ORAU TEAM
Dose Reconstruction
Project for NIOSH

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Summary Site Profile for the Pacific Proving Ground	ORAUT-TKBS-0052	Rev. 02
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☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
08/30/2006	00	New document to describe the Pacific Proving Ground and other oceanic test locations to enable the preparation of dose reconstructions. First approved issue of Revision 00. Incorporates internal and NIOSH formal review comments. There is no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Lori J. Arent.
07/11/2016	01	Revision initiated to update occupational medical and external dose information. Added excerpts to Section 1.3 from EEOICPA Bulletin No. 06-15 and EEOICPA Bulletin No. 07-05 clarifying that 83 days of continuous presence on land or ships would be equivalent to the 250-workday requirement for eligibility for compensation. Removed reference in Section 3.0 to ORAUT-PROC-0061 and added evaluation requirements under ORAUT-OTIB-0079. Provided additional information about the assignment of X-ray procedures based on various DOE responses. Revised Section 6.0 requirement to assign 95th-percentile doses from Attachment A for unmonitored workers and added requirement to Attachment A for comparison and assignment of the larger of missed plus recorded dose to the 95th-percentile doses. Removed requirement to assume beta-to-gamma ratios from the Nevada Test Site profile. Added Section 6.1 to provide beta-to-gamma ratios as a function of time after detonation and distance from source plane, which is favorable to claimants. Added Section 6.2 to provide methods for reconstructing dose from fallout from the GREENHOUSE operation for workers on contaminated islands and ships. Added Sections 6.3.1 and 6.3.2 to provide methods for determining penetrating and nonpenetrating dose. Added Section 6.3.3 for determining penetrating and nonpenetrating dose from fallout. Revised Section 7.0 to include all dose reconstruction methods. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Eugene M. Rollins.
07/23/2018	02	Revision initiated to revise 95th-percentile doses. Revised Section 6.3.1 to allow for prorating 95th-percentile doses. Added clarifying text to Section 7.0 on how recorded dose should be compared with 95th-percentile dose. Revised entire Attachment A. Incorporates formal internal review comments. No changes were needed as a result of NIOSH formal review. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Eugene M. Rollins.

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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AWE	atomic weapons employer
CE	Claims Examiner
cm	centimeter
d	day
DCF	dose conversion factor
DEEOIC	Division of Energy Employees Occupational Illness Compensation
DNA	Defense Nuclear Agency
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
EG&G	Edgerton, Germeshausen, and Grier
ft	foot
GSD	geometric standard deviation
H&N	Holmes & Narver
H(10)*	ambient dose equivalent at 10 millimeters depth in tissue
hr	hour
in.	inch
keV	kiloelectron-volt (1,000 electron-volts)
km	kilometer
kt	the explosive force of 1,000 tons of TNT
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
mo	month
mR	milliroentgen
mrem	millirem
Mt	the explosive force of 1 million tons of TNT
NIOSH	National Institute for Occupational Safety and Health
NTS	Nevada Test Site
ORAU	Oak Ridge Associated Universities
PER	program evaluation report
PPG	Pacific Proving Ground
R	roentgen
SEC	Special Exposure Cohort
SNL	Sandia National Laboratory
SRDB Ref ID	Site Research Database Reference Identification (number)

t	ton
TBD	technical basis document
TNT	trinitrotoluene
U.S.C.	United States Code
wk	week
yd	yard
yr	year
§	section or sections

1.0 INTRODUCTION

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in the preparation of dose reconstructions at particular Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities or categories of DOE or AWE facilities. They will be revised in the event additional relevant information is obtained about the affected DOE or AWE facility(ies). These documents may be used to assist NIOSH staff in the evaluation of Special Exposure Cohort (SEC) petitions and the completion of the individual work required for each dose reconstruction.

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

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

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

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

1.1 PURPOSE

The purpose of this document is to provide guidance for dose reconstruction of non-SEC cancers and those presumptive cancer claims that have less than 250 days of employment for EEOICPA claimants who participated in Pacific Proving Ground (PPG) operations.

1.2 SCOPE

This site profile consists of the following sections: Introduction, Site Description, Occupational Medical Dose, Occupational Environmental Dose, Occupational Internal Dose, Occupational External Dose, and Summary. Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 8.0.

1.3 SPECIAL EXPOSURE COHORT

The Secretary of the U.S. Department of Health and Human Services has designated the following class of PPG employees as an addition to the SEC (Leavitt 2006):

> *Department of Energy (DOE) employees or DOE contractor or subcontractor employees who worked at the Pacific Proving Grounds (PPG) from 1946 through 1962 for a number of work days aggregating at least 250 work days, either solely under this employment or in combination with work days within the parameters (excluding aggregate work day requirements) established for other classes of employees included in the SEC, and who were monitored or should have been monitored.*

NIOSH established in its SEC evaluation report (NIOSH 2005) that it lacks access to sufficient information to estimate either the maximum radiation dose incurred by any member of the class being evaluated, or to estimate such radiation doses more precisely than a maximum dose estimate. The sum of information from the available resources is insufficient to document or estimate the potential maximum internal exposure to members of the class, under plausible circumstances during the period of U.S. Atomic Energy Commission (AEC) operations at the PPG, 1946 through 1962. There does appear to be sufficient information and data, however, to estimate most or all external radiation exposures to members of this class.

