949, disassembly of oxidized weapons was assumed to start in 1950. Hence, these intakes would apply to 1950 through 1957 only.

2.3 OTHER SOURCES

In addition to DU, EU, plutonium, ^{210}Po, and perhaps thorium were present during assembly or disassembly of nuclear weapons. These sources were sealed, and with the careful control of contamination before work on the pits was allowed, it is unlikely these radioelements would have been available for intake. This is consistent with the experience at Pantex.

3.0 ESTIMATION OF EXTERNAL RADIATION EXPOSURE

3.1 INTRODUCTION

Information concerning the early history of IAAP nuclear weapons assembly activities still involves classified information and, therefore, a clear description of events at that time is not publicly available. DOE (1997) states that the AEC built two nuclear weapons assembly plants to supplement Sandia nuclear weapons assembly activities that began in about 1945. One of these was at IAAP in 1947 and the second was the Pantex Plant in 1951. As described in Section 1, construction of IAAP actually began in 1941 to produce conventional explosives for the U.S. Army. As of 2004, IAAP continues to operate as an ammunition manufacturing plant; however, nuclear weapon assembly activities ended in 1975 when the work was transferred to the Pantex Plant. Archival information for IAAP workers has been collected by University of Iowa College of Public Health researchers under funding provided by DOE to support medical screening of former IAAP workers.[1] This information has been examined as part of the effort to develop this technical basis document (TBD). Workers involved in nuclear weapon assembly activities for the AEC from about 1949 through 1975 at the IAAP were associated with a facility known as Line 1 or Division B. The primary work activity involving external radiation exposure involved testing nuclear components using DU, handling sealed nuclear components called pits containing enriched uranium or plutonium (Brinck and Jacobson 1977), and industrial radiography operations.

3.2 BASIS OF COMPARISON

Since the initiation of the Manhattan Engineer District (MED) project in the early 1940s, various concepts and quantities have been used to measure and record occupational radiation dose at the many MED/AEC/DOE facilities. A common basis of comparison has been selected to assess the

[1] In 1993, Congress passed Public Law 102-484. Section 3162 of this law required DOE to screen for occupational health conditions among former employees who might be at risk.

consistency of the available historical recorded dose at IAAP, which terminated AEC/ERDA operations in 1975, and at Pantex, which assumed the IAAP activities in 1975, compared to current Pantex dosimetry performance and field tested capabilities. Dates of changes in the IAAP and Pantex dosimetry systems are known and comparisons of recorded doses prior to and following these changes provides a capability to assess consistency. Similar radiation beams have been used historically to calibrate and conduct performance testing of dosimetry systems (AEC 1955, Unruh et al. 1967, McDonald et al. 1983). This basis, to be used in dose evaluation or reconstruction, is the personal dose equivalent, $H_p(d)$, where d identifies the depth (in mm) and represents the point of reference for dose in tissue. For weakly penetrating radiation of significance to skin dose, d = 0.07 mm and is noted as $H_p(0.07)$. For penetrating radiation of significance to whole-body dose, d = 10 mm and is noted as $H_p(10)$. Both $H_p(0.07)$ and $H_p(10)$ are recommended for use as the operational quantity to be recorded for radiological protection by the International Commission on Radiological Units and Measurements (ICRU 1993). These are the radiation quantities used in the DOE Laboratory Accreditation Program (DOELAP) since the 1980s to accredit personnel dosimetry systems in the DOE Complex (DOE 1986) including Pantex.

3.3 WORKPLACE EXTERNAL RADIATION FIELDS

Doses to IAAP workers conducting nuclear weapon assembly activities were considered to be low (Fix and Bihl 2003). The nuclides in the sealed nuclear weapon component pits emit beta, X- and gamma rays, and neutron radiation. However, radiation exposure to the workers depended significantly on processes used in the preparation, design, and construction of the respective weapons. The main workplace radiation fields at IAAP were due to processes involving depleted uranium (DU), nuclear weapon components associated with plutonium and highly enriched uranium (HEU) and their radioactive progeny. Some early nuclear weapons contained ^{210}PoBe initiators in the center of the core, what we would now call a pit, which is a solid, hermetically sealed object (DOE 1997). Thus, people at the weapons assembly and disassembly plants (Pantex, Burlington, Clarksville, and Medina) never directly handled Po-Be initiators. A nuclear weapon must be initiated by neutrons at the proper time. Stray neutrons are avoided around a nuclear weapon. Significant aspects of the information are classified. However, some general information is available.

3.3.1 Photon Radiation

Photon (x-ray and gamma) radiation was associated with several IAAP work activities. Sources of ionizing radiation at IAAP included low-activity radioactive sources, such as those used to check or calibrate radiation detectors, as well as analytical devices employing X-rays produced by a radiation generating device (RGD). These sources could have included alpha, beta, photon, and neutron emitters and were of the types and source strengths typically used by mainstream industrial or process-related users. No inventory of these small sources was found in the archival material reviewed. Doses associated with the proper, and widespread, use of small check sources is generally comparatively negligible. In addition to the small sources, there were at least two larger ^{60}Co sources with original activities of 5 and 50 curies, respectively (Shaykin 1969). These larger ^{60}Co sources, as well as the RGDs, had the potential for producing significant exposure to workers if not used properly. Gamma radiation of 2.2 MeV resulted from ^{1}H (neutron, gamma) ^{2}H interactions caused by neutron radiation scattering (i.e., moderation) and absorption in the hydrogen-rich materials in the nuclear components and building materials (concrete) (Shleien, Slayback, and Birky 1998).

Weapons assembly at IAAP was performed with nuclear components of purified metals. The purification process separates natural progeny radionuclides from their parent metals. This process provides some insight into potential sources of radiation. Plutonium is purged of progeny radionuclides when it is purified. However, ^{241}Am starts growing in as its parent radionuclide ^{241}Pu

decays with a half-life of 14.4 years. The ^{241}Am reaches a maximum activity after about 80 years, but it reaches about 85% of this maximum in 40 years. Thus, for IAAP nuclear weapon assembly activities between approximately 1948 and 1975, this is likely to be much less significant than experience with weapons disassembled years after their assembly where ^{241}Am activity is significant.

An important progeny nuclide for potential worker exposure in the ^{238}U decay is ^{234m}Pa with a half-life of 24 days. Thus in a matter of a few months, DU components have ^{234m}Pa activities nearly equal to that of ^{238}U. The radionuclide ^{234m}Pa emits beta radiation 98.6% of the time when it transitions 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, IRPA 1983). An additional source of exposure in the IAPP workplace is 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 depleted uranium or ^{238}U. MCNP was used to model spectral characteristics of bremsstrahlung photons from 1-cm and 30-cm diameter ^{238}U spheres. The results were similar for both sphere. Figure 2 shows the MCNP calculated photon spectrum emitted from ^{238}U as excited by the ^{234m}Pa beta spectrum shown on a logarithmic vertical axis. Note the smooth bremsstrahlung spectrum and the uranium characteristic K x-rays at 90-109 keV and the L x-rays in the range of 13-19 keV. The bremsstrahlung and characteristic x-ray components of the calculated spectrum in Figure 2 has been presented, respectively, on a linear vertical axis in Figures 3 and 4. The average energy of the photon spectrum is 0.41 MeV. The spectrum below 30 keV is insignificant. The characteristic x-ray photons also produce their own Compton scattered photons, visible as elevated fluences underlying the characteristic x-rays. Importantly the assembled weapon components were encased in a metallic cladding that significantly attenuates the photon, particularly lower energy, radiation. Also, much of the interior surfaces of the buildings where nuclear components are handled or stored are concrete. Most elements comprising ordinary concrete have a low atomic number. Oxygen (Z=8) is 50% of concrete by weight and silicon (Z=14) is 32%. Higher-energy photons would scatter within this facility losing energy in each collision and resulting in photons of lower energy. No comprehensive data have been located describing measured photon energy spectra in IAAP workplaces. Photon radiation could have been readily measured at IAAP, with available dosimeter technology, during all years of operation.

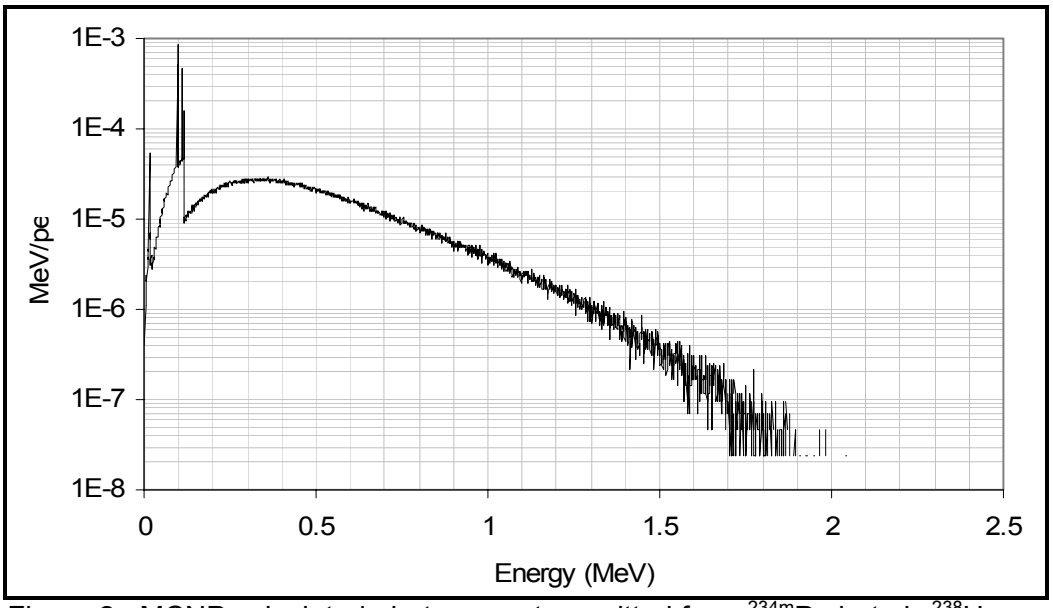

Figure 2. MCNP calculated photon spectra emitted from ^{234m}Pa beta in ^{238}U spheres.

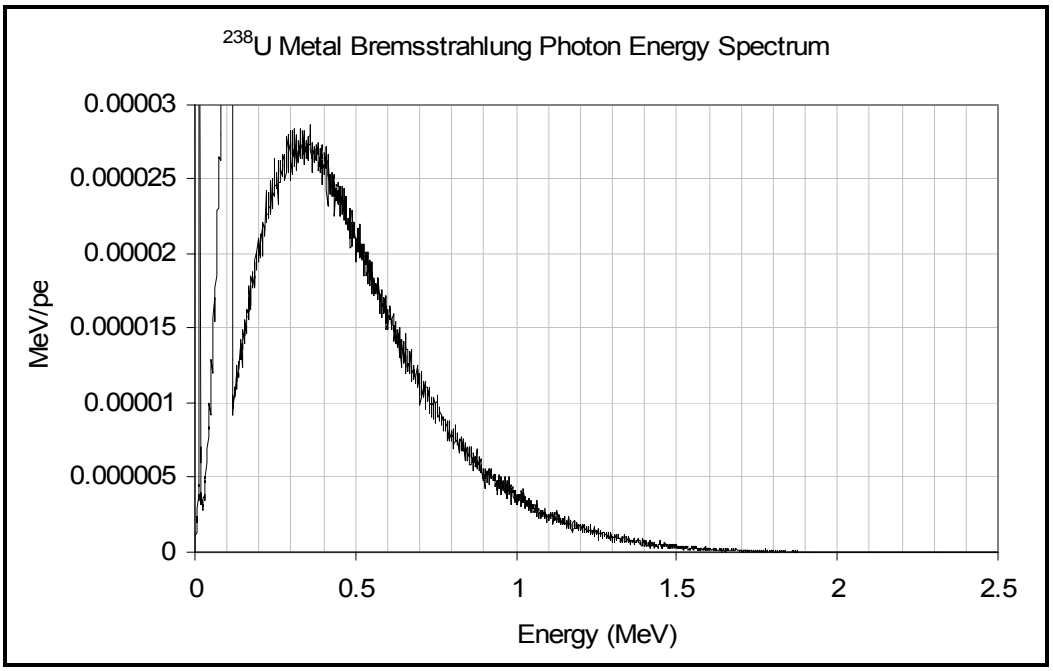

Figure 3. Bremsstrahlung component of the calculated spectrum on a linear vertical axis.

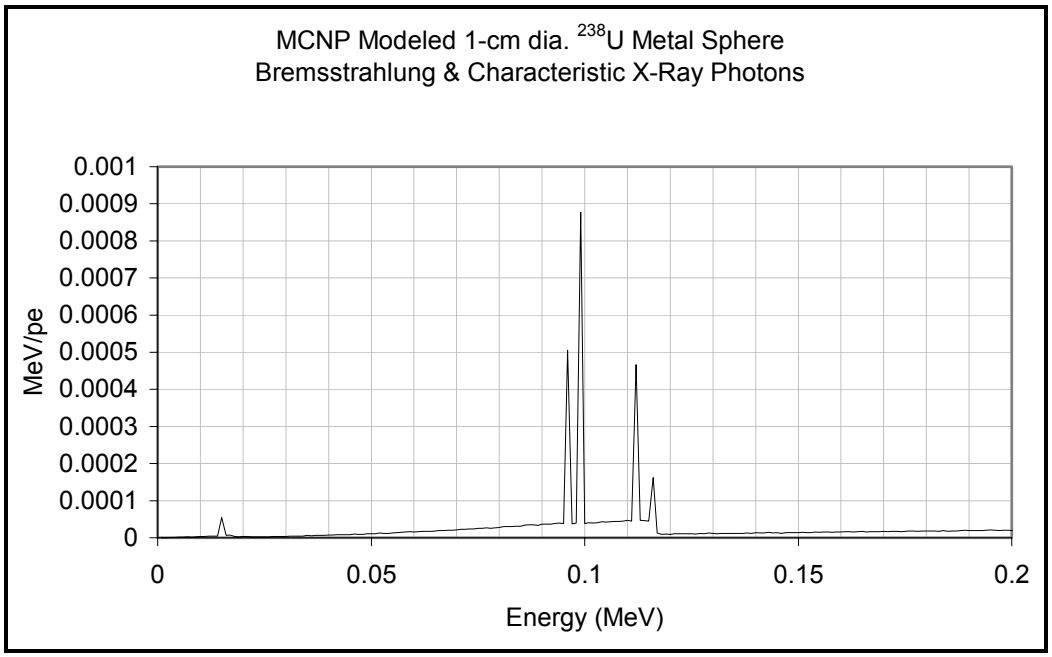

Figure 4. Characteristic X-ray component of calculated spectrum on a linear vertical axis.