The 250-workday requirement for PPG workers was subsequently interpreted by DOL in two separate bulletins. EEOICPA Bulletin No. 06-15 states (DOL 2006):

> *1. This new addition to the SEC affects DOE employees and DOE contractor employees or subcontractor employees employed at the PPG from 1946 through 1962 for a number of work days aggregating at least 250 work days, either solely under this employment or in combination with work days established for other classes of employees included in the SEC…. This new SEC designation is established for workers who were "monitored or should have been monitored" while employed at the PPG. Using the current standards for monitoring of workers at a nuclear facility site, DOL is interpreting "monitored or should have been monitored" as including all employees who worked at the PPG during the period from 1946 to 1962….*
>
> *Please note that for this new SEC class, the 250 work day calculation includes any time spent at any of the islands or atolls that make up the PPG during its SEC time period. This includes time spent working or living at the PPG during the SEC time period. In addition, employees were evacuated to ships from the PPG prior to nuclear weapons tests being performed. Time spent on ships just prior to a nuclear weapons test is*

counted toward meeting the 250 work day requirement. For any 24-hour period that the employee was present (either worked or lived) on the PPG or on ships (evacuated prior to a nuclear weapon testing), the CE [Claims Examiner] *would credit the employee with the equivalent of three (8-hour) work days. If there is evidence the employee was present at the PPG or on ships for 24 hours in a day for 83 days, the employee would have the equivalent of 250 work days and would meet the 250 work day requirement.*

Since continuous time spent at this site is credited toward the calculation of 250 work days, it is important the CE establish any period when the employee was not present at the site and exclude these periods from the 250 work day calculation. In determining the actual employment period, the CE must have clear and convincing evidence of a beginning date (hire) and end date (termination) of employment at the PPG. Where the evidence is not clear and convincing or consists only of film badge date(s) without a beginning date or end date, the CE must await further policy guidance before proceeding with the verification of covered SEC employment at the site. The National Office of DEEOIC [Division of Energy Employees Occupational Illness Compensation] *continues to explore methods by which confirmation of employment can occur for workers alleging employment at the PPG.*

EEOICPA Bulletin No. 07-05, states (DOL 2007):

1. This bulletin is in addition to the guidance specifically referenced in Item 5 of Bulletin 06-15….

Absent evidence of hire and end dates of employment, the CE may utilize external film badge (dosimetry) records to establish covered employment at PPG. As confirmed by DEEOIC, employees working at PPG during its SEC period were issued individual film badges to monitor for radiation exposure. These individual film badges were generally issued for one day, one week or a month depending on potential exposure to the individual. Typically, film badge records would include the issue date and the end (return) date which can be used to document employment periods at the PPG.

As noted for this SEC class in Bulletin 06-15, continuous time spent (including working or living) at PPG is credited toward the calculation of 250 work days. If the film badge records include an issue date and end (return) date within the PPG SEC time period, the CE is to credit the employee with the equivalent of three (8-hour) work days for each date the employee was badged, inclusive of the issue date and end (return) date. For example, an employee with a film badge with the issue date of 3/27/1954 and the end (return) date of 3/31/1954 would be credited with 15 (8-hour) work days.

2.0 SITE DESCRIPTION

Between 1946 and 1962, the military and AEC (a DOE predecessor agency) conducted over a hundred atmospheric and underwater nuclear weapon tests at sites at the PPG (DOE 2000). In the Pacific, 29 atolls and 5 islands spread over 770,000 mi^2 with a total land area of about 70 mi^2 make up the Marshall Islands. Enewetak Atoll, Bikini Atoll, and Johnston Island in the Marshall Islands, and Christmas Island in the Indian Ocean are known collectively as the PPG (NIOSH 2005).

Oceanic nuclear testing by the United States consisted mostly of the unconfined detonation of nuclear devices in the atmosphere. An operation includes one or more individual tests, typically designed and conducted for a common purpose. Table 2-1 summarizes the PPG tests, including test name, date, sponsor(s), location, type, purpose, and yield.

Personnel who worked on the PPG tests were based at various DOE sites and traveled to the test location for part or all of an operation. Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratory (SNL), and the Nevada Test Site (NTS) were the main work locations for most civilian participants during the various operations. However, DOE contractors such as Edgerton, Germeshausen, and Grier (EG&G) and Holmes & Narver (H&N) for example, provided civilian participants who usually worked at other locations. The military cosponsored some tests with the national laboratories.

Table 2-1. PPG tests.[a,b,c]

Operation Crossroads

To determine effects on ships.

Test	Date	Sponsor	Location	Type	Purpose	Yield
Able	06/30/1946	LANL/DOD	Bikini	Airdrop	Weapons effects	21 kt
Baker	07/24/1946	LANL/DOD	Bikini	Underwater	Weapons effects	21 kt

Operation Sandstone

AEC scientific tests to proof-test improved design.

Test	Date	Sponsor	Location	Type	Purpose	Yield
X-ray	04/14/1948	LANL	Enewetak	Tower	Weapons related	37 kt
Yoke	04/30/1948	LANL	Enewetak	Tower	Weapons related	49 kt
Zebra	05/14/1948	LANL	Enewetak	Tower	Weapons related	18 kt

Operation Greenhouse

Thermonuclear weapon development and observation of physical and biological effects of nuclear weapons.

Test	Date	Sponsor	Location	Type	Purpose	Yield
Dog	04/07/1951	LANL	Enewetak	Tower	Weapons related	81 kt
Easy	04/20/1951	LANL	Enewetak	Tower	Weapons related	47 kt
George	05/08/1951	LANL	Enewetak	Tower	Weapons related	225 kt
Item	05/24/1951	LANL	Enewetak	Tower	Weapons related	45.5 kt

Operation Ivy

Thermonuclear weapon development.

Test	Date	Sponsor	Location	Type	Purpose	Yield
Mike	10/31/1952	LANL	Enewetak	Surface	Weapons related	10.4 Mt
King	11/15/1952	LANL	Enewetak	Airdrop	Weapons related	500 kt

Operation Castle

To gauge military effects of the explosions (i.e., measure power and efficiency of devices).

Test	Date	Sponsor	Location	Type	Purpose	Yield
Bravo	02/28/1954	LANL	Bikini	Surface	Weapons related	15 Mt
Romeo	03/26/1954	LANL	Bikini	Barge	Weapons related	11 Mt
Koon	04/06/1954	LLNL	Bikini	Surface	Weapons related	110 kt
Union	04/25/1954	LANL	Bikini	Barge	Weapons related	6.9 Mt
Yankee	05/04/1954	LANL	Bikini	Barge	Weapons related	13.5 Mt
Nectar	05/13/1954	LANL	Enewetak	Barge	Weapons related	1.69 Mt

Operation Wigwam[d]

To determine lethal distances for nuclear effects vs. submerged submarines; one detonation was conducted in 16,000 ft of water.