3.3.2 Neutron Radiation

Uranium (^{234}U, ^{235}U, ^{236}U, and ^{238}U) and plutonium (primarily ^{239}Pu, but also ^{240}Pu and ^{242}Pu) are alpha-emitting nuclides with the expectation of (alpha, neutron) interactions with light elements in addition to spontaneous fission. The significance of neutron radiation exposure to IAAP nuclear weapon component assembly workers cannot be directly assessed because there are no available

measurements using adequate technology during the period of IAAP operation. Mr. Shannan considered the neutron dose to IAAP workers from pits to be very low (Fix and Bihl 2003). Experience and measured doses at Pantex is used to infer neutron doses to IAAP workers.

3.3.3 Depleted Uranium

As noted in Chapter 2, workers handled DU during disassembly of bomb components containing DU, during and following hydrotesting, and during machining. DU fragments were collected by workers from the test area after each non-nuclear detonation (Archive 010000914 "BAECP Former Worker Program Needs Assessment"). The DU could contribute a significant extremity and skin dose to workers unless precautions were taken to protect workers from the beta radiation. A bare slab source of DU contributes an $H_p(0.07)$ dose of approximately 230 mrad/h compared to an $H_p(10)$ dose of approximately 2 mrad/h (ORAUT-TKBS-0001 2003).

3.4 EXTERNAL RADIATION DOSE RECORDS

A considerable number of R. S. Landauer Company dose reports for IAAP were found in the archival records (Landauer 1955 – 1975). The earliest obtained dose records apparently begin with the availability of eight Landauer-provided film badges for the week beginning November 14, 1955. There is mention of TracerLab dosimeters being used prior to Landauer dosimeter use (Fix and Bihl 2003), but no records of TracerLab dosimeters have been located. Based on written notations in some Landauer dose reports, the film badges apparently were assigned to selected IAAP workers based on work activity in the early years and the reported dose data were reviewed (i.e., hand-written on the report by a person using one of the dosimeters, numbered 130-0001 to 130-0008). In general, reported doses were noted only in the "Gamma and X-Ray Exposure" column of the dose report. Based on the records available for inspection, IAAP routinely assigned and evaluated pocket ionization chamber (PIC) measured doses from at least June 18, 1965, through November 7, 1974. The content of these records is consistent with information from Shannan that monitoring was done sporadically depending on need (Fix and Bihl 2003). Table 6 summarizes examination of available IAAP dose records. For the report for the weekly period beginning January 16, 1956, an apparent test of the dosimetry service was done by exposing one of the film dosimeters to about 600 mR (probably from one of the radiography sources). The reported dose was 560 mR "gamma and x-ray exposure" and 80 mR (assumed unit to be mR) open window. The dose reports examined are not complete for all periods of IAAP operation, as described in Fix and Bihl (2003) and listed in Table 6.

Individual IAAP worker dose records were received for analysis. Only records with realistic personal and dosimeter badge identifications and non-AEC (i.e., Mason and Hanger) contractor affiliation were used. Several thousand acceptable records were identified and the results are presented in Table 7. The dose data available for analysis ranged from 1955 (only four positive dose results) through 1974 (no positive dose in 1975). The data included primarily recorded deep dose and in some cases skin, extremity and neutron doses. Table 7 presents the respective lognormal and normal distribution parameters for equivalent annual doses at IAAP during the different years. It should be noted that prior to 1963 it was necessary to convert a weekly or monthly partial year doses to an equivalent annual dose (i.e., multiply the dose for the monitored period to estimate an equivalent annual dose). No individual dosimeter dose data has been located for the years prior to 1955, 1956, and 1957. There is dose data for 1961 and for 1971 but it was not available for the analyses presented in Table 7, however this is expected to have little impact on the analysis. The geometric mean and standard deviations for these years was calculated from the adjoining years (i.e., mean of previous and subsequent year).

Table 6. Summary of examination of IAAP worker dose records.

Period	Description	Comments
11/14/55–2/6/56	Weekly availability of 8 film dosimeters from Landauer apparently assigned to workers, as needed, based on notes on dose reports.	Maximum reported dose was 40 mR; most results were zero. Test of dosimetry service done for week beginning 1/16/56 using exposure of 600 mR (reported dose was 560 mR "gamma and x-ray" and 80 mR (assumed) "open window."
5/6/57–7/29/57	Weekly availability of 8 film dosimeters apparently assigned to workers based on notes on dose reports.	Maximum reported dose was 30 mR "gamma and x-ray."
7/28/57–11/27/58	Routine weekly assignment of film dosimeters to 19 workers and one area (near hospital X-ray)	Maximum reported dose was 60 mR. Same workers monitored for each weekly exchange.
6/29/59–9/28/59	Routine weekly assignment of film dosimeters to 16 workers	Maximum reported dose was 95 mR. Same workers monitored for each weekly exchange. Pattern in worker dose with repeated higher relative dose for certain workers for each weekly period.
3/7/60–6/13/60	Routine weekly assignment of film dosimeters to 23 workers. Calendar year dose included on routine reports (i.e., 3/7/60 report was No. 1) as well as total number of dosimeters for year.	Maximum reported dose was 55 mR. Beginning with the 6/13/60 exchange period, approximately, the notation "M" was used to indicate dose results less than the detection level.
8/62–12/63	Routine biweekly assignment of film dosimeters to workers to include some area/facility monitoring locations (i.e., crane area).	Exchange cycle is noted on dose report. Start date for continuing weekly service is estimated based on examination of next available dose report (1/26/63) that includes columns for number of badge reports to date, missing badges to date, and inception date for permanent dose total.
1/64 - 12/74	Routine 4-week assignment of film dosimeters to about 60 workers.	As above but now includes some reported neutron dose and exchange periods of 1 quarter.

Figure 5 presents trends in the measured collective annual dose for the respective dose components summarized in Table 7. The data show a significant peak in measured dose during the early 1970s likely associated with IAAP operational activities.

Another source of IAAP dosimetry data is the annual whole-body external dose statistical reports reported to the AEC (using AEC Form 190) from 1962 to 1973 (AEC 1962-1973b). The form provides information on the numbers of personnel monitored or not monitored and a distribution of whole-body doses received. Information on these forms reported for Mason and Hanger IAAP workers only is summarized in Table 8. The data for the operating contractor were selected as being the most meaningful to the evaluation of dose to workers. Although the lowest reported dose category on AEC Form 190 was 0 - 1 rem, in reality the recorded annual dose for most workers was much less than 1 rem, as noted in Table 7 and in Figure 5, with many workers with annual recorded doses of zero.

From the foregoing information and consideration of potential sources of external radiation exposure, it appears that IAAP worker whole-body dose was:

- Generally not measured prior to 1955, inferred because monitoring data have not been located.

- Relatively low prior to about 1968, as listed in Tables 7 and 8. Routine film dosimeter monitoring was begun in 1962 and all doses prior to about 1968 are relatively low in comparison with the criteria of 10% of AEC-allowed dose limits of 300 mrem per week prior to 1960 (i.e., as noted on Landauer dose reports) and 1,25 rem per quarter beginning in about 1969. The criterion of 10% was commonly used as a decision level to require routine monitoring.

Table 7. IAAP worker recorded dose data statistics.

Year	IAAP deep dose data[a]				Lognormal fit	
	Workers with reported dose	Dose, mrem			Median dose	GSD
		Mean	Maximum	Collective		
1948-54	reserved					
1955	reserved					
1956	reserved					
1957	reserved					
1958	22	548	1,500	12,052	444	1.88
1959	13	350	446	4,551	344	1.22
1960	18	366	609	6,591	352	1.33
1961	(b)				298	1.24
1962	43	245	364	10,535	243	1.14
1963	57	229	1,060	13,043	195	1.70
1964	84	96	292	8,062	87	1.51
1965	44	139	375	6,123	115	1.83
1966	74	168	833	12,449	127	2.04
1967	62	145	620	8,997	112	1.95
1968	170	135	1,625	22,927	94	2.01
1969	199	119	1,207	23,685	91	1.80
1970	308	426	7,750	131,310	174	3.27
1971	224	331	3,496	75,069	109	4.53
1972	514	179	4,806	92,108	106	2.25
1973	332	210	4,350	69,590	113	2.41
1974	226	236	3,813	53,304	117	2.62
1975	0					

n.a. data not available for analysis

a. Doses are "annualized" by multiplying the sum of the measured doses by (50 weeks / actual number of weeks monitored).

b. Statistical parameters calculated as linear interpolation from 1960 and 1962.

c. Dose data analyzed for 1971 only were based on the 1975 IAAP AEC termination (1965-74) report.

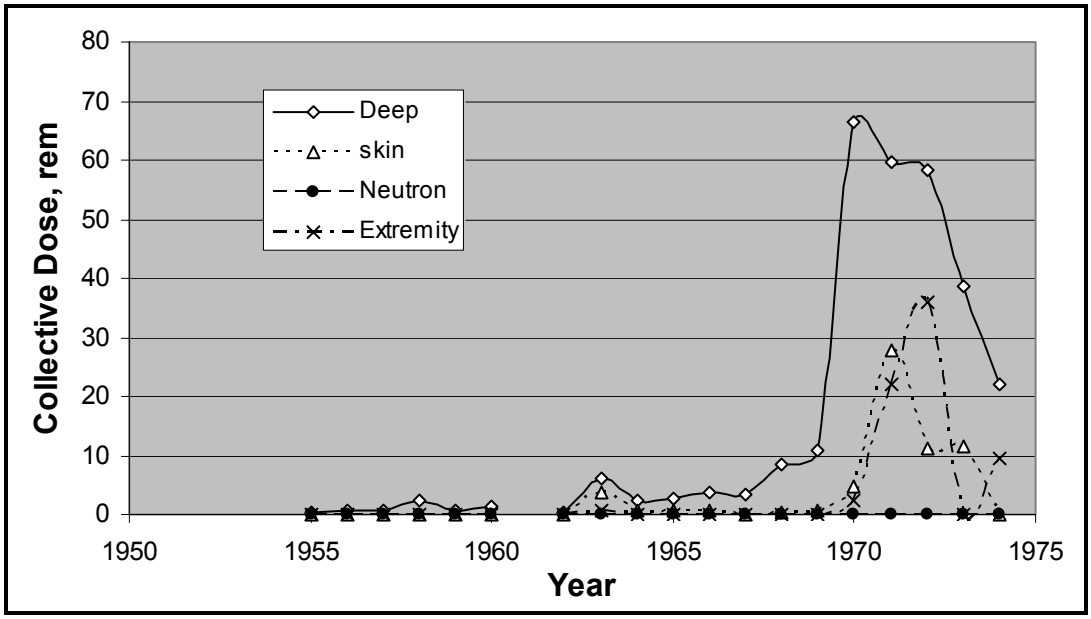

Figure 5. Trends in dosimeter measured IAAP worker deep, skin, neutron and extremity collective dose.

Table 8. IAAP Mason and Hanger monitored workers and reported whole-body doses (AEC 1962–1973b).

Calendar year	Number not monitored	Total monitored	Percent not monitored	0–1 rem	1–2 rem	2–3 rem	3–4 rem	4–5 rem
1962	1,030	29	97	29				
1963	796	41	95	40	1			
1964	650	36	95	36				
1965	692	35	95	35				
1966	824	62	93	62				
1967	818	61	93	61				
1968	798	131	86	130	1			
1969	812	152	84	152				
1970	803	243	77	225	12	5	1	
1971	825	293	74	261	15	8	8	1
1972	818	312	72	304	5	3		
1973	635	226	74	220	3	2	1	

- Not completely monitored with personnel dosimeters particularly prior to 1963, such that recorded IAAP worker career whole body doses are underestimated.

- There was awareness of the potential for extremity doses (Fix and Bihl 2003) and some workers have recorded extremity doses in the worker dose data as shown in Figure 5.

- Probably considered a relatively low hazard because of the relatively low photon (and neutron) radiation exposure levels to workers in routine nuclear weapon component assembly activities.

In addition, Tables 7 and 8 indicate that the number and percentage of workers routinely monitored with dosimeters generally increased, particularly in the 1970s when higher doses were recorded. The 1970s likely represented a time of increased work activity on assembly of new weapons and perhaps preparation for the transfer of the AEC IAAP activities to Pantex by July 1975.

3.5 DOSIMETER TECHNOLOGY

The specific designs of the Landauer film dosimeters used at IAAP have not been located, and no records of the mentioned earlier use of TracerLab dosimeters have been found. However, from the content of IAAP-submitted AEC termination reports and personal testimony (Fix and Bihl 2003), it is likely that the film dosimeter was, at least, a two-region design (i.e., nonpenetrating dose calculated from film response to open window or generally unfiltered region of the film and penetrating dose calculated from film response under a selected, usually metallic, filter). Table 9 summarizes the monitoring technique and exchange frequency for the IAAP dosimeters contracted from a commercial service. The history of the type of dosimeter used at IAAP is very similar to Pantex, which assumed the IAAP work in 1975. The Minimum Detectable Limit (MDL) of these dosimeters is summarized in Table 9 along with the maximum potential missed dose (NIOSH 2002). The MDL is widely used in other NIOSH documents and can vary depending on dosimeter type, processing equipment, calibration techniques, and procedures. Because of these variations, a review of typical MDLs for photon dosimeters was conducted and is documented in (NIOSH 2004b). The typical MDL (maximum missed dose) per exchange cycle for photon dose for film dosimeters is 40 mrem.

Table 9. Summary of IAAP beta/photon dosimeters, MDL, exchange frequency and potential missed dose.

Period		Dosimeter	MDL[b] (rem)	Exchange frequency	Max. annual missed dose (rem)[c]
Year	Period of use[a]				
1948-55	None	None			
1955–1962	Occasional	Landauer Film	0.040	Weekly (n=50)	1.0
1962	Occasional prior to 8/1962	Landauer Film	0.040	2-weeks (n=25)	0.5
1963–1975	Routinely	Landauer Film	0.040	4-weeks (n=13)	0.26

a. Prior to 1963, dosimeters were not routinely assigned to IAAP workers throughout an entire year.
b. Estimated MDLs for Landauer film dosimeter in the workplace.
c. Maximum annual missed dose calculated from OCAS-IG-001 (NIOSH 2002).

3.6 DOSIMETER PERFORMANCE STUDIES

3.6.1 Photon Radiation

The AEC conducted performance testing of several commercial and in-house film dosimeter services during 1954 with exposures provided by the National Bureau of Standards (AEC 1955). Specific dosimeter design specifications are included in the documentation. The testing included 40-, 70-, and 210-keV narrow spectral beam X-ray techniques, ^{60}Co gamma radiation, and selected mixtures of these beams. Measured response data are provided in the report for each of the respective dosimeter open-window and filtered regions of the film. This information exhibits the significant over-response of the open-window and lightly filtered regions of the film at lower (i.e., 40 and 70 keV) photon energies. Certainly, the data illustrate capabilities, in spite of many differences in organizations, emulsion types, and dosimeter designs, to reasonably detect and measure the photon radiation levels and energies potentially received by IAAP workers.