Test	Date	Sponsor	Location	Type	Purpose	Yield
Wigwam	05/14/1955	LANL/DOD	Pacific	Underwater	Weapons effects	30 kt

Operation Redwing

High-yield thermonuclear tests to gauge military effects and measure power and efficiency of devices.

Test	Date	Sponsor	Location	Type	Purpose	Yield
Lacrosse	05/04/1956	LANL	Enewetak	Surface	Weapons related	40 kt
Cherokee	05/20/1956	LANL	Bikini	Airdrop	Weapons related	3.8 Mt
Zuni	05/27/1956	LLNL	Bikini	Surface	Weapons related	3.5 Mt
Yuma	05/27/1956	LLNL	Enewetak	Tower	Weapons related	190 t
Erie	05/30/1956	LANL	Enewetak	Tower	Weapons related	14.9 kt
Seminole	06/06/1956	LANL	Enewetak	Surface	Weapons related	13.7 kt
Flathead	06/11/1956	LANL	Bikini	Barge	Weapons related	365 kt
Blackfoot	06/11/1956	LANL	Enewetak	Tower	Weapons related	8 kt
Kickapoo	06/13/1956	LLNL	Enewetak	Tower	Weapons related	1.49 kt
Osage	06/16/1956	LANL	Enewetak	Airdrop	Weapons related	1.7 kt
Inca	06/21/1956	LLNL	Enewetak	Tower	Weapons related	15.2 kt
Dakota	06/25/1956	LANL	Bikini	Barge	Weapons related	1.1 Mt
Mohawk	07/02/1956	LLNL	Enewetak	Tower	Weapons related	360 kt
Apache	07/08/1956	LLNL	Enewetak	Barge	Weapons related	1.85 Mt
Navajo	07/10/1956	LANL	Bikini	Barge	Weapons related	4.5 Mt
Tewa	07/20/1956	LLNL	Bikini	Barge	Weapons related	5 Mt
Huron	07/20/1956	LANL	Enewetak	Barge	Weapons related	250 kt

Hardtack I

Three parts to test: (1) continued development of nuclear weapons with detonation of experimental devices from various AEC laboratories, (2) underwater tests to improve understanding of effects on underwater explosions on ships and material, and (3) nuclear weapons in air and ballistic missile defense (first high-yield rocket tests).

Test	Date	Sponsor	Location	Type	Purpose	Yield
Yucca (Operation Newsreel)	04/28/1958	LANL/DOD	Pacific	Balloon	Weapons effects	1.7 kt
Cactus	05/05/1958	LANL	Enewetak	Surface	Weapons effects	18 kt
Fir	05/11/1958	LLNL	Bikini	Barge	Weapons related	1.36 Mt
Butternut	05/11/1958	LANL	Enewetak	Barge	Weapons related	81 kt
Koa	05/12/1958	LANL	Enewetak	Surface	Weapons related	1.37 Mt
Wahoo	05/16/1958	LANL/DOD	Enewetak	Underwater	Weapons related	9 kt
Holly	05/20/1958	LANL	Enewetak	Barge	Weapons related	5.9 kt
Nutmeg	05/21/1958	LLNL	Bikini	Barge	Weapons related	25.1 kt
Yellowwood	05/26/1958	LANL	Enewetak	Barge	Weapons related	330 kt
Magnolia	05/26/1958	LANL	Enewetak	Barge	Weapons related	57 kt
Tobacco	05/30/1958	LANL	Enewetak	Barge	Weapons related	11.6 kt
Sycamore	05/31/1958	LLNL	Bikini	Barge	Weapons related	92 kt
Rose	06/02/1958	LANL	Enewetak	Barge	Weapons related	15 kt
Umbrella	06/08/1958	LANL/DOD	Enewetak	Underwater	Weapons effects	8 kt
Maple	06/10/1958	LLNL	Bikini	Barge	Weapons related	213 kt
Aspen	06/14/1958	LLNL	Bikini	Barge	Weapons related	319 kt
Walnut	06/14/1958	LANL	Enewetak	Barge	Weapons related	1.45 Mt
Linden	06/18/1958	LANL	Enewetak	Barge	Weapons related	11 kt
Redwood	06/27/1958	LLNL	Bikini	Barge	Weapons related	412 kt
Elder	06/27/1958	LANL	Enewetak	Barge	Weapons related	880 kt
Oak	06/28/1959	LANL	Enewetak	Barge	Weapons related	8.9 Mt
Hickory	06/29/1958	LLNL	Bikini	Barge	Weapons related	14 kt
Sequoia	07/01/1958	LANL	Enewetak	Barge	Weapons related	5.2 kt
Cedar	07/02/1958	LLNL	Bikini	Barge	Weapons related	220 kt
Dogwood	07/05/1958	LLNL	Enewetak	Barge	Weapons related	397 kt
Poplar	07/12/1958	LLNL	Bikini	Barge	Weapons related	9.3 Mt

Test	Date	Sponsor	Location	Type	Purpose	Yield
Scaevola	07/14/1958	LANL	Enewetak	Barge	Safety experiment	0
Pisonia	07/17/1958	LANL	Enewetak	Barge	Weapons related	225 kt
Juniper	07/22/1958	LLNL	Bikini	Barge	Weapons related	65 kt
Olive	07/22/1958	LLNL	Enewetak	Barge	Weapons related	202 kt
Pine	07/26/1958	LLNL	Enewetak	Barge	Weapons related	2 Mt
Teak (Operation Newsreel)	08/01/1958	LANL/DOD	Johnston	Rocket	Weapons effects	3.8 Mt
Quince	08/06/1958	LLNL/DOD	Enewetak	Surface	Weapons related	0
Orange (Operation Newsreel)	08/12/1958	LANL/DOD	Johnston	Rocket	Weapons effects	3.8 Mt
Fig	08/18/1958	LLNL/DOD	Enewetak	Surface	Weapons related	20 tons

Argus[d]

Tests in upper regions of atmosphere to test Christofilos theory, which argued that high-altitude nuclear detonations would create radiation belt in upper regions of Earth's atmosphere that would include degradation of radio and radar transmissions, etc.