In recent years, further studies of early dosimeter performance compared to Hp(10) have been done. The IARC conducted a dosimeter intercomparison study to higher energy (i.e., >100 keV) photons of 10 dosimetry systems commonly used throughout the world (Thierry-Chef et al. 2002). Two of the U.S. film dosimeter designs were from the Hanford Site – the two-element design (identified as US-2) used from 1944 through 1957 and the multielement design (identified as US-8) used from 1958 through 1971. These dosimeter designs were commonly used at many AEC laboratories (Hanford, Oak Ridge National Laboratory, University of Chicago, etc.) (NIOSH 2004b). The IARC Study considered that exposure to dosimeters worn by workers could be characterized as anterior-posterior (AP), rotational and isotropic irradiation geometries, or a combination thereof. Dosimeter response to selected photon energies was measured using two phantoms to simulate the effect of the worker's body on the measured dosimeter response. The first phantom was the International Standards Organization (ISO) water-filled slab phantom, which is used for dosimeter calibration and performance testing. The second was an anthropomorphic Alderson Rando Phantom, which is constructed from a natural human skeleton cast material that has a tissue equivalent response. The results of IARC testing, for U.S. dosimeters only, are listed in Table 10.

The Hanford Site conducted intercomparison testing of all its historic film dosimeter designs using AP (Wilson et al. 1990) and angular (Fix, Gilbert, and Baumgartner 1994) irradiations on an Alderson Rando phantom essentially identical to the phantom used in the IARC studies. These studies included lower energy (i.e., < 100 keV) photons that are significant in plutonium facilities. Data from Wilson et al. (1990) are summarized in Table 11. The dosimeter results for energies greater than 100 keV are consistent with the IARC results, showing an overestimate of Hp(10) for the two- element dosimeter. For energies much less than 100 keV, such as in unshielded plutonium glovebox operations, the Hanford two-element dosimeter can underestimate the photon dose. However, this situation would not occur at IAAP with sealed nuclear weapon components.

Table 10. IARC testing results for U.S. beta/photon dosimeters (Thierry-Chef et al 2002).

Geometry	Phantom	118 keV		208 keV		662 keV	
		Mean[a]	SD/Mean[b]	Mean[a]	SD/Mean	Mean[a]	SD/Mean
US-2 (Hanford two-element film dosimeter)							
AP	Slab	3.0	2.1	1.3	1	1.0	0.8
AP	Anthropomorphic	3.0	4.2	1.2	1.9	1.0	1.8
Rotational	Anthropomorphic	2.2	2	1.4	3	1.2	3.2
Isotropic	Anthropomorphic	1.5	4.4	1.1	1.6	1.0	2.7
US-8 (Hanford multielement film dosimeter)							
AP	Slab	1.0	1.5	1.0	0.8	0.8	1.7
AP	Anthropomorphic	0.8	9.5	0.9	6	0.8	1.8
Rotational	Anthropomorphic	1.2	1.9	1.2	17	1.1	1.8
Isotropic	Anthropomorphic	1.0	3	1.2	9	1.0	2.3

a. Ratio of recorded dose to Hp(10).
b. Ratio of mean to standard deviation.

Table 11. Testing results for Hanford two-element and multielement film dosimeters for energy and angular response.[a,b]

Photon beam	AP exposure		Rotational exposure	
	Two-element 1944–56	Multielement 1957–71	Two-element 1944–56	Multielement 1957–71
16[b]	0.1	0.9		
59[b]	0.5	1.1		
M150(70)	0.7	0.70	1.31	1.31
H150(120)	1.6	0.64	3.00	1.20
^{137}Cs(662)	1.0	1.0	1.46	1.46

a. From Table 6-5 in the Hanford Technical Basis Document (ORAU 2003a.)
b. Divide recorded dose by table value to estimate Hp(10).
c. Based on Wilson et al (1990).

3.6.2 Neutron Radiation

A few neutron doses were reported by Landauer for some IAAP workers on dose reports beginning in about January 1964. Eastman Kodak nuclear emulsion type A (NTA) film probably was used for these measurements, similar to the NTA dosimetry by Landauer used at Pantex beginning in 1958 (ORAU 2004a). NTA was basically the only common dosimeter method available to measure neutron dose in AEC facilities at that time. Results reported at the first AEC Neutron Dosimetry Workshop in 1969 indicated that SRS calibration laboratory dose measurements made with NTA film were about one-half to one-fourth of those measured with other methods, including the neutron thermoluminescent dosimeter (TLD)(Vallario, Hankins, and Unruh 1969). It is likely that NTA neutron dose measurements at IAAP were highly uncertain for all years and certainly not complete prior to 1964. One of the most important parameters related to performance of NTA is the difference between calibration and workplace neutron energy spectra. There are no measurements of neutron spectra at IAAP, and the method(s) used to calibrate the Landauer NTA film known is unknown. Neutron spectra have been measured at various Pantex Plant facilities (classified) and the performance of the Pantex 809/812 thermoluminescent dosimeter used beginning in 1993 has been validated for weapon and workplace exposures. Significant neutron exposure from nuclear weapons components at IAAP was typically associated with a photon dose that would be readily and reliably measured with film dosimeters and PICs.

3.7 IAAP WORKER EXTERNAL DOSE RECONSTRUCTION

The primary objective of dose reconstruction for IAAP workers is to utilize a claimant-favorable method to retrospectively calculate:

- Dose to unmonitored workers prior to the routine use of personnel dosimeters.
- Missed dose for monitored workers for low-dose results less-than minimum detection level (*MDL*) of the personnel dosimeter.
- Unmeasured neutron dose to monitored workers.
- Unmonitored and missed skin dose to monitored workers.

3.7.1 Photon Dose

The available IAAP worker dose data from 1955 through 1975 were analyzed as providing the best option to estimate photon dose for years for which routine personnel dosimetry data are not available. Figure 6 presents a lognormal distribution plot of the recorded annual deep (photon) dose for measured dose for IAAP workers presented in Table 7. The year to year variability is significant with much of the recorded dose occurring in the 1970s. As such, the analysis of photon dose is done for each year as described in the following sections for unmonitored and monitored workers.

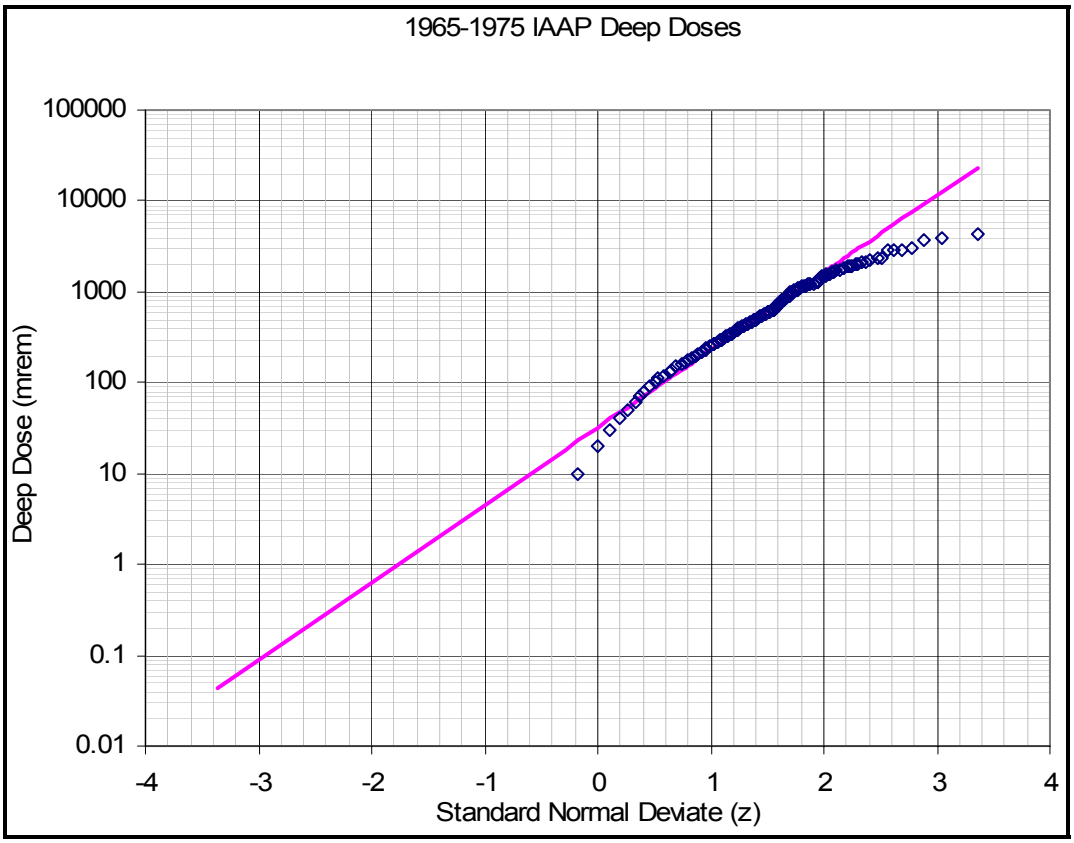

Figure 6. Lognormal probability plot of measured annual IAAP worker deep (photon) dose (update for more years of data).

Unmonitored workers

Estimates of the dose at IAAP to unmonitored workers prior to 1962 when routine monitoring was implemented is based on the measured doses received by the monitored workers summarized in Table 7. It is assumed that unmonitored (i.e., non-radiation) workers did not and would not receive a significant dose compared the monitored workers. Therefore, assigning a photon dose distribution for

each year as noted in Table 7 based on the dose received by monitored workers would certainly assure a claimant-favorable estimate of any unmonitored worker dose. For years when there was no recorded dose, a value was estimated from the adjacent years. For years, prior to 1955, the recommended dose to be assigned is based on 1958 as representing the year when routine assignment of dosimeters to identified workers, although still not complete throughout the year, was begun. Unmonitored workers would not be expected to have received significant neutron dose as discussed in section 3.7.2.

Monitored workers
The DOE reported dose for monitored workers should be adjusted for any missed photon dose using estimates from other doses for the same person doing similar work for different time periods (Watson et al. 1994) or calculated by multiplying the MDL by the number of zero dose results and dividing by 2 to estimate the mean potential missed dose (NIOSH 2002) as shown in Table 12.

Table 12. Missed photon dose adjustments to recorded deep dose.

Period		Dosimeter	MDL[b] (rem)	Exchange frequency	Mean annual missed dose (rem)[c]
Year	Period of use[a]				
1948-55		None			(d)
1955–1962	Occasional	Landauer Film	0.040	Weekly (n=50)	1.0
1962	Occasional prior to 8/1962	Landauer Film	0.040	2-weeks (n=25)	0.50
1963–1975	Routinely	Landauer Film	0.040	4-weeks (n=13)	0.26

a. Prior to 1963, dosimeters were not routinely assigned to IAAP workers throughout an entire year.
b. Estimated MDLs for Landauer film dosimeter in the workplace.
c. Mean annual missed dose calculated from NIOSH (2002).
d. Estimate of dose for unmonitored workers based on Table 7.

3.7.2 Neutron Dose

The recommended approach to estimate potential neutron dose for IAAP monitored workers is to utilize the distribution of neutron-to-photon dose ratio calculated for Pantex workers using measured Pantex worker doses during the period of 1993 through 2003. These measurements were made with the performance validated Pantex 809/812 dosimetry system. Dose records were analyzed for each Pantex worker with a positive neutron dose greater than 50 mrem for the period of 809/812 use. Analysis of this information is shown in Figure 7 as a lognormal probability plot of the ratio of neutron-to-photon doses. A Finney (1971) analysis, used to reduce the effect of outliers at the extremes, yields a geometric mean of 0.81 and a geometric standard deviation (GSD) of 1.51. The measured Pantex neutron and photon doses from 1993 through 2003 are expected to be associated with plutonium based nuclear weapon components. The neutron-to-photon ratio for the older HEU based nuclear weapon components expected to have been handled at IAAP is expected to be similar. However, it should be noted that the photon dose from HEU based components is low and this may explain why the IAAP worker doses were considered to be low by IAAP safety professionals (Fix and Bihl 2003) and the occasional film badge results were also low. Assigning the distribution of measured dose from Table 7, corrected for the missed dose, to IAAP workers prior to the routine use of personnel dosimeters and using the distribution of the neutron-to-photon dose ratio based on the Pantex worker measurements is expected to be claimant-favorable.

Neutron radiation can be created with (*alpha, neutron*) interactions; however, for several reasons this is not considered to be a significant source of exposure. A conservative analysis of the potential neutron dose relative to the photon dose, could be based on neutron fields measured at Hanford and Savannah River sites associated with workers who actually handled plutonium [plutonium fluoride (*alpha,neutron*)] interactions. The analysis of the lognormal distribution of Hanford plutonium worker neutron-to-photon ratio in Figure 8 showed a geometric mean of 0.73, a geometric standard deviation of 2.10, and an upper 95th percentile of 2.47. Considering the uncertainty in the measured photon

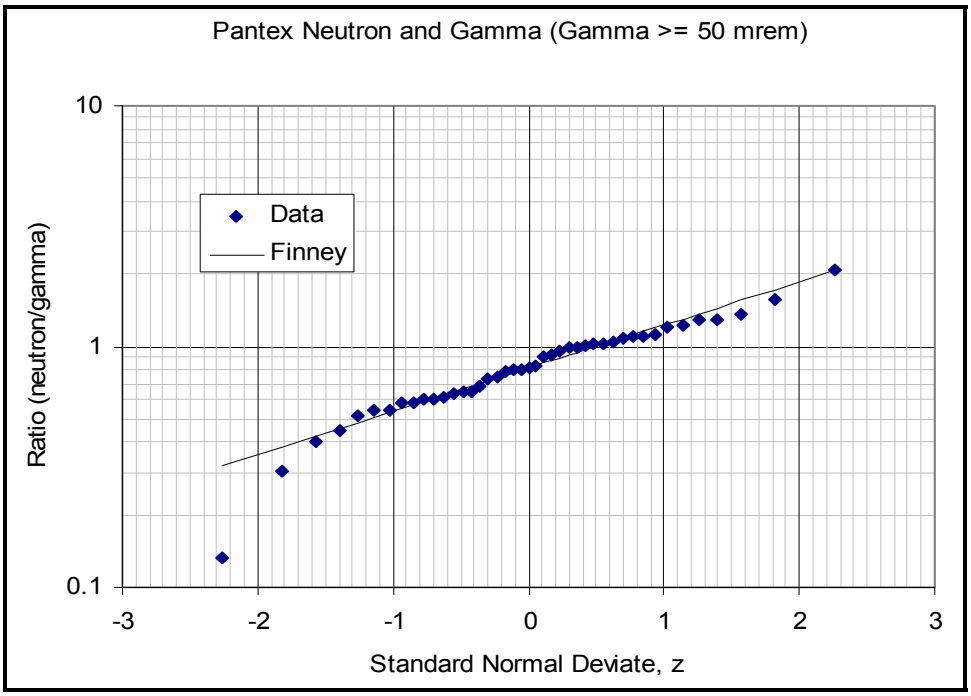

Figure 7. Lognormal plot of Pantex worker positive neutron 809/812 dosimeter data.

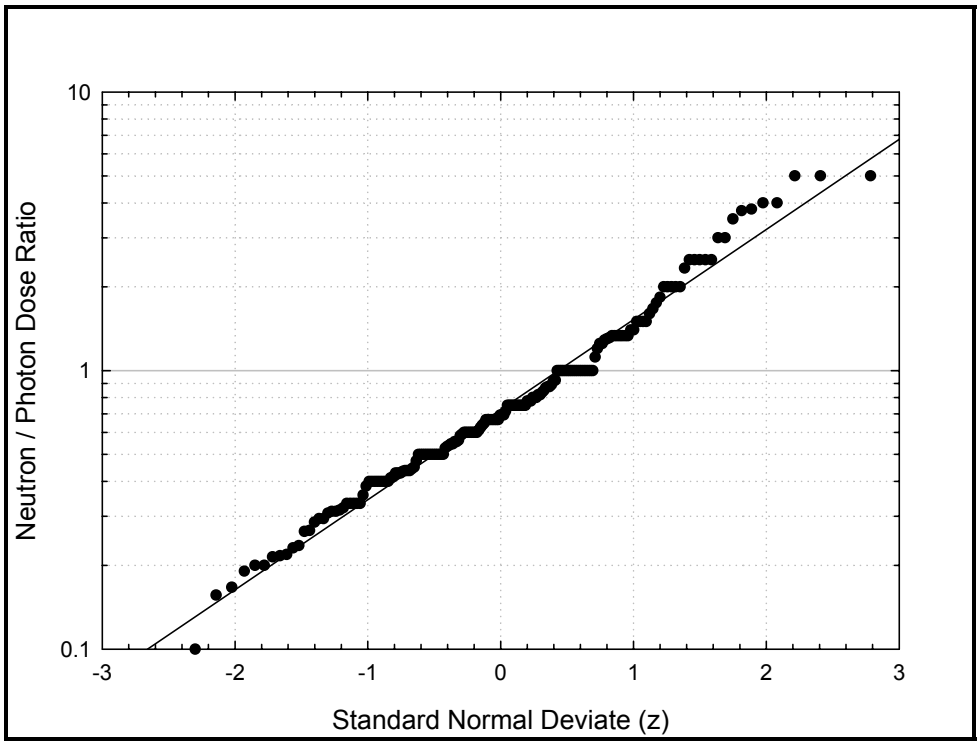

Figure 8. Lognormal probability plot of Hanford plutonium facility worker measured neutron-to-photon dose ratio.

dose at IAAP and the retrospective analysis of early doses, it is recommended to use this distribution of neutron-to-photon ratios of 2.5 (i.e., 2.47 rounded to 2.5) to estimate neutron doses to IAAP workers prior to 1960.

The respective statistical parameters for the lognormal distribution of neutron-to-photon dose ratios for application to dose reconstruction for IAAP monitored workers are presented in Table 13.

Table 13. Statistical parameters for lognormal probability distribution for neutron-to-photon dose ratios.

Parameter	Neutron-to-photon dose ratio	
	Pre-1960	1960–1975
Geometric Mean	0.7	0.8
Geometric Standard Deviation	2.1	1.5
Upper 95% percentile	2.5	1.6

This estimate of the neutron dose must be adjusted to include the conversion to the ICRP Publication 60 neutron weighting factor required for input of the dose into the Interactive RadioEpidemiological Program (IREP) by using the assumed neutron energy and dose fraction listed in Table 14 (ICRP 1994). The approach can be simplified using the following expressions:

Neutron dose = adjusted photon dose × upper 95% percentile neutron/photon dose ratio × ICRP 60 CF

Table 14. IAAP neutron dose fractions and associated ICRP 60 correction factors.

Process	Description/buildings	Neutron energy (MeV)	Default dose fraction (%)	ICRP 60 correction factor (CF)
Nuclear weapon component assembly	Neutron exposure associated with weapon assembly and disassembly activities.			
		0.1 - 2 MeV	100	1.91

3.7.3 Skin and Extremity Dose (Reserved)

3.7.4 IAAP Facilities

The IAAP archival information associated with the DOE program to screen former workers for potential occupational health conditions provides a summary of IAAP facilities with some potential for radiation exposure to workers. Table 15 lists such facilities.

3.7.5 IAAP Nuclear Workers

An historical summary of IAAP workers associated with nuclear weapons assembly activities or with industrial radiography activities has not been located. Some information from archival records from 1949 through 1973 for workers associated with Division B nuclear weapon assembly activities is listed in Table 16 along with the total number of workers monitored based on IAAP reports to the AEC (Form 190) from 1962 to 1975 (AEC 1962-1973b). These sources of data are generally consistent, although the exact number of workers in Line 1 or Division B activities is not fully known and not all of these workers were monitored as shown in the AEC Form 190 information.

3.7.6 Summary of Dose Reconstruction Recommendations

Substantial information necessary to evaluate worker exposure primarily during the early years is not available. Therefore, the following claimant-favorable assumptions have been made:

Table 15. IAAP facilities handling radiation.

Building number	Description	Use	Comments
1-11	Vault storage for components (pits)	Received and unloaded pits, some assembly.	Stationary air monitors in building. Some contamination measured at squash press area and squash removal area.
1-12	High explosives, fabrication, pressing and machining	Explosives pressed beginning mid-to-late 1960s.	Radiation swipe sampling, 1972-1975.
1-13	Assembly area, U-235 pits		Assembly of larger nonplutonium weapons (U-235) detonators and covers. Radiation swipe data - 1974 for bays A-G.
1-18	Research and Development		References to disposing of radioactive waste (1971)
1-19	Assembly bays	"Experimental Building"	Tritium monitors
1-61	Assembly area, U-235 pit assembly	Nonplutonium-bearing weapons (i.e., uranium) 1950-1953 (dates not confirmed)	Tritium monitors
1-63	Operating bays and assembly cells, plutonium pits post 1956	Cells with Gravel Gerties (i.e., used to contain distribution of radioactive material in event of accident).	Built after 1957 as area to bring together explosives and plutonium physics package (prior to 1957 fissionable material inserted in flight). Tritium monitors.
1-63-7	Assembly cell	Gravel Gerty	
1-64	Storage	Including pit storage	
1-65			
1-66-1 1-66-2			Radiation swipe data, 1972-73
1-67			Radiation swipe data, 1972-73
1-73	Storage and receiving	Storage and receiving in early years until about 1957, then used as pit storage 1957 to late 1960s.	Pits were received in 1958, nuclear weapons built until 1-63 building was built, then was used as storage area for pits.
1-77	Pit storage and inspection	Pit receiving and inert assembly, built in mid-1960s	Radiation swipes and air sampling data, tritium bottles were charged here.
1-80			Radiation swipes data 1974
1-85-2			For subcomponents of depleted center items. Building built but not used by AEC.
1-100	X-Ray	Linitron X-ray	Radiation - explosives X-rayed for air cavities
1-100-1	X-Ray	X-ray facility and film development center	
1-100-2	X-Ray	X-ray built for Linitron accelerators	Built but not used

- The period of IAAP worker handling of nuclear weapon components (baratols) started in 1948 even though significant activity probably did not occur until the early 1950s. The actual date of the start of nuclear weapons assembly has not been discovered and interviews with several retired plant workers lead to disparate dates.

- Utilize options listed in Table 17 to reconstruct photon, neutron, skin (Reserved) and skin+extremity doses (Reserved) using the DOE reported deep, skin, neutron and/or extremity dose. For all years, the highest value for each dose parameter and for each year should be used.

- Because of the overall uncertainty, a claimant-favorable assumption is recommended to assume that 100% of the neutron dose to the worker results from 0.1 to 2 MeV neutrons based on measurements at Pantex. These assumptions will provide the most claimant-favorable estimates of organ dose and probability of causation for most types of cancer.

- Because of the overall uncertainty, a claimant-favorable assumption is recommended to assume that 100% of the photon dose to the worker results from 30- to 250-keV photon

Table 16. IAAP total manpower and Division B workers, and AEC Form 190 reported nuclear and monitored workers.

Calendar year	IAAP archive data[a]		IAAP AEC Form 190	
	Manpower	Division B	Total	Monitored
1948				0
1949				0
1950				0
1951	4,879			0
1952	6,739	1,535		0
1953	4,603			0
1954	2,150			0
1955	2,020			0
1956	1,803			0
1957	1,621			0
1958	1,945			0
1959	2,019			0
1960	1,951			0
1961	2,012			0
1962	2,137		1,030	29
1963	2,173		796	41
1964	1,276	920	650	36
1965	1,268	979	692	35
1966	2,629	1,081	824	62
1967	6,066		818	61
1968	6,278		798	131
1969	6,218		812	152
1970	4,014		803	243
1971	3,330		825	293
1972	3,170		818	312
1973	1,807		635	226
1974	1,462			
1975	1,255			
IAAP nuclear assembly activities transferred to Pantex				

a. Information collected by the University of Iowa.

Table 17. Summary of IAAP worker claimant-favorable dose reconstruction options.

Dose	Period	Monitored worker	Unmonitored worker
Photon dose	<1958	Reserved	Reserved
	1958-75	Fig. 6, Tables 7, 12	Table 7
Neutron dose	<1958	Reserved	Reserved
	<1961	Fig. 7, Table 13	n.a.
	1961-75	Fig. 8, Table 13	n.a.
Skin dose (Reserved)	<1961	Reserved	n.a.
Skin + extremity dose (Reserved)	<1961	Reserved	n.a.

n.a. normally not applicable

radiation. The exposure to dose conversion factors should be used. These assumptions will provide the most claimant-favorable estimates of organ dose and probability of causation for most types of cancers.

The methods to reconstruct dose are presented in Attachment B. Using the above claimant-favorable assumptions for retrospective calculation of IAAP workers dose, there is no need to correct further the

recorded dose for underestimates in film dosimeter response because of lower energy photon radiation, which probably was not significant based on the sealed (and therefore shielded) nuclear components and the available nonpenetrating dosimeter data that implies a relatively low lower energy component (i.e., many nonpenetrating doses shown as zero).

3.7.7 Radiation Dose Fraction

Table 18 summarizes the recommended fractions for IAAP dose according to the energy categories required by IREP. For the photon dose, 100% is assigned to the 30 to 250-keV category and for the neutron dose, 100% is attributed to the 0.1- to 2-MeV category. This will provide claimant-favorable analysis of the organ dose and probability of causation for most cancers.

Table 18. Beta, photon, and neutron radiation energies and percentages for IAAP external radiation exposures.

Process/ buildings	Description	Operations		Radiation type	Energy selection	%
		Begin	End			
Line 1 or Division B (see Table 15 and Att. A)	Assembly and disassembly of nuclear weapon (i.e., depleted uranium, enriched uranium, plutonium) components.					
	Parameters to estimate dose to "whole body" organs	1949	1975	Beta	> 15 keV	100[a]
				Photon	30–250 keV	100[b]
				Neutron	0.1-2 MeV	100[c]
Radiography (see Table 15 and Att. A)	Industrial radiography					
	Parameters to estimate dose to whole-body organs	1948	1975	Beta	> 15	100
				Photon	30–250 keV	25
					> 250 keV	75

a. Beta particles from depleted or enriched uranium are greater than 15 keV.
b. Most photons from depleted uranium are greater than 30 keV; some are greater than 250 keV unless shielding materials are present, assuming that 100% of the photons from depleted uranium are between 30 and 250 keV is claimant-favorable.
c. The neutron energy region of 0.1 – 2 MeV was selected to be claimant-favorable for whole-body dose to provide the highest calculated organ dose.

3.8 UNCERTAINTY IN PHOTON AND NEUTRON DOSE

For the usual analysis of measured film badge doses, the minimum detection levels (MDLs) quoted in the literature range from about 30 to 50 mrem for beta/photon irradiation; it is possible to read a photon dose of 100 mrem to within ±15 mrem if the exposure involved photons with energies between several hundred keV and several MeV (Morgan 1961). The estimated standard error in recorded film badge doses from photons of any energy is ±30%. Estimation of the measured neutron dose is not nearly as precise as for photons. With NTA films, the estimated standard error is much larger and varied significantly with the energy of the neutrons.

For the calculated photon and neutron dose assigned to IAAP workers, the estimated standard error for the assigned photon and neutron dose is ±30% and ±50%, respectively.

3.9 ORGAN DOSE

Once the photon and neutron doses and their associated standard errors have been calculated for each year, the values are used to calculate organ doses of interest using NIOSH (2002). There are many complexities and uncertainties when applying organ dose conversion factors to adjusted doses of record. Many of the factors that affect the dose of record have been discussed in tables in this TBD. ICRU (1988) indicated that film badge dosimeters, while not tissue-equivalent, can be used for personnel dosimetry. It also indicated that it is more difficult to ensure that the variation in response with energy and angle of incidence with low energy. Given the many uncertainties, especially with

film badge dosimetry in the 1950s to the 1970s, a claimant-favorable approach is used to estimate organ dose. The exposure to organ dose conversion factors shown in Table 19 results in a higher organ dose and higher probability of causation, given the Radiation Effectiveness Factors (REFs) of the intermediate energy photons. As such, these dose conversion factors (DCFs) are used to convert recorded film badge gamma (photon) doses to organ dose. For neutrons, the deep dose to organ dose conversion factors are shown in Table 20. In the conversion of all photon and neutron doses of record to organ doses, the exposure geometry must be given careful consideration. The anterior-posterior exposure geometry is used to estimate the organ dose to conduct an initial screening.

Table 19. Annual photon exposure to organ dose conversion factors.[a]

Organ	Exposure to organ dose factors (A-P geometry)		
	< 30 keV	30-250 keV	>250 keV
Bladder	0.175	1.244	0.883
Bone (red marrow)	0.025	0.626	0.720
Bone (surface)	0.209	1.229	0.764
Breast (female)	0.561	1.266	0.930
Colon	0.075	1.060	0.844
Esophagus	0.014	0.688	0.745
Eye	0.936	1.236	0.880
Gonads (female-ovaries)	0.047	0.955	0.819
Gonads (male-testes)	0.622	1.434	0.941
Liver	0.106	1.064	0.845
Lung	0.100	0.986	0.842
Remainder organs	0.071	0.879	0.787
Skin	0.504	0.892	0.835
Stomach	0.182	1.251	0.885
Thymus	0.288	1.408	0.892
Thyroid	0.473	1.440	0.972
Uterus	0.061	1.011	0.786

a. OCAS-IG-001, Rev 1(NIOSH 2002).