Test	Date	Sponsor	Location	Type	Purpose	Yield
Argus I	08/27/1958	LANL/DOD	S. Atlantic	Rocket	Weapons effects	1–2 kt
Argus II	08/30/1958	LANL/DOD	S. Atlantic	Rocket	Weapons effects	1–2 kt
Argus III	09/06/1958	LANL/DOD	S. Atlantic	Rocket	Weapons effects	1–2 kt

Dominic

Primarily high-altitude air bursts with little fallout.

Test	Date	Sponsor	Location	Type	Purpose	Yield
Adobe	04/25/1962	LANL	Christmas	Airdrop	Weapons related	190 kt
Aztec	04/27/1962	LANL	Christmas	Airdrop	Weapons related	410 kt
Arkansas	05/02/1962	LLNL	Christmas	Airdrop	Weapons related	1.09 Mt
Questa	05/04/1962	LANL	Christmas	Airdrop	Weapons related	670 kt
Frigate Bird	05/06/1962	LLNL/DOD	Pacific	Rocket	Weapons related	200–1,000 kt
Yukon	05/08/1962	LLNL	Christmas	Airdrop	Weapons related	100 kt
Mesilla	05/09/1962	LANL	Christmas	Airdrop	Weapons related	100 kt
Muskegon	05/11/1962	LLNL	Christmas	Airdrop	Weapons related	50 kt
Swordfish	05/11/1962	LANL/DOD	Pacific	Underwater	Weapons effects	Low
Encino	05/12/1962	LANL	Christmas	Airdrop	Weapons related	500 kt
Swanee	05/14/1962	LLNL	Christmas	Airdrop	Weapons related	97 kt
Chetco	05/19/1962	LLNL	Christmas	Airdrop	Weapons related	73 kt
Tanana	05/25/1962	LLNL	Christmas	Airdrop	Weapons related	2.6 kt
Nambe	05/27/1962	LANL	Christmas	Airdrop	Weapons related	43 kt
Alma	06/08/1962	LANL	Christmas	Airdrop	Weapons related	782 kt
Truckee	06/09/1962	LLNL	Christmas	Airdrop	Weapons related	210 kt
Yeso	06/10/1962	LANL	Christmas	Airdrop	Weapons related	3 Mt
Harlem	06/12/1962	LLNL	Christmas	Airdrop	Weapons related	1.2 Mt
Rinconada	06/15/1962	LANL	Christmas	Airdrop	Weapons related	800 kt
Dulce	06/17/1962	LANL	Christmas	Airdrop	Weapons related	52 kt
Petit	06/19/1962	LLNL	Christmas	Airdrop	Weapons related	2.2 kt
Otowi	06/22/1962	LANL	Christmas	Airdrop	Weapons related	81.5 kt
Bighorn	06/27/1962	LLNL	Christmas	Airdrop	Weapons related	7.65 Mt
Bluestone	06/30/1962	LLNL	Christmas	Airdrop	Weapons related	1.27 Mt

Operations Fishbowl and Dominic (a.k.a. Dominic I)

Test	Date	Sponsor	Location	Type	Purpose	Yield
Starfish Prime (Operation Fishbowl)	07/09/1962	LANL/DOD	Johnston	Rocket	Weapons effects	1.4 Mt
Sunset (Operation Dominic)	07/10/1962	LANL	Christmas	Airdrop	Weapons related	1 Mt
Pamlico (Operation Dominic)	07/11/1962	LLNL	Christmas	Airdrop	Weapons related	3.88 Mt
Androscoggin (Operation Dominic)	10/02/1962	LLNL	Johnston	Airdrop	Weapons related	75 kt
Bumping (Operation Dominic)	10/06/1962	LLNL	Johnston	Airdrop	Weapons related	11.3 kt
Chama (Operation Dominic)	10/18/1962	LANL	Johnston	Airdrop	Weapons related	1.59 Mt
Checkmate (Operation Fishbowl)	10/20/1962	LANL/DOD	Johnston	Rocket	Weapons effects	Low
Bluegill 3 Prime (Operation Fishbowl)	10/26/1962	LANL/DOD	Johnston	Rocket	Weapons effects	<1 Mt
Calamity (Operation Dominic)	10/27/1962	LLNL	Johnston	Airdrop	Weapons related	800 kt
Housatonic (Operation Dominic)	10/30/1962	LLNL	Johnston	Airdrop	Weapons related	8.3 Mt
Kingfish (Operation Fishbowl)	11/01/1962	LANL/DOD	Johnston	Rocket	Weapons effects	<1 Mt
Tightrope (Operation Fishbowl)	11/04/1962	LANL/DOD	Johnston	Rocket	Weapons effects	Low

a. Prepared from Weary et al. (1981), Martin and Rowland (1982), Jones et al. (1982), Gladeck et al. (1982a, 1982b), Bruce-Henderson et al.1982, Berkhouse et al. (1983a, 1983b, 1983c, 1984), and DOE (2000).
b. DOD = military cosponsorship.
c. Dates are Greenwich Mean Time rather than local.
d. Operations Wigwam and Argus and their tests are not considered to have occurred as part of PPG operations. These data should be used to estimate dose only if these oceanic testing locations become recognized as covered DOE facilities.

3.0 OCCUPATIONAL MEDICAL DOSE

Multiple organizations based at various sites in the DOE complex sponsored and took part in the operations. Based on records from DOE, the dose reconstructor must, if possible, determine the facility or facilities in the complex with which the employee was associated during participation in an oceanic test or operation.