Table 20. Annual neutron deep dose equivalent to organ dose conversion factors.[a]

Organ	Deep dose equivalent to organ dose factors (A-P geometry)		
	10-100 keV	0.1-2 MeV	2-20 MeV
Bladder	1.268	0.796	1.105
Bone (red marrow)	0.651	0.361	0.720
Bone (surface)	0.656	0.436	0.675
Breast (female)	1.111	1.145	1.121
Colon	0.947	0.490	0.912
Esophagus	0.775	0.412	0.869
Gonads (female-ovaries)	0.935	0.424	0.903
Gonads (male-testes)	1.466	1.307	1.222
Liver	0.983	0.641	0.990
Lung	0.737	0.557	0.950
Remainder organs	0.819	0.525	0.889
Skin	0.986	0.853	0.918
Stomach	1.221	0.824	1.099
Thyroid	1.066	1.086	1.123

a. OCAS-IG-001, Rev 1(NIOSH 2002)

Some of the more common exposure geometries encountered in the workplace are defined as follows:

- An AP exposure is typical for an individual who works in a directional radiation field and faces the source of the radiation source, such as a nuclear weapon component, while working.

- A rotational (ROT) exposure is typical of an individual who is constantly turning in a directional radiation field, such as when conducting inventories in the nuclear weapon storage vaults, while working.

- An isotropic (ISO) exposure is typical of a worker involved in activities involving a highly nondirectional or omnidirectional radiation field. An example of a work facility with an omnidirectional radiation field that leads to ISO irradiation of a worker might be maintenance activities where scattered neutrons and photon radiation are incident on the worker from all directions.

The proposed initial screening option to identify likely noncompensable cases based on claimant-favorable organ dose estimates for long-term workers is to use the organ dose factors for an anterior-posterior exposure geometry as shown in Tables 19 and 20. Claims that require a more realistic assessment to determine compensability should consider the geometries mentioned above. NIOSH (2002) appendix B provides dose conversion factors to convert IAAP worker photon and neutron dose to the primary organ dose for many selections of exposure geometry, target organ and radiation quantities.

4.0 OCCUPATIONALLY RELATED MEDICAL X-RAYS

Medical examinations at the IAAP were similar to those at Pantex. A chest X-ray was given to each IAAP employee annually. There is also evidence that male employees in certain job categories (heavy lifters, perhaps) received lumbar spine examinations, the frequency of which was not available. At Pantex lumbar spine examinations were given to men when they were hired. Because the operating contractor was the same at Pantex and the IAAP AEC facilities, the same protocol was assumed for lumbar spine X-rays at IAAP.

Background information on X-ray doses can be found in *Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures* (NIOSH 2003). No information concerning X-ray machine parameters pertinent to dose received by the workers was uncovered. Therefore, default values provided in the NIOSH document (2003) should be used for chest X-rays (Tables 3.3-1 and 4.0-1). Assume an annual posterior-anterior (PA) chest X-ray for all employees applicable from 1947 through 1975. Do not apply X-ray dose for years other than 1947 through 1975, regardless if the worker was employed at IAAP during other years.

NIOSH (2003) does not provide default values for lumbar spine examinations. The Occupational Medical Dose TBD for the Rocky Flats site (ORAU 2004b) provides a method for calculating organ doses from lumbar spine examinations. Estimated median entrance skin exposures were 1.79 R for the PA view and 5.79 R for the lateral view based on information in Lincoln and Gupton (1958). Distributions of entrance skin exposures were created using the Crystal Ball® computer program (Decisioneering Inc. 2000) for different filtration half-value layers (HVL) as presented in Lincoln and Gupton. Tables A2 through A8 in ICRP Publication 34 provide organ doses in units of mGy per Gray entrance skin exposure for the thyroid, ovaries, testes, lungs, female breast, uterus, and active bone marrow (ICRP 1982). For practical purposes the units can be considered mrem per R. Multiplying the entrance skin exposure to the kerma-to-organ dose factors in ICRP Publication 34 results in the

organ doses and geometric standard deviations listed in Table 21, varying the HVL from 1.5 to 3.0 mm AL. NIOSH (2003) provides guidance for dose to organs not provided in ICRP 34 by relating their proximity to organs that are listed in ICRP 34. To account for a field of direct exposure larger than that used by ICRP 34 (as might have happened in the 1940s and 50s), additional organs were added to the ovary category, including stomach, kidneys, adrenals, and pancreas. Organs not listed by ICRP 34 but arbitrarily added by proximity are listed in Table 21 after the ICRP 34 organ. For skin.

Table 21. Organ doses from lumbar spine X-rays at IAAP.

Organ	View	Organ dose geometric mean (GSD) (mrem)
Thyroid, eye, brain	PA	0.50 (3.0)
	LAT	0.10 (1.9)
Ovaries, liver, gall bladder, stomach, intestines, colon, rectum, kidneys, adrenals, pancreas, spleen	PA	330 (2.6)
	LAT	230 (2.1)
Lungs, thymus, esophagus, bone surfaces	PA	120 (2.5)
	LAT	64 (2.0)
Active bone marrow	PA	58 (2.6)
	LAT	110 (2.1)
Testes[a]	PA	26 (3.1)
	LAT	40 (1.5)
Skin[a]	PA	1,800 (2.4)
	LAT	5,800 (1.8)

a. Calculated from information in Lincoln and Gupton (1958) as presented in the Rocky Flats site TBD (ORAU 2004b).

and testes, consistent with the approach taken in the Rocky Flats Occupational Medical Dose TBD, the values measured in the Lincoln and Gupton paper were used directly to account for the difference in collimation in the Lincoln and Gupton measurements versus ICRP 34 factors.

The PA view should be used unless person-specific information is found indicating otherwise. The lumbar spine organ dose should be assigned to males in the year of hire from 1947 through July 1975. The dose is assigned in the year of hire and is assumed to be lognormally distributed.

5.0 OCCUPATIONAL ENVIRONMENTAL DOSE

5.1 INTRODUCTION

The occupational environmental dose refers to the dose received by workers on the site but outside facilities. These doses can be internal and external depending on the characteristics of the individual radionuclides. Radionuclides present at IAAP include tritium, uranium, plutonium, and thorium. No noble gases are used or released at the IAAP site. While most radionuclides when inhaled would give a dose to particular organs in the body, tritium gas would give a dose to the whole body. These radionuclides are addressed in the following sections.

5.2 INTAKES FROM ONSITE ATMOSPHERIC RADIONUCLIDE CONCENTRATIONS

Intakes to workers outside facilities are determined from air concentrations that resulted from individual facility releases and ground-level releases (e.g., burning activities). Unmonitored workers could have received internal or external occupational doses (or both) from any or all of these sources.

5.2.1 Intakes from Tritium Releases

As indicated in Section 2, there were no records of atmospheric releases at IAAP. The University of Iowa Needs Assessment for IAAP (Fuortes 2001) quotes an annual release of 0.006 Ci (6,000 µCi) of tritium from the site; however, an effluent summary document lists a total of 0.13 Ci for the period December 1965 through December 1970, for an average of 26,000 µCi per year. To be claimant-favorable, the latter value was used. In comparison to other sites that handled tritium, this release level is very small and provides some indication that not much tritium escaped containment. It is likely that most of the tritium released from stacks or vents was tritium gas, whereas the worker dose would come from tritiated water.

To estimate the intakes to workers outside facilities when little or no atmospheric information is available, the NCRP has suggested screening techniques. These techniques were originally published as NCRP Commentary No. 3 (NCRP 1989) and updated in NCRP Report 123 (NCRP 1996). The NCRP recommends a graded approach, with three screening levels. Level 1 is the most conservative and requires the least amount of input information. The Level 1 method for determining a conservative upper bound air concentration can be written as:

$$X(pCi/m^3) = f * Q(pCi/sec) / V(m^3/sec)$$

where
- X is the annual average upper-bound air concentration,
- f is an assumed fraction of time the wind blows in the direction of the subject, assumed to be 0.25,
- Q is the release rate of the radionuclide from the source, and
- V is the volumetric flow rate of the vent. The default value is 0.3 m^3/sec, typical of hood ventilation rates.

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

Supporting documentation for Federal Guidance Report 13 (Eckerman et al. 1999) shows that dose per unit intake of tritium in the form of water vapor (HTO) is 10,000 times larger than the dose per unit intake for elemental tritium gas (HT). 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.

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

$$26{,}000\ \mu Ci/yr * 1 \times 10^6\ pCi/\mu Ci * 0.25\ */\ (3.15 \times 10^7\ sec/yr * 0.3\ m^3/sec) = 688\ pCi/m^3$$

Assuming a breathing rate of 2400 m^3/yr and assuming all the tritium is in the form of water results in an estimated annual intake of

$$688\ pCi/m^3 * 1.5 * 2{,}400\ m^3 = 2.5 \times 10^6\ pCi.$$

This intake is claimant-favorable because it uses the highest value for tritium releases, assumes minimal dilution between the release point and the worker, and much, perhaps most, of the inhaled tritium would have been tritium gas. The dose reconstructor should assign a 2,500,000-pCi intake per year as HTO to all workers (chronic, 6,800 pCi/d). The annual doses from these intakes are constant upper bound distribution types for input into IREP.

5.2.2 Intakes from Release of DU from Burning Sites

High explosives contaminated with DU were routinely burned in the Explosive Disposal Area, which is an irregularly shaped region of slightly less than 1 square mile just north of the "C" Yard and about 1 km south southwest of Line 1.

The source term has been determined to be about 2,000 g/year of DU (TN & Associates 2001). This is an estimate of the material handled in the burn yard. Burning of DU-contaminated high explosives can be assumed to create aerosolized particles of DU. The most likely form of uranium released in the air from the burning would be in the form of an oxide, although the TN & Associates report suggested that much of the metal might not have been oxidized because the temperature was too low and the burning of explosives too rapid. Because uranium metal and some uranium oxides can exist in a chemical form associated with absorption type M, dose reconstructors should assume exposure to either type S or type M to maximize the dose to the organ/tissue of concern.

The burning was sufficiently frequent that modeling might consider it a continuous source during normal working hours. Thus, the 2,000 g/yr can be estimated as 1 g/work-hr.

The NCRP screening models for atmospheric releases provide a generic and conservative approach for estimating atmospheric dispersion (NCRP 1996). This approach is

$$C = f\ Q\ P/\ U$$

where C is the annual average air concentration, g/m^3,
f is the fraction of time the wind blows in the direction of the subject, assumed to be 0.25,
Q is the release rate, g/sec, and
U is the average wind speed, assumed to be 2 m/sec.

Values of P are provided in NCRP (1996, Figure 2.2). For ground-level releases for distances of 100 m, 500 m, and 1000 m, the values are 3.5×10^{-3}, 2.0×10^{-4}, and 5×10^{-5}, respectively.

Individuals not directly involved in the burning operations could have been anywhere on the IAAP Site. The nearest portions of the C Yard are about 500 m, and the nearest portions of Line 1 are about 1,000 m away. The average calculated air concentration at 500 m is about 6.9×10^{-9} g/m^3; and at 1,000 m C is about 1.7×10^{-9} g/m^3, assuming that all the DU becomes airborne, certainly a conservative upper bound. This approach neglects lofting of the plume caused by heat from the fire, which would reduce the calculated concentrations.

Assuming a breathing rate of 2400 m^3/yr, the amount inhaled at a location in or near the C Yard would be:

$$6.9 \times 10^{-9}\ g/m^3 * 2{,}400\ m^3/yr = 1.7 \times 10^{-5}\ g/yr \text{ or } 6.3\ pCi/yr\ DU.$$

Similarly, for locations at or beyond Line 1:

$$1.7 \times 10^{-9}\ g/m^3 * 2{,}400\ m^3/yr = 4.1 \times 10^{-6}\ g/yr \text{ or } 1.5\ pCi/yr\ DU.$$

If there is no information regarding location of worker activities, use the claimant-favorable C yard value.

5.3 EXTERNAL DOSE

Dosimetry records for IAAP indicate that radiation workers were the only employees monitored for radiation exposure. These personnel worked primarily in facilities in Line 1, the Explosive Disposal Area, and the Firing Site. It is likely that workers handling, transporting, or storing weapons and weapon parts were monitored. Radiation workers accounted for a small fraction of the workers on the site. Employees working in other areas of the site were not monitored and there was a potential for external dose from occupational environmental sources.

Workers at IAAP were subjected to external doses from the ambient radiation levels on the site. From at least 1955 through1975, film badges were used for radiation monitoring of personnel and fixed operating areas. Before 1966, surveys of ambient radiation levels were probably measured with pressurized ionization chambers and Geiger-Mueller detectors. However, because no records of these monitoring activities were found, direct determination of external dose is not possible. Data from the Pantex Plant (ORAU 2004c) indicate that, outside of the nuclear weapons areas, there was no external radiation dose measured by monitoring devices above background anywhere on the Pantex site. Because the same operations were performed at IAAP, it was concluded that no external environmental dose of significance to dose reconstruction would have been received. Therefore, no environmental external dose should be assigned to unmonitored workers outside facilities at IAAP.

5.4 UNCERTAINTY

As discussed above, estimates of annual occupational environmental doses were based on accepted screening techniques (NCRP 1989, 1996). These techniques in themselves rely on considerable conservatism based on nominal values and uncertainties of known parametric values. In addition, the analyses made additional claimant-favorable assumptions, as stated. Because of the scarcity of available environmental data and the use of multiple claimant-favorable assumptions, the environmental intakes should be considered a constant upper bound.

6.0 RADON

Weapons assembly/disassembly was conducted in bays and special cells called Gravel Gerties that were at ground level but had an overlay of earth on the roof and part-way up the sides. Three hundred forty-two radon measurements were taken in various buildings at IAAP by the Army from December 1989 through January 1991 (not including a few outlier values that had been scratched off the dataset) (Tec/Ops Landauer, Inc. 1991). To date the authors have gained access to the results of the measurements, but not the link between results and specific buildings; hence, the information is of marginal value. Nevertheless, the average, standard deviation and geometric mean of the data are less than the corresponding values from the Pantex data discussed below. Without additional information, it was deemed claimant-favorable to use the Pantex data.