LANL, LLNL, SNL, and NTS provided many of the civilian scientific, research, and support participants during these operations. H&N and EG&G provided support personnel (e.g., cafeteria workers, electronics technicians, construction workers, etc.). The assignments were for all or part of an operation and lasted from 2 to 4 months for most civilian participants. Employees of some contractors, such as EG&G and H&N, were associated with more than one DOE facility. The dose reconstructor should use the occupational medical dose technical basis documents (TBDs) for the participant's associated DOE and AWE sites to determine X-ray dose.

For most participants, specific guidance for occupational medical dose can be found in the current published revision of:

- ORAUT-TKBS-0008-3, *Nevada Test Site – Occupational Medical Dose* (ORAUT 2012a);
- ORAUT-TKBS-0010-3, *Los Alamos National Laboratory – Occupational Medical Dose* (ORAUT 2010c); and

- ORAUT-TKBS-0035-3, *Lawrence Livermore National Laboratory – Occupational Medical Dose* (ORAUT 2010b).

While these sites provided many participants, other sites across the complex also provided participants or workers who might have been hired from the local population as support personnel. Other employers might have been associated with only one facility or none at all. If an employee's records cannot be associated with a facility for which a TBD has or is being developed at the time of the dose reconstruction, dose reconstructors should use the guidance in ORAUT-OTIB-0006, *Dose Reconstruction from Occupational Medical X-Ray Procedures* (ORAUT 2011).

NIOSH has concluded it is feasible to determine maximum potential occupational medical exposures. Because most civilian participants spent the interval of the operation (or part of the operation) at the test location and then returned to the United States, the use of site-specific information (for example, the documents listed above for NTS, LANL, and LLNL) for the participant is reasonable. Occupational medical exposures for participants that were hired on location or do not have available X-ray records linked to a covered site (e.g., NTS, LANL, and LLNL) should be evaluated in accordance with ORAUT-OTIB-0079, *Guidance on Assigning Occupational X-Ray Dose Under EEOICPA for X-Rays Administered Off Site* (ORAUT 2017).

Participants who have been linked to a covered site but for whom records are not available fall into three categories according to the DOE response (or lack thereof): (1) records are not readily available, (2) records do not exist, or (3) no DOE response was provided. In the first and third cases where DOE indicated that the records are not readily available (or not retrieved) or no response was provided, X-ray procedures should be applied in accordance with the occupational medical TBD for that site if a best estimate is not required. If a best estimate is required, the case should be put on hold and a request should be sent to the covered site to provide the X-ray records. For the second case, in which DOE indicated that the X-ray records do not exist, dose from X-ray procedures should not be assigned.

4.0 OCCUPATIONAL ENVIRONMENTAL DOSE

Participants with the potential for radiological exposure received dosimeters during the tests (see Table 6-1). Starting with Operation Castle, PPG adopted LANL film badge dosimetry procedures (Lalos 1989). According to ORAUT-TKBS-0010-4, *Los Alamos National Laboratory – Occupational Environmental Dose* (ORAUT 2010a), external onsite ambient dose does not need to be assigned for employees who were monitored under LANL procedures. Beginning in 1955 with Operation Wigwam, all participants were issued permanent film badges. In addition, some participants were issued mission badges in addition to film badges with longer exchange frequencies. For these individuals, the mission badge dose was subtracted from the permanent badge dose; the difference became the dose of record. Therefore, beginning in 1955, external ambient dose does not need to be applied. For PPG operation participants, coworker doses have been developed using summary data (see Attachment A). Because of the large uncertainties, coworker doses should be assigned to workers at the 95th-percentile level as described in Section 6.0 in lieu of other environmental doses.

The primary source of occupational environmental dose was exposures to fallout. Assignment of potential fallout dose is discussed in Section 6.2.

5.0 OCCUPATIONAL INTERNAL DOSE

NIOSH has determined that it lacks sufficient personnel monitoring, air monitoring, or source term data to adequately reconstruct the internal exposures at the PPG. Consequently, NIOSH finds that it is not feasible to estimate with sufficient accuracy the radiation doses from internal exposures during PPG operations (NIOSH 2005).

6.0 OCCUPATIONAL EXTERNAL DOSE

A review of the records from DOE and application of the operation-specific parameters in Table 6-1 will provide a dose estimate for the employee. Before universal badging in 1955, because of deficiencies in the film badge dosimetry data and procedural practices that were identified in *Film Badge Dosimetry in Atmospheric Nuclear Tests* (Lalos 1989) and *Navy Film Badge Review: DOMINIC, Navy Nuclear Test Personnel Review Program* (Perkins and Hammond 1980), available DOE records might be incomplete, inaccurate, or might not include unmonitored exposures associated with employee badging. To account for these large uncertainties, the 95th-percentile coworker doses in Attachment A should be assigned for cases in which the data are incomplete or nonexistent. If, before 1955, the employee had recorded dose, the dose reconstructor should compare that recorded dose with the 95th-percentile doses in Attachment A and assign the larger of the two doses. NIOSH considers the available data and these methods adequate for performing external photon dose reconstruction for PPG activities.

NIOSH determined that it lacks sufficient information to adequately reconstruct neutron doses at the PPG (NIOSH 2005). The following specific guidance is provided for external dose reconstruction:

- Energy distribution. Assume an energy distribution of 100% 30 to 250 keV for photons. This is very favorable to claimants because it is likely that participants present during the events were exposed to photons >250 keV. Beta dose was not evaluated from the film dosimeters used during these operations. For methods to assign beta dose, see Section 6.1.

- Missed dose. Assign missed dose based on the number of exchanges in the dosimetry records. After 1955, compare the recorded dose plus the missed dose with the 95th-percentile dose in Attachment A and assign the larger dose. It should be noted that before universal badging began in 1955, it is not possible to reconstruct missed dose because of deficiencies in film badge dosimetry data and procedural practices identified by Lalos (1989) and Perkins and Hammond (1980). During the tests, operation badges were worn for the entire test sequence or some other established interval of the operation and mission badges were worn for the duration of a specific task. Because both badges were to be worn at the same time, only one zero should be assigned.

- Uncertainty and bias. Assign uncertainty to the measured photon dose. As an assignment that is favorable to claimants, bias has been defaulted to 1.0 for both the missed and measured doses. According to the information in Lalos (1989), the dose of record was to be divided by the bias, but it is favorable to claimants to assign as discussed above.

Table 6-1. External dosimetry using gamma dosimeters, 1946 to 1962.[a,b]

Year	Operation	Dosimeter	Description	Issue and exchange	MPE	Bias[c]	Uncertainty	MDL
1946	Crossroads (2 events)	Dental film packet	Single component type K double-emulsion dental film packet covered by 0.020-in.-thick lead cross filter. This filter was not totally effective in correcting over-response caused by photons of lower energy. Plastic envelope was used to minimize damage to film from moisture. Exposure range 0 to 2 R.	Issued to RadSafe monitors or a few RadSafe monitors in groups (approximately 1 to 2 monitors with dosimeters for 100 participants – cohort badging). Also issued to aircrews. Exchanged daily but record indicates some were worn up to 9 d. Used during decontamination of ships and for unloading ammunition at Kwajalein after August 1946.	Photon exposure with objective of keeping daily exposure below 0.1 R, not to exceed 50–60 R/2 wk. Employee withdrawn from operation at 10 R/d or 60 R/2 wk.	1.1	1.7	40 mR
1948	Sandstone (3 events)	Eastman types K and A film	Type K exposure range (0.06 to 2 R). Type A exposure range (1 to 10 R). Covered by 0.020-in.-thick lead cross filter. This filter was not totally effective in correcting the overresponse caused by photons of lower energy. Plastic envelope was used to minimize damage to film from moisture.	Issued for single-day use to all personnel with exposure potential. Example: on 04/24/1948, 9 d after test “X-Ray,” all participants who were expected to come closer than 530 yd of ground zero were issued dosimeters.	Exposure to be below 0.1 R/d or 3 R for certain missions.	1.1	1.8	60 mR
1951	Greenhouse (4 events)	DuPont 553 packet	DuPont 553 packet, including Type 502 low-range element (0.05 to 10 R), type 510 high-range element (1 to 50 R), and type 606 high-range element (10 to 300 R). No measurable density above background was reported for type 606 element. Lead filters 0.020 in. thick. This filter was not totally effective in correcting over-response caused by photons of lower energy.	Cohort representative, aircrews, and ground crews maintaining contaminated aircraft. Originally recorded dose probably reflects subtraction for fallout.	3.9 R/13 wk; 0.1 R/d not to exceed 0.7 R/wk.	1.1	1.9	40 mR

Year	Operation	Dosimeter	Description	Issue and exchange	MPE	Bias[c]	Uncertainty	MDL
1952	Ivy (2 events)	DuPont 558 packet	DuPont 558 packet including type 508 low-range element (0.05 to 10 R) and type 1290 high-range element (10 to 750 R). Lead filters 0.020 in. thick. This filter was not totally effective in correcting over-response caused by photons of lower energy.	Issued to aircrews, ground crews assigned to working on contaminated aircraft, and reentry parties. Badges were usually issued on mission basis and worn for approximately 1 d.	3.9 R/operation for gamma only.	1.1	1.5[d]	40 mR
1954	Castle (6 events)	DuPont 509 packet	DuPont 509 packet including type 502 low-range element (0.02 to 10 R) and type 606 high-range element (10 to 300 R). Lead filters 0.028 in. thick (symmetrical coverage on both sides with open area). This change in thickness from previous filter caused 20% change in response to 120- and 70-keV photons.	Issued to all aircrews in air at time of detonation within 185 km of the shot site. Also to all participants likely to receive a significant amount of radiation exposure and a representative 10% of other personnel.	3.9 R/13 wk augmented with 0.3 R/wk after that.	1.0	2.1	40 mR
1955	Wigwam[e] (1 event)	DuPont 559 packet	DuPont 559 packet including type 502 low-range element (0.02 to 10 R) and type 606 high-range element (10 to 300 R). Lead filters 0.028 in. thick (symmetrical coverage on both sides with open area).	Issued to almost all participates with extra exchanges for those involved in posttest sampling and recovery of test instruments. Badge indicated beta-to-gamma ratios ranged from 1:1 to 3:1.	3.5 R/operation; 20 R/operation hands and feet.	1.0	1.4	40 mR
1956	Redwing (17 events)	DuPont 559 packet	DuPont 559 packet including type 502 low-range element (0.02 to 10 R) and type 606 high-range element (10 to 300 R). Lead filters 0.028 in. thick (symmetrical coverage on both sides with open area).	Permanent badges were issued to all participants. Cellulose acetate holder was found to be defective, so after first 6 wk film packets were dipped in ceresin wax to keep out moisture. Mission badges (exchanged daily) were issued to personnel entering contaminated areas.	3.9 R/13 wk.	1.0	1.5	40 mR