A DOE complex-wide survey of radon levels was performed in 1990 (UNC Geotech 1990). Most of the Pantex measurements were made over a 2-month period during the winter, normally expected to be the time with the highest radon concentrations because buildings are closed and heated most of the time. There were 137 locations sampled at Pantex including in bays and Gravel Gerties of similar design to those at IAAP. The data for the Pantex Plant were listed in their entirety in Table 5-11 in the Pantex Internal Dosimetry TBD (ORAU 2004d) and are summarized in Table 22. Pantex radon measurements and dose calculations were assumed to be the best indicators of radon exposure at IAAP, and were used as discussed below.

Table 22. Summary statistics of 1990 radon measurements at Pantex.

Parameter	All buildings	Underground buildings	Above-ground buildings
GeoMean (pCi/L)	1.37	1.51	1.33
GSD	1.68	1.75	1.66
Min (pCi/L)	0.8	0.8	0.8
Max (pCi/L)	8.1	7.1	8.1
Max/Min	10.1	8.9	10.1
Count	137	31	106

As listed in Table 22, the geometric mean (median) for all buildings at Pantex was1.4 pCi/L with a GSD of 1.7. Values ranged from 0.8 to 8.1 pCi/L. Underground buildings had a slightly higher median concentration than above-ground buildings. Gravel Gerties and bays were considered "underground," albeit not below "grade."

The Pantex measured radon concentrations were converted to equilibrium equivalent concentrations by multiplying the radon concentration by the equilibrium factor *F* using an assumed *F* of 0.4, as recommended by the ICRP (1981) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1993). The equilibrium equivalent concentration was divided by 100 pCi/L per working level (WL) to arrive at a potential alpha energy concentration (PAEC). These operations were combined to create

$$PAEC = CxF/100 \text{ pCi/L/WL}$$

where C is the radon concentration in pCi/L and PAEC is in working levels. The PAEC is multiplied by the months per year the worker is exposed to determine the exposure in working level months (WLM) for input into IREP.

Because knowledge of whether a worker spent most of his/her time in a facility with an earthen cover will probably not be obtainable, dose reconstructors should use the Pantex median value for underground buildings, 1.5 pCi/L, for C and 12 months for the period (unless the person only worked for part of a year.) This results in an annual average exposure of

$$(1.5 \text{ pCi/L})(0.4)(12 \text{ M})/100 \text{ [pCi/L]/WL} = 0.072 \text{ WLM per year.}$$

Radon exposure is only assigned when lung is selected as the cancer model in IREP. The exposure distribution is lognormal. Parameter 1 is the median value in working level months. Parameter 2 is the GSD. Use a GSD of 3 to allow for uncertainties in the application of the 1990 radon measurements to the full time period 1948-1975 and possible differences between Pantex and IAAP.

7.0 YEARLY INTAKES

Attachment C, Table C-1 summarizes intakes by workers from both workplace tasks (Section 2), environmental releases (Section 5) and radon (Section 6).

REFERENCES

AEC (US Atomic Energy Commission), 1955, "Intercomparison of Film Badge Interpretations," *Isotopics*, April.

AEC (US Atomic Energy Commission), 1962–1973a, *Summary of Radiation Exposures Resulting In the Internal Body Deposition of Radioactive Material For The Year*, AEC Form 191 submitted by Mason & Hanger-Silas Mason Co. Inc., Burlington, Iowa.

AEC (US Atomic Energy Commission), 1962–1973b, *Summary of Radiation Exposures To External Penetrating Radiation Accumulated During The Year*, AEC Form 190 submitted by Mason & Hanger-Silas Mason Co. Inc., Burlington, Iowa.

ATSDR (Agency for Toxic Substances and Disease Registry), 2003, *Health Consultation – Environmental Pathway Evaluation for Beryllium and Depleted Uranium*, Iowa Army Ammunition Plant, August 15, 2003.

Brinck, W. L., and G. A. Jacobson, 1977, *Trip Report - Iowa Army Ammunition Plant - September 7, 1977*, U. S. Environmental Protection Agency, September 12.

Carbaugh, E. H., 2003 (or current version), *Methods and Models of the Hanford Internal Dosimetry Program*, PNL-MA-860, available from Radiological Records files or on the Internet at http://www.pnl.gov/eshs/cap/dss/epub.html.

Davis, C. E., 1969, *Health Protection Survey Report, Burlington AEC Plant*, report on annual health protection survey by the AEC Albuquerque Office of Burlington operations held September 17-19, 1969 (ORAU file locator 000923).

Decisioneering Inc., 2000, *Crystal Ball 2000 User Manual*, Denver, Colorado.

DOE (U.S. Department of Energy), 1986, *Department of Energy Standard for the Performance Testing of Personnel Dosimetry Systems*, DOE/EH-0027, Washington, D.C.

DOE (U.S. Department of Energy), 1994, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities, Volume 1 – Analysis of Experimental Data*, DOE Handbook DOE-HDBK-3010-94, Washington, D.C.

DOE (U.S. Department of Energy), 1997, *Linking Legacies*, DOE/EM-0319, Washington, D.C.

Eckerman, K. F., R. W. Leggett, C. B. Nelson, J. S. Puskin, and A. C. B. Richardson, 1999, Cancer Risk Coefficients for Environmental Exposure to Radionuclides, Federal Guidance Report No. 13, CD Supplement, U.S. Environmental Protection Agency Report EPA 402-R-99-001 (National Technical Information Service, Springfield, Virginia).

Finney, D. J.,1971, *Probit Analysis,* Cambridge University Press, New York, New York.

Fix, J. J, E. S. Gilbert, and W. V. Baumgartner, 1994, *An Assessment of Bias and Uncertainty in Recorded Dose from External Sources of Radiation for Workers at the Hanford Site*, PNL-10066, Pacific Northwest Laboratory, Richland, Washington.

Fix, J. J., and D. E. Bihl, 2003, "Transcription of telephone discussion on December 19, 2003 with Don Bihl and Jack Fix," letter to J. Shannan with attached notes from telephone interview.

Fuortes, L., 2001, Burlington Atomic Energy Commission Plant - Former Worker Program - Needs *Assessment- December 2001*, College of Public Health, University of Iowa, Iowa City, Iowa.

ICRP (International Commission on Radiation Protection), 1968, Report of Committee IV on *Evaluation of Radiation Doses to Body Tissues from Internal Contamination due to Occupational Exposure*, Publication 10, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection), 1981, *Limits for Inhalation of Radon Daughters by Workers*, Publication 32, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiation Protection), 1982, *Protection of the Patient in Diagnostic Radiology*, Publication 34, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection), 1991, "1990 Recommendations of the International Commission on Radiological Protection," *Annals of the ICRP*, Publication 60, Pergamon Press, Oxford, England.

ICRU (International Commission on Radiation Units and Measurements), 1988, *Determination of Dose Equivalents from External Radiation Sources*, Part 2, Report 43, Bethesda, Maryland.

ICRU (International Commission on Radiation Units and Measurements), 1993, *Quantities and Units in Radiation Protection Dosimetry*, Report 51, Bethesda, Maryland.

JAYCOR (JAYCOR and ICAIR Life Systems, Inc.), 1996, *Remedial Investigation/Risk Assessment Iowa Army Ammunitions Plant Revised Draft Final*, 11 Volumes, May 21.

Landauer (R. S. Landauer, Jr. and Company), *Reports of film badge exposure for selected periods during 1955 - 1975*, Matteson, Illinois (ORAU file locators 000935 – 000955).

Lincoln, T.A. and E.D. Gupton, 1958, "Radiation Doses in Diagnostic X-ray Procedures," Radiology. 71:208-215.

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

Meek, L., and L. S. Shahan, 1972, *Natural and Depleted Uranium (D-38) Concentration in the IAAP Area*, BAECP Technical Report 181 Part 5, Burlington Atomic Energy Commission Plant, May 11.

Morgan, K. Z., 1961, "Dosimetry Requirements for Protection from Ionizing Radiation," in *Selected Topics in Radiation Dosimetry*, International Atomic Energy Agency, Vienna, Austria, pp. 3-23.

NBS (National Bureau of Standards), 1959, *Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water*, Handbook 52, U.S. Department of Commerce, Government Printing Office, Washington, D.C.

NCRP (National Council on Radiation Protection and Measurements), 1989, Screening Techniques for Determining Compliance with Environmental Standards - Releases of Radionuclides to the Atmosphere, NCRP Commentary No. 3, Bethesda, Maryland.

NCRP (National Council on Radiation Protection and Measurements), 1996, Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground, Report No. 123, Volume 1, Bethesda, Maryland.

NIOSH (National Institute for Occupational Safety and Health), 2002, *External Dose Reconstruction Implementation Guidelines*, OCAS-IG-001, Revision 1, Office of Compensation Analysis and Support, Cincinnati, Ohio.

NIOSH (National Institute for Occupational Safety and Health), 2003, *Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures*, ORAUT-OTIB-0006, Rev. 0, Office of Compensation Analysis and Support, Cincinnati, Ohio.

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

NIOSH (National Institute for Occupational Safety and Health), 2004b, *A Standard Complex-Wide Correction Factor for Overestimating External Doses Measured with Film Badge Dosimeters*, ORAUT-OTIB-0010, Rev. 0, Office of Compensation Analysis and Support, Cincinnati, Ohio.

NRC (U.S. Nuclear Regulatory Commission), 1983, *Information for Establishing Bioassay Measurements and Evaluations of Tritium Exposure*, NUREG-0938, National Technical Information Service, Springfield, Virginia.

ORAU (Oak Ridge Associated Universities), 2003, *Technical Basis Document for the Hanford Site – Occupational External Dosimetry*, ORAUT-TKBS-0006-6, Rev. 0, Oak Ridge, Tennessee.

ORAU (Oak Ridge Associated Universities), 2004a, *Technical Basis Document for the Pantex Plant – Occupational External Dosimetry*, ORAUT-TKBS-0013-6, Rev. 0,Oak Ridge, Tennessee.

ORAU (Oak Ridge Associated Universities), 2004b, *Technical Basis Document for the Rocky Flats Plant – Occupational Medical Dose*, ORAUT-TKBS-0011-3, Rev. 0, Oak Ridge, Tennessee.

ORAU (Oak Ridge Associated Universities), 2004c, *Technical Basis Document for the Pantex Plant – Occupational Environmental Dosimetry*, ORAUT-TKBS-0013-4, Rev. 0, Oak Ridge, Tennessee.

ORAU (Oak Ridge Associated Universities), 2004d, *Technical Basis Document for the Pantex Plant – Occupational Internal Dosimetry*, ORAUT-TKBS-0013-5, Rev. 0, Oak Ridge, Tennessee.

ORAUT-TKBS-0001. 2003. Technical Basis Document: *Basis for Development of an Exposure Matrix for Bethlehem Steel Corporation.* Rev 00, March 31, 2003, Oak Ridge Associated Universities (ORAU), Oak Ridge, TN.

Pantex, 2001, *Internal Dosimetry Technical Basis and Quality Assurance Document,* RSD-TBD-0001, Rev. 03, BWXT Pantex, Radiation Safety Department, Amarillo, Texas.

Poole, C.R. and K.C. Harrison, 1954. "Project History of Line 1 Operations at Iowa Ordnance Plant, January 1, 1947 through July 1, 1954," Silas Mason Company, Inc., Burlington, Iowa. ORAU file locator 001487.

Shleien, B., L. A. Slayback, and B. K. Birky, 1998, *Handbook of Health Physics and Radiological Health*, Third Edition, Williams & Wilkins, Baltimore, Maryland.

Shaykin, J. 1969, *Health Protection Appraisal Report – Burlington AEC Plant*, ORAU file locator 000922, January.

Tech/Ops Landauer, Inc. 1991. "Radon Monitoring Report for Mason & Hanger-Silas Mason, Co, Inc. – c/o Iowa Army Amm. Plant." Process Nos. A11370 and A11371, March 22, 1991, (file locator 000xxxx)

Thierry-Chef, I., F. Pernicka, M. Marshall, E. Cardis, and P. Andreo, 2002, "Study of a Selection of 10 Historical Types of Dosimeters: Variation of the Response of Hp(10) with Photon Energy and Geometry of Exposure," *Radiation Protection Dosimetry*, volume 102, number 2, pp. 101-113.

TN & Associates, Inc., 2001, *Work Plan for Supplemental Remedial Investigation for Line 1 (Including Historical Site Assessment) for the US Army Corps of Engineers*, final draft, September (file locator 000910)

UNC Geotech, 1990, *Results of the U.S. Department of Energy Indoor Radon Study Volume 1*, DOE/ID/12584-75 v.1, U.S. Department of Energy, Grand Junction, Colorado.

Unruh, C.M., H.V. Larson, T. M. Beetle and A.R. Keene, 1967, *The Establishment and Utilization of Film Dosimeter Performance Criteria*, BNWL-542, Battelle Northwest Laboratory, Richland, Washington.

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), 1993, *Sources and Effects of Ionizing Radiation*.

U.S. Army, 1988, *Review of Draft Endangerment Assessment Iowa Army Ammunitions Plant (IAAP)*, Toxic and Hazardous Materials Agency, November 28.

Vallario, E. J., D. E. Hankins, and C. M. Unruh, 1969, *AEC Workshop on Personnel Dosimetry*, BNWL-1340, Battelle Northwest Laboratory, Richland, Washington.

Wilson, R. H., 1958, "The Hanford Uranium Bioassay Program," unpublished report to file available in Radiation Records Historical Files, Hanford Laboratories, Richland, Washington.

Wilson, R. H., W. V. Baumgartner, J. J. Fix, and L. L. Nichols, 1990, *Description and Evaluation of the Hanford Personnel Dosimeter Program From 1944 Through 1989*, PNL-7447, Pacific Northwest Laboratory, Richland, Washington.

GLOSSARY

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

baratol
A castable mixture of explosives used in nuclear weapons.

beta (β) dose
A designation (i.e., beta) on some Pantex external dose records referring to the dose from less-energetic beta, X-ray, or gamma radiation.

beta radiation
Radiation consisting of charged particles of very small mass (i.e., the electron) emitted spontaneously from the nuclei of certain radioactive elements. Physically, the beta particle is identical to an electron moving at high velocity.

curie
A special unit of activity. One curie (1 Ci) exactly equals 3.7×10^{10} nuclear transitions per second.

deep absorbed dose (D_d)
The absorbed dose at the depth of 1.0 cm in a material of specified geometry and composition.

deep dose equivalent (H_d)
The dose equivalent at the respective depth of 1.0 cm in tissue.

detection limit (lower)
The minimum quantifiable exposure or neutron flux that can be detected.

dose equivalent (H)
The product of the absorbed dose (D), the quality factor (Q), and any other modifying factors. The special unit is the rem. When D is expressed in Gy, H is in sieverts (Sv). (1 Sv = 100 rem).

dose of record
The dose files provided by DOE to NIOSH as part of the individual worker files.

dosimeter
A device used to measure the quantity of radiation received. A holder with radiation-absorbing elements (filters) and an insert with radiation-sensitive elements packaged to provide a record of absorbed dose or dose equivalent received by an individual. (See *film dosimeter*, *neutron film dosimeter*, *thermoluminescent dosimeter*).

dosimetry
The science of assessing absorbed dose, dose equivalent, effective dose equivalent, etc., from external or internal sources of radiation.

dosimetry system
A system used to assess dose equivalent from external radiation to the whole body, skin, and extremities. This includes the fabrication, assignment, and processing of dosimeters as well as interpretation and documentation of the results.