Year	Operation	Dosimeter	Description	Issue and exchange	MPE	Bias[c]	Uncertainty	MDL
1958	Hardtack and Newsreel (35 events)	DuPont 559 packet	DuPont 559 packet including type 502 low-range element (0.02 to 10 R) and type 834 high-range element (5 to 800 R). Lead filters 0.028 in. thick (symmetrical coverage on both sides with open area). Film was wax covered and housed in rigid polyvinylchloride case. Designed to be worn for several months, no significant failure observed with up to 6 mo of use.	Film badges were called in at 60-d intervals. All participants were to wear dosimetry at all times.	3.75 R/13 wk; 5 R for operation.	1.2	1.4	40 mR
1958	Argus[e] (3 events)	DuPont 559 packet	Uncertain which film badge was used. Possibly same as Operation Plumbbob at NTS [i.e., type 502 low-range element (0.02 to 10 R) and type 606 high-range element (10 to 300 R)].	4,000 film badges were provided but, due to classified nature of tests only 264 film badges were assigned, all to personnel with knowledge of the tests. No records of the dosimetry are available. Highest exposure recorded by individual's packet was 0.010 R.	3 rem/13 wk and 5(N – 18)[f] rem/yr.[g]	1.09[h]	1.4[g]	40 mR
1962	Dominic (Dominic I) and Fishbowl (36 events)	DuPont 556 packet	DuPont 556 packet including type 508 low-range element (0.02 to 10 R) and type 834 high-range element (5 to 800 R). Lead filters 0.028 in. thick (symmetrical coverage on both sides with open area). Film was wax covered and housed in rigid polyvinylchloride case.	Aircrews and all participants with exception of certain remote locations.	3 rem/13 wk and 5(N – 18)[f] rem/yr.	1.2	1.4	40 mR

a. Sources: Weary et al. (1981), Martin and Rowland (1982), Jones et al. (1982), Gladeck et al. (1982a, 1982b), Bruce-Henderson et al. (1982), Berkhouse et al. (1983a, 1983b, 1983c, 1984), and Lalos (1989).
b. MDL = minimum detection limit; MPE = maximum permissible exposure.
c. For the purpose of providing an assignment of dose that is favorable to claimants, the bias will default to 1.
d. Bias is 1.4 for flight personnel.
e. Operations Wigwam and Argus are not considered part of the PPG cohort. These data should be used to estimate dose only if these oceanic testing locations are recognized as covered DOE facility.
f. N equals the age of the participant.
g. Routine MPE is from IEER (2000).
h. Information is from Operation Plumbbob at NTS.

6.1 UNMONITORED SKIN DOSE BETA-TO-GAMMA RATIOS

Beta dose was not evaluated from the film dosimeters that were used during PPG operations. In the absence of shallow dose measurements from beta radiation from fallout, dose reconstructors should use the beta-to-gamma ratios in Table 6-2 to derive appropriate ratios to apply for each cancer location.

Table 6-2. Beta-to-gamma dose ratios for bare skin exposures to mixed fission products at PPG test sites at various distances from the source plane.[a]

Time after detonation	1 cm	20 cm	40 cm	80 cm	100 cm	120 cm	160 cm	200 cm
0.5 hr	36.4	24.2	17.7	11.9	10.4	9.1	7.0	5.4
1 hr	32.5	21.4	15.5	10.3	8.9	7.8	5.9	4.5
2 hr	32.0	20.8	15.0	9.9	8.5	7.4	5.5	4.2
4 hr	40.3	25.9	18.5	12.0	10.3	8.9	6.7	5.0
6 hr	51.1	32.6	23.1	14.9	12.7	11.0	8.2	6.2
12 hr	65.6	41.0	28.6	17.8	15.0	12.8	9.3	6.8
1 d	65.1	38.7	25.8	14.9	12.2	10.0	6.8	4.7
2 d	64.4	35.2	22.1	11.8	9.3	7.4	4.7	2.9
3 d	62.8	32.2	19.3	9.8	7.6	6.0	3.6	2.1
1 wk	62.3	29.0	16.3	7.7	5.8	4.5	2.5	1.4
2 wk	65.5	30.5	17.1	8.1	6.2	4.7	2.7	1.6
1 mo	72.4	34.7	19.9	9.8	7.6	6.0	3.7	2.2
2 mo	85.7	39.8	22.8	11.8	9.5	7.8	5.1	3.3
4 mo	907.0	40.4	23.0	12.5	10.5	9.0	6.4	4.4
6 mo	94.6	42.5	24.5	13.9	11.9	10.4	7.7	5.5
9 mo	116.7	54.5	32.5	19.6	15.4	15.4	11.8	8.8
1 yr	166.1	81.2	50.3	31.7	25.6	25.6	20.1	15.2
2 yr	494.2	251.9	160.5	104.2	85.3	85.3	68.0	52.3

a. Source: Barrs and Weitz (2006).

The factors that determine a ratio that is favorable to the claimant include the time after detonation and the distance of the skin cancer location from the source plane. To determine a reasonable maximum time after detonation, the frequency of the detonations must be considered as well as the elapsed time between separate operations. For example, during some PPG operations, detonations occurred on a daily basis while other operations involved weekly or biweekly detonations. Because the dose rate for both gamma and beta radiation diminishes exponentially with time after detonation, the relative importance of the dose from older fallout is significantly less than the importance of fresh fallout to total dose. Therefore, the maximum “effective” age of the fallout during PPG operations is probably no more than 2 months.

However, the time between operations varied between 1 and 4 years. Therefore, if participants were exposed, for example, in the first quarter of 1958 before the start of Operation Hardtack-I, according to Tables 6-3 and 6-4, a beta-to-gamma ratio as high as 85 would be expected for exposure to a skin cancer on the upper arm because the fallout from the previous operation (Redwing) would have been the likely source of the exposure and that fallout would have aged more than 2 years. However, empirical studies at NTS (ORAUT 2012b) indicate that, for fallout that has been exposed to weathering for more than 6 months (atmospheric testing at the NTS ceased in July of 1962), the actual measured beta-to-gamma ratio was much lower. The NTS data showed that, for the period from 1966 to 1987, the 50th-percentile beta-to-gamma ratio from 369 data pairs of measured shallow and penetration dose was 1.04 and that the 95th-percentile ratio was 4.59, each with a geometric standard deviation (GSD) of 2.41. These measurements were performed with badges on the chest (i.e., 120 cm from source plane). Therefore, for exposures to fallout that has weathered for less than

6 months or more, between different operations, the ratios shown in Table 6-3 for weathered fallout should be applied.