DU
Depleted uranium; uranium having less than the natural mass of ^{235}U; used as components in nuclear weapons or as a surrogate for enriched uranium or plutonium in testing.

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

exposure
As used in the technical sense, a measure expressed in roentgens (R) of the ionization produced by photons (i.e., gamma and X-rays) in air.

extremity
That portion of the arm extending from and including the elbow through the fingertips, and that portion of the leg extending from and including the knee and patella through the tips of the toes.

field calibration
Dosimeter calibration based on radiation types, intensity and energies present in the work environment.

film
Generally means a "film packet" that contains one or more pieces of film in a light-tight wrapping. The film when developed has an image caused by radiation that can be measured using an optical densitometer. (See *Dupont 552*, *Dupont 558*, *Eastman Kodak*, *Nuclear Emulsions*).

film density
See optical density.

film dosimeter
A small packet of film in a holder that attaches to a wearer.

gamma rays (γ)
Electromagnetic radiation (photons) originating in atomic nuclei and accompanying many nuclear reactions (e.g., fission, radioactive decay, and neutron capture). Physically, gamma rays are identical to X-rays but with higher energy; the only essential difference is that X-rays do not originate in the nucleus.

Gerty
A facility covered with crushed gravel used to suppress the potential radioactive contamination from the accidental explosion of a nuclear weapon during assembly. Also referred to as a Gravel Gerty.

Gray
SI unit of absorbed dose. Unit symbol, Gy. 1 Gy = 100 rad.

hydroshot
Detonation of a mixture of explosives and DU used as a quality control technique for measuring the performance of plastic-bonded explosives.

ionizing radiation
Electromagnetic or particulate radiation capable of producing charged particles through interactions with matter.

Line 1
Facilities and operations taken over by the AEC in 1947 for casting of baratols and processes related to the assembly of nuclear weapons.

Minimum Detectable Level (MDL)
A~~l~~ term used in this document and other NIOSH documents to refer to a statistically determined minimum detection level, Lower Limit of Detectability (L_D), and related quantities.

Minimum Reportable Dose (MRD)
A general term used to identify the minimum dose recorded and reported, normally based on site-specific policy.

neutron
A basic particle that is electrically neutral weighing nearly the same as the hydrogen atom.

neutron, fast
Neutrons with energy equal or greater than 10 keV.

neutron, intermediate
Neutrons with energy between 0.5 eV and 10 keV.

neutron, thermal
Strictly, neutrons in thermal equilibrium with surroundings. Generally, neutrons with energy less than about 0.5 eV.

neutron film dosimeter
A film dosimeter that contains a Neutron Track Emulsion, type A, film packet.

nuclear emulsion
Often referred to as “NTA” film and used to measure personnel dose from neutron radiation.

nuclear track emulsion, type A (NTA)
A film that is sensitive to fast neutrons. The developed image has tracks caused by neutrons that can be seen by using an appropriate imaging capability such as oil immersion and a 1000X power microscope or a projection capability.

open window
Designation on film dosimeter reports that implies the use of little shielding. It commonly is used to label the film response corresponding to the open window area.

optical density
The quantitative measurement of photographic blackening with the density defined as D = Log_{10} (I_o/I).

Parameter 1
The column in the IREP template where the dose reconstructor will enter the calculated dose. Multiple entries based on year of employment, type of radiation, and appropriate energy ranges; internal and external exposures are possible.

Parameter 2
The column in the IREP template where the dose reconstructor will enter the lower limit of the dose distribution based on the radiation type and the dose distribution type.

personal dose equivalent $H_p(d)$
Represents the dose equivalent in soft tissue below a specified point on the body at an appropriate depth d. The depths selected for personnel dosimetry are 0.07 mm and 10 mm, respectively, for the skin and body. These are noted as $H_p(0.07)$ and Hp(10), respectively.

photon
A unit or "particle" of electromagnetic radiation consisting of X- or gamma rays.

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

quality factor, Q
A modifying factor used to derive dose equivalent from absorbed dose.

radiation
Alpha, beta, neutron, and photon radiation with sufficient energy to ionize atoms. See also ionizing radiation.

radioactivity
The spontaneous emission of radiation, generally alpha or beta particles, gamma rays, and neutrons from unstable nuclei.

rem
A special unit of dose equivalent, which is equal to the product of the number of rad absorbed and the "quality factor."

roentgen (R)
A unit of exposure to gamma (or x-ray) radiation. It is defined precisely as the quantity of gamma (or x) rays that will produce a total charge of 2.58×10^{-4} coulomb in 1 kg of dry air. An exposure of 1 R is approximately equivalent to an absorbed dose of 1 rad in soft tissue for higher (>100 keV) energy photons.

shallow absorbed dose (D_s)
The absorbed dose at a depth of 0.007 cm in a material of specified geometry and composition.

shallow dose equivalent (H_s)
Dose equivalent at a depth of 0.007 cm in tissue.

shielding
Any material or obstruction that absorbs (or attenuates) radiation and thus tends to protect personnel or materials from radiation.

skin dose
Absorbed dose at a tissue depth of 7 mg/cm^2.

thermoluminescent
Property of a material that causes it to emit light as a result of being excited by heat.

thermoluminescent dosimeter (TLD)
A holder containing solid chips of material that when heated will release the stored energy as light. The measurement of this light provides a measurement of absorbed dose.

whole-body dose
Commonly defined as the absorbed dose at a tissue depth of 1.0 cm (1000 mg/cm^2); however, this term is also used to refer to the recorded dose.

X-ray
Ionizing electromagnetic radiation that originates external to the nucleus of an atom.

ATTACHMENT A
POSITION TITLES AND TASKS

The IAAP was principally an Army ordnance facility with only a fraction of the activities being performed under the direction of or on behalf of the AEC. The EEOICPA applies to the AEC work only. However, at the time of this writing, the OCAS position is that a claim in NOCTS has passed screening and the dose reconstructor should consider the claimant eligible.

However, not every worker doing AEC work at IAAP had the same potential for intakes. Table 17 provides radiation energy assumptions based on tasks, and Table C-1 relates assumed intakes to tasks. The information below provides an attempt to correlate position titles in NOCTS claims folders to the job tasks provided in Tables 17 and C-1. The correlations below should be considered estimates only. If possible, additional information in a worker's file should be used to help determine if an individual worker did the tasks listed in Tables 17 or C-1. Table 14 may also be helpful toward determining potential for exposure in the workplace.

All personnel: any claimant in NOCTS

Machinist: machinist; foreman, repairman, machinist; set-up machinist, maintenance; foreman machine shop; machinist helper; press operator

Assembly/disassembly: production operator line 1; foreman line 1, assembler; assembly; assembly and inspection; assembly line; assembly worker; dismantled nuclear weapons; inspector line 1; line 1 assembly production worker; line 1 worked underground; warhead assembly plant; tore down hydrogen and atom bombs; laborer in production; laborer line 1; load lines line 1; top secret underground; safety engineer; safety inspector; safety technician or anything implying radiation safety worker

Hydroshot operations: driver; firing sites; test fire technician; test site supervisor; test fire specialist, truck driver

Hydroshot cleanup: firing sites; test fire technician; clean-up crew; test fire specialist

Burn yard crew: burning field; supervisor assembly burn yard

Radiography: x-ray technician; metallurgy

Positions with no exposure in the categories above: carpenter, maintenance, component operator, component inspector, electrician, electrical worker, explosive operator, ironworker, insulator, matron (in charge of the clothes changing stations), stoker, melt operator, millwright, pipefitter, administrative positions.

Many job descriptions are vague in relation to the specific tasks listed above; examples are given below. Hopefully, interview information or other information in the claimant's folder can help with assigning workers to tasks.

Position descriptions needing more information: Line 9; engineer, engineering aid, engineering assistant, engineering tech., equipment operator, foreman, IEP operator, inspector, line inspector, machine operator, operating engineer, pipefitter, production worker, production operator, production, production control, production foreman, PS-10 cleaning line.

ATTACHMENT B
OCCUPATIONAL EXTERNAL DOSE FOR IAAP WORKERS

TABLE OF CONTENTS

Section — Page

B1.0 DOE IAAP Dose Records 50

B2.0 Dose Parameters 51
- B2.1 Years of Exposure 52
- B2.2 Rate 52
- B2.3 Radiation Type 52
- B2.4 Radiation Energy and Dose Fraction 52

B3.0 Distribution Parameters 53
- B3.1 Type 53
- B3.2 Parameter 1 53
- B3.3 Parameter 2 56

LIST OF TABLES

Table — Page

B-1 IREP dose parameter input screen 51
B-2 Selection of radiation type, energies and percentages 52
B-3 Distribution parameters for IAAP worker measured photon dose 53
B-4 Missed photon dose adjustments to DOE reported gamma dose 54
B-5 Statistical parameters for lognormal probability distribution for neutron-to-photon dose ratios 54
B-6 IAAP neutron dose fractions, energies, percentages, and associated ICRP 60 correction factors 54
B-7 Annual photon exposure to organ dose conversion factors 55
B-8 Annual neutron deep dose equivalent to organ dose conversion factors 55

B1.0 DOE IAAP DOSE RECORDS

U.S. Department of Energy (DOE)-provided dose of record information for IAAP energy employees might be incomplete for the following reasons:

No records of personnel dosimeter assignment have been located prior to 1955

- Only samples of workers were assigned dosimeters, and then only temporarily, prior to August 1962 when dosimeters were apparently first routinely assigned to workers for each succeeding year.

- Neutron dosimeters were not generally assigned, and the NTA dosimeter used beginning in about 1964 likely did not provide a complete and accurate measurement of neutron dose to workers in IAAP facilities.

- The nonpenetrating dose is often recorded as a blank or zero on the observed dose records when the skin (i.e., nonpenetrating) dose should be equal to or greater than the penetrating dose.

The DOE provided dose of record information generally assigns a skin (nonpenetrating, beta, shallow, etc.) and whole-body (penetrating, gamma, deep, etc.) dose for each year of record. The recorded penetrating photon doses for 1963 through 1975 are expected to reasonably estimate the actual dose at exposure levels significantly greater than the minimum detection level (~0.04 R) of the dosimeter. IAAP nuclear weapon assembly activities are assumed to have first occurred in 1948 and continued until July 1975 when this work was transferred to the Pantex facility. Estimates of IAAP neutron, beta (Reserved) and beta plus extremity (Reserved) doses are based on using lognormal probability distributions of the respective neutron-to-photon, beta-to-photon and beta plus extremity-to-photon dose ratios based on measured IAAP individual worker doses from 1965 through 1975 and measured Pantex individual worker dose during period of 1993 through 2003 using improved dosimeter technology and field validation. The Pantex information is expected to be applicable to IAAP.

IAAP workers involved in nuclear weapons assembly and radiography activities were identified as Line 1 or Division B. The IAAP facilities with potential worker exposure are presented in Table 15.

B2.0 DOSE PARAMETERS

Several technical parameters are considered in the evaluation of the DOE-provided dose of record information for each claim. The focus of this attachment is to identify options for a claimant-favorable analysis of the dose to be assigned to IAAP workers for each year of employment. The recorded doses are often based on less capable technology than currently available and there is often uncertainty in historical radiation monitoring practices. A basis of comparison for a consistent evaluation of the DOE-provided recorded dose through time and among different facilities is the *Personal Dose Equivalent,* Hp(d), where d identifies the depth (in mm) and represents the point of reference for dose in tissue. For weakly penetrating radiation of significance to skin dose, d = 0.07 mm and is noted as *Hp(0.07).* For penetrating radiation of significance to whole-body dose, d = 10 mm and is noted as $H_p(10)$. *Hp(0.07)* and $H_p(10)$ are the radiation quantities recommended for use as the operational quantity to be recorded for radiological protection purposes by the International Commission on Radiological Units and Measurements (ICRU). These are the dose quantities used to accredit DOE dosimetry programs since the mid-1980s.

The primary Interactive RadioEpidemiological Program (IREP) screen used to input dose parameters is presented in Table B-1. Input to these fields is obtained from the DOE-reported dose of record information. The claim provides the primary organ of interest and other worker information needed to run IREP. Guidance for the selection of the external dosimetry parameters in Table B-1 by the dose reconstruction analyst is presented in the following sections.

Table B-1. IREP dose parameter input screen.

Exposure				Distribution parameters			
#	Year	Rate	Radiation type	Type	1	2	3
1	1960	Acute	Photon, 30-250 keV	Normal			
2	1960	Chronic	Neutron, 0.1-2 MeV	Normal			
3	..	..	..	..	..	..	

B2.1 YEARS OF EXPOSURE

The years of exposure during the period from 1948 through 1975 should be identified from employment information on the claim and from DOE radiation dose reports. For unmonitored workers at any time during IAAP employment, an assigned dose is calculated based on the distribution of measured doses for monitored workers. For monitored workers with years with no recorded radiation dose, a missed dose, as described later in this section, is calculated for all zero or missing records. The early period of IAAP operations which apparently involved assembly of nuclear weapon components is uncertain because relevant information such as the number of components handled per year is classified. Therefore, a claimant-favorable assumption is that IAAP Line 1 or Division B nuclear weapon activities began in 1948 and a deep (photon) dose is assigned based on the lognormal probability distribution of measured dose in later years. The photon dose is assigned to each worker for every year of exposure from 1948 through 1975 using the methods described in Section 3 of this TBD and abbreviated in this attachment. (Reserved) Estimates of skin (beta - cancer site on torso) and beta plus extremity (cancer site on extremities) are estimated using lognormal probability distributions of the skin-to-photon dose, and skin plus extremity-to-photon dose ratios obtained from analyses of measured doses for IAAP and Pantex workers.

B2.2 RATE

Acute is selected for all types of external beta and photon dose and *chronic* is selected for neutron dose (NIOSH 2002).

B2.3 RADIATION TYPE

IAAP Line 1 or Division B nuclear weapon assembly workers were exposed, potentially, to beta, photon (X-rays and gamma rays) and neutron radiation. Nuclear weapon components were sealed with a metallic covering that significantly reduces the potential beta and lower energy photon exposure to workers. IAAP workers were likely exposed to depleted uranium (DU) particularly in picking up DU fragments after conventional detonations. The precise circumstances of individual worker exposures to nuclear weapon components are not available. Therefore, claimant-favorable assumptions of the radiation type and energies are recommended using the guidance in Table B-2 based on recent individual worker photon and neutron dose measurements at Pantex. The purpose of the values in this table is to identify options to estimate the parameters used in calculating organ doses for long-term IAAP workers for time spent in any of the facilities listed in Table 14 that are generally identified as Line 1 or Division B.

Table B-2. Selection of radiation type, energies and percentages.

Process/ buildings	Description	Operations		Radiation type	Energy selection	%
		Begin	End			
Line 1 or Division B (see Table 15 or Att. A)	Assembly and disassembly of nuclear weapon (i.e., depleted uranium, enriched uranium, plutonium) components.					
	Parameters to estimate dose to “whole body” organs	1948	1975	Beta	> 15 keV	100
				Photon	30–250 keV	100
				Neutron	0.1-2 MeV	100
Radiography (see Table 15 or Att. A)	Industrial radiography					
	Parameters to estimate dose to “whole body” organs	1948	1975	Beta	> 15	100
				Photon	30–250 keV	25
					> 250 keV	75

B2.4 RADIATION ENERGY AND DOSE FRACTION

Table B-2 summarizes the recommended IAAP dose fractions according to the energy categories required by the IREP. This will provide claimant-favorable analysis of the organ dose and probability of causation for most cancers.

B3.0 DISTRIBUTION PARAMETERS

The selection of the distribution parameters in Table B-1 is discussed in the following sections.

B3.1 TYPE

The type of distribution is selected. This determines the definition of Parameters 1 and 2. For a normal and lognormal distribution, Parameter 3 is not used.

B3.2 PARAMETER 1

The assigned photon and neutron dose is determined using the following steps.

Photon Dose, Unmonitored Workers
The dose to unmonitored workers at any time during their employment at IAAP is calculated for each year from the distribution of dose measured for monitored workers. The respective geometric mean and geometric standard deviation is selected for each year of employment from Table B-3. It is assumed that unmonitored (i.e., non-radiation) workers did not and would not receive a significant dose compared that measured for monitored workers. Assigning a photon dose distribution for each year as noted in Table B-3. A neutron dose is not calculated for unmonitored workers since it is not expected that significant neutron dose would be received.

Monitored Workers
Workers are considered to have been monitored if, at any time during IAAP employment, a dose is assigned as noted in the DOE dose report. The DOE reported photon dose (i.e., whole-body, penetrating, or gamma) for IAAP workers will provide a reasonable estimate of the $H_p(10)$ dose used as parameter #1 for the periods of dosimeter assignment. Missed photon dose for IAAP workers will occur particularly prior to 1955 when no personnel dosimeters were used and during the period of 1955 through 1962 when dosimeters were not used throughout the work year. As such, a missed dose distribution is estimated for each year with parameter #1 calculated from MDL/2 for each dosimeter and exchange period with a zero or less-than (i.e., "m") dose result using information shown in Table B-4. Table B-4 summarizes the potential missed photon dose adjustments according to exchange period if all dose results were zero.

Table B-3. Distribution parameters for IAAP worker measured photon dose.

Year	Lognormal fit	
	Median dose	GSD
1948-57	Reserved	
1958[e]	444	1.88
1959[e]	344	1.22
1960[e]	352	1.33
1961	298	1.24
1962[e]	243	1.14
1963	195	1.70
1964	87	1.51
1965	115	1.83
1966	127	2.04
1967	112	1.95
1968	94	2.01
1969	91	1.80
1970	174	3.27
1971	1.09	4.53
1972	106	2.25
1973	113	2.41
1974	117	2.62
1975[a]		

a. It is understood there is no reported IAAP dose in 1975. However, if necessary, use 1974 parameters.

Table B-4. Missed photon dose adjustments to DOE reported gamma dose.

Period		Dosimeter	MDL[b] (rem)	Exchange frequency	Mean annual missed dose (rem)[c]
Year	Period of use[a]				
1948-55		None			(d)
1955–1962	Occasional	Landauer Film	0.040	Weekly (n=50)	1.0
1962	Occasional prior to 8/1962	Landauer Film	0.040	2-weeks (n=25)	0.50
1963–1975	Routinely	Landauer Film	0.040	4-weeks (n=13)	0.26

a. Prior to 1963, dosimeters were not routinely assigned to IAAP workers throughout an entire year.
b. Estimated MDLs for Landauer film dosimeter in the workplace.
c. Mean annual missed dose calculated from NIOSH (2002).
d. Base estimate for unmonitored workers if there is no recorded dose at any time.

Neutron Dose

The proposed claimant-favorable option, for monitored workers only, is separated into distinct time periods: 1) pre-1959 (reserved) 2) 1958-60 and 3) 1960-through 1975, respectively, is to utilize the distribution parameters shown in Table B-5.

Table B-5. Statistical parameters for lognormal probability distribution for neutron-to-photon dose ratios.

Parameter	Neutron-to-photon dose ratio		
	Prior to 1958	1958 - 1960	1960 - 1975
Geometric Mean	Reserved	0.7	0.8
Geometric Standard Deviation		2.1	1.5
Upper 95% percentile		2.5	1.6

The neutron dose must be adjusted to include the conversion to the ICRP Publication 60 neutron weighting factor required for input of the dose into Table B-1 using factor identified in Table B-6. The approach can be simplified using the following expressions:

Neutron dose = adjusted photon dose × geometric mean neutron/photon dose ratio × ICRP 60 CF

Table B-6. IAAP neutron dose fractions, energies, percentages and associated ICRP 60 correction factors.

Process	Description/buildings	Neutron energy (MeV)	Default dose fraction[a,b] (%)	ICRP 60 correction factor
Nuclear weapon component assembly	Neutron exposure associated with weapon assembly and disassembly activities.			
		0.1 1 2 MeV	100	1.91

Reserved - Beta Dose (skin cancer site on body torso)

Reserved - Beta Dose (skin cancer site on extremity)

Organ Dose

Once the adjusted photon and neutron doses have been calculated for each year with the associated standard deviation, the organ dose is calculated for the primary organ of interest identified in the claim. For photon radiation, the exposure to dose conversion factors should be used to provide a claimant favorable analysis. The proposed initial screening option to identify likely non-compensable cases based on claimant-favorable organ dose estimates for long-term workers is to utilize an anterior-posterior.

NIOSH (2002) appendix B provides dose conversion factors to convert IAAP worker photon and neutron dose to the primary organ dose for many selections of exposure geometry, target organ and

radiation quantities. Photon and neutron organ dose conversion factors for a claimant-favorable analysis of worker anterior-posterior (A-P) exposure are:

- Photon exposure to organ dose conversion factors in Table B-7.
- Neutron deep dose to organ dose conversion factors in Table B-8.

Table B-7. Annual photon exposure to organ dose conversion factors.[a]

Organ	Exposure to organ dose factors (A-P Geometry)		
	< 30 keV	30-250 keV	>250 keV
Bladder	0.175	1.244	0.883
Bone (red marrow)	0.025	0.626	0.720
Bone (surface)	0.209	1.229	0.764
Breast (female)	0.561	1.266	0.930
Colon	0.075	1.060	0.844
Esophagus	0.014	0.688	0.745
Eye	0.936	1.236	0.880
Gonads (female-ovaries)	0.047	0.955	0.819
Gonads (male-testes)	0.622	1.434	0.941
Liver	0.106	1.064	0.845
Lung	0.100	0.986	0.842
Remainder organs	0.071	0.879	0.787
Skin	0.504	0.892	0.835
Stomach	0.182	1.251	0.885
Thymus	0.288	1.408	0.892
Thyroid	0.473	1.440	0.972
Uterus	0.061	1.011	0.786

a. OCAS-IG-001, Rev 1(NIOSH 2002)

Table B-8. Annual neutron deep dose equivalent to organ dose conversion factors.[a]

Organ	Deep dose equivalent to organ dose factors (A-P Geometry)		
	10-100 keV	0.1-2 MeV	2-20 MeV
Bladder	1.268	0.796	1.105
Bone (red marrow)	0.651	0.361	0.720
Bone (surface)	0.656	0.436	0.675
Breast (female)	1.111	1.145	1.121
Colon	0.947	0.490	0.912
Esophagus	0.775	0.412	0.869
Gonads (female-ovaries)	0.935	0.424	0.903
Gonads (male-testes)	1.466	1.307	1.222
Liver	0.983	0.641	0.990
Lung	0.737	0.557	0.950
Remainder organs	0.819	0.525	0.889
Skin	0.986	0.853	0.918
Stomach	1.221	0.824	1.099
Thyroid	1.066	1.086	1.123

Claims that require a more realistic assessment to determine compensability should consider the geometries described as follows:

- An AP exposure is typical for an individual who works in a directional radiation field and faces the source of the radiation source, such as a nuclear weapon component, while working.

- A rotational (ROT) exposure is typical of an individual who is constantly turning in a directional radiation field, such as when conducting inventories in the nuclear weapon storage vaults, while working.

- An isotropic (ISO) exposure is typical of a worker involved in activities involving a highly nondirectional or omnidirectional radiation field. An example of a work facility with an omnidirectional radiation field that leads to ISO irradiation of a worker might be maintenance activities where scattered neutrons and photon radiation are incident on the worker from all directions.

B3.3 PARAMETER 2

Parameter 2 is the standard deviation of the identified distribution for the respective variables involved in the calculation of the organ dose. The individual dose result for each dosimeter exchange period reported by DOE may be used to calculate the mean and standard deviation for each year.

ATTACHMENT C
SUMMARY OF INTAKES AND DETAILS OF INGESTION CALCULATIONS

TABLE OF CONTENTS

C1.0 Intakes 57

C2.0 Ingestion Intake Calculation 57

LIST OF TABLES

C-1 Summary of intakes by AEC workers at IAAP 57

C1.0 INTAKES

Table C-1 lists intakes by work tasks for time periods applicable for input into IMBA. The table includes intakes from environmental releases and exposure from radon. The worker category, "all personnel," applies to all AEC workers even if they are also included in the other categories.

Table C-1. Summary of intakes by AEC workers at IAAP.

			Dose calculation parameters				IREP input	Parameters	
Work or worker category[a]	Period	Material	Mode	Absorption type	pCi/d	mg/d	Distribution	1	2
All personnel	1/1/1948-7/1/1975	DU	Chronic inhalation	M, S	0.017	4.5E-05	Constant	Dose	
All personnel	12/2/1965-3/3/1969	DU	Chronic inhalation	M, S	0.024	6.4E-05	Lognormal	Dose	4
All personnel	3/4/1969-7/14/1969	DU	Chronic inhalation	M, S	0.0012	3.3E-06	Lognormal	Dose	4
All personnel	7/15/1969-12/31/1973	DU	Chronic inhalation	M, S	0.0055	1.5E-05	Lognormal	Dose	4
All personnel	1/1/1954-7/1/1975	HTO	Chronic inhalation/ absorption		6.8E+03		Constant	Dose	
All personnel	1/1/1948-7/1/1975	Radon[b]	Chronic inhalation				Lognormal	0.072 WLM/1 2 month period	3
Machinist	1/1/1948-12/31/1962	DU	Chronic inhalation	M, S	6.6	1.8E-02	Constant	Dose	
Machinist	1/1/1948-12/31/1962	DU	Chronic ingestion	Insoluble	0.2	5.4E-4 (mean)	Triangular	0.5 mean	mean[c]
Burning yard operations	1/1/1948-7/1/1975	DU	Chronic inhalation	M, S	38	0.10	Lognormal	Dose	3
Weapons disassembly	1/1/1954-7/1/1975	HTO	Chronic inhalation/ absorption		2.2E+06		Constant	Dose	
Weapons disassembly	1/1/50 – 12/31/1957	DU	Acute inhalation at start of each year	M,S	5.7E+04 pCi	150 mg	Constant	Dose	
Hydroshot operations	12/2/1965-3/3/1969	DU	Chronic inhalation	M, S	0.28	7.5E-04	Lognormal	Dose	4.6
Hydroshot operations	3/4/1969-7/14/1969	DU	Chronic inhalation	M, S	0.014	3.8E-05	Lognormal	Dose	4.6
Hydroshot operations	7/15/1969-12/31/1973	DU	Chronic inhalation	M, S	0.064	1.7E-04	Lognormal	Dose	4.6
Hydroshot cleanup	12/2/1965-3/3/1969	DU	Chronic ingestion	Insoluble	1.2E+03	3.3	Constant	Dose	
Hydroshot cleanup	3/4/1969-7/14/1969	DU	Chronic ingestion	Insoluble	6.4E+01	0.17	Constant	Dose	
Hydroshot cleanup	7/15/1969-12/31/1973	DU	Chronic ingestion	Insoluble	2.9E+02	0.78	Constant	Dose	

a. Workers performing specific listed tasks, e.g., burning yard operations, are also assigned the intakes for "all personnel."
b. Applies to workers on Line 1. However, unless it is clear that the worker did not work inside the Line 1 buildings, apply the radon intake to everyone.
c. Parameter 3 is 2 x mean.

C2.0 INGESTION INTAKE CALCULATION

Because the ingestion intake calculation for the hydroshot cleanup crew involved picking up source material, not touching surfaces contaminated by settling of particles from the air in a room, the intake calculation was not based on the draft OTIB on ingestion (NIOSH 2004a). Instead an experiment was conducted for this TBD, wherein a small amount of ordinary soil, judged by the author to be similar to

what a worker would get on his/her hands by handling a dirty object, was acquired on a small piece of paper with double-sided sticky tape. The net weight of the dirt was measured to be 83 mg with an uncertainty of about 2 mg. The largest uncertainty was in the judgment of the volume of dirt that would be on someone's hand. Soil has a density of about 2 g/cm^3 so the volume of dirt was about 0.042 cm$^{3.}$

For the hydroshot cleanup crew, it was assumed that surfaces of the DU chards were partially covered with unexploded HE and dirt from the impact with the ground. In addition the action of picking up chards from the ground would have introduced more dirt to the hands. So it was assumed that 10% of the volume of material on the hands would have been DU. Assuming the form of the DU was mostly metal with some oxide, the density of the DU would have been about 18 g/cm^3. So the DU contamination on the hands would have weighed about 76 mg [(18,000 mg/cm^3)(0.0042 cm^3)]. It was then assumed that 10% of the DU on the hands was ingested (as suggested in the draft OTIB on ingestion). This is an upper bound assumption which includes the possibility that the worker ate or drank without washing his/her hands. It was further assumed that this activity occurred after each hydroshot, so the ingestion rate in mg/calendar day is simply

(7.6 mg)(no. shots in period)/(calendar days in period)