The shallow doses that were derived using the weathered ratios should be applied as a lognormal distribution with a GSD of 2.41.

In relation to the minimum time of exposure to fallout after detonation, inspection of the data in Table 6-2 shows a peak effect at 12 hours. Therefore, to derive a beta-to-gamma ratio that is favorable to claimants, the largest ratio between 2 months and 12 hours was chosen for each of the distances in Table 6-2. These ratios are shown in Table 6-3.

Table 6-3. Maximum beta-to-gamma ratios between 12 hours and 2 months after detonation at various distances above the source plane.

Distance above source plane (cm)	Maximum beta-to-gamma ratio from 12 hours to 2 months
20	41
40	28.6
80	17.8
100	15
120	12.8
160	9.3
200	6.8

Table 6-4. Anatomical distances to source plane and corresponding beta-to-gamma ratios.

Location	Distance from source plane (cm)	Beta-to-gamma ratio, fresh fallout[a]	Beta-to-gamma ratio, weathered fallout[b]
Lower leg	25	37	13
Upper leg	69	21	8
Hand	65	22	8
Wrist	84	18	7
Lower arm	97	16	6
Upper arm	125	12	4
Shoulder	142	11	4
Neck	151	10	3
Head	162	9	3
Scalp	173	8	3

a. Calculated doses using these ratios should be entered as constants.
b. Calculated 95th-percentile doses using these ratios should be entered as a lognormal distribution with a GSD of 2.41.

Table 6-4 provides the approximate distances for various body locations for the average man (5 ft, 8 in. tall). Using linear interpolation, beta-to-gamma ratios at these distances can be derived and are also provided in Table 6-4. Shallow dose derived from application of the fresh fallout beta-to-gamma ratios should be applied as a constant.

As an efficiency method when a best estimate is not required, the beta-to-gamma ratios in Table 6-5 may be used.

Table 6-5. Efficiency beta-to-gamma ratios for fresh and weathered fallout.

Location	Beta-to-gamma ratio, fresh fallout[a]	Beta-to-gamma ratio, weathered fallout[b]
Lower leg	40	13
Upper leg/hand/wrist/lower arm/chest	20	8
Upper arm/shoulder/neck/head/scalp	10	3

a. Calculated doses using these ratios should be entered as constants.
b. Calculated 95th-percentile doses using these ratios should be entered as a lognormal distribution with a GSD of 2.41.

Another consideration in the assignment of beta dose is attenuation. Beta dose should not be assigned to locations below the ankles because the workers always wore shoes during the recovery and decontamination operations. Further, photographic records indicate these activities often involved only short pants and shoes because of the heat and humidity. Therefore, attenuation factors should not be applied except for cancer locations from the waist down to just above the knees. For cancer locations from the waist to just above the knees, the best-estimate attenuation factor of 0.855 (ORAUT 2005) should be applied.

6.2 UNMONITORED SKIN DOSE FROM FALLOUT

Exposure to ionizing radiation during atmospheric nuclear testing is the sum of exposures from activities that required personnel to undertake missions in radioactive areas, or to deal with radioactive materials, and of exposures from increased background radiation in normally nonradioactive areas that might be caused, for example, by fallout. All nuclear testing had some exposures of the first type, but Operation Greenhouse in 1951 also had fallout exposures. Three shots of the series deposited radioactive fallout over the base islands at Enewetak and six nearby ships, which exposed personnel to radiation.

Before 1955, film badges were almost exclusively used for personnel on missions that had the potential for radiation exposure. Only a portion of the personnel in areas where exposure was not expected were badged. Therefore, radiation from the unexpected fallout was unrecorded for the large majority of Operation Greenhouse participants. However, fallout radiation was recorded by instruments that monitored background radiation on film badges outside of buildings on Parry Island as well as by sample badges that were issued to selected personnel working in the affected fallout areas. These basic background measurements and sample badges were used by radiation safety personnel at the time of Operation Greenhouse to estimate the maximum possible exposures from the fallout. Estimates were made for personnel on the base islands of Enewetak, Parry, and Japtan as well as the support ships (DNA 1983).

Cumulative radiation exposure data were used to produce a matrix of the estimated doses in rem for the entire Operation Greenhouse test period for Parry, Enewetak, and Japtan Islands as shown in Figures 6-1, 6-2, and 6-3, respectively.

About 70% of the 2,952 U.S. Navy personnel at Operation Greenhouse were badged. These included the boat pool personnel who were expected to enter radioactive areas as they ferried scientific parties to the shot islands. The air patrol squadron personnel who could have flown in the vicinity of the radioactive clouds and air transport personnel who flew radioactive samples to Hawaii and the U.S. mainland were also badged.

A search of Navy medical records indicates that 1,609 doses were assigned immediately after the tests to nearly all personnel aboard the USS *Curtiss* (*AV-4*), USS *Sproston* (*DDE-577*), USS *Walker* (*DDE-517*), USS *Cabildo* (*LSD-16*), the USS *LST-859*, and those in the boat pool, for the period they were not badged. These doses accounted for fallout exposure. The documentation for these calculations has not been found. However, a 1981 scientific reconstruction of the probable fallout exposures for these ships is consistent with the assigned levels (DNA 1983). Assignments for the *Cabildo* and the boat pool appear to have considered individual assignment or work area and the number of days not badged because the same assignment was not made for all crewmembers of these units.

The fallout exposure to personnel aboard ships should be considerably lower than to land-based personnel. Not only were ship structures more effective radiation shields than the light aluminum and canvas shelters on the islands, but decontamination of the ships during and after fallout removed radiating particles from the ships.

Unless particles on the islands were covered, leached into the soil, or blown away, they continued to retain exposure potential until completely decayed.

Arrival date Parry Island \ Departure date	Apr 16	Apr 18	Apr 20	Apr 22	Apr 24	Apr 26	Apr 28	Apr 30	May 2	May 4	May 6	May 8	May 10	May 12	May 14	May 16	May 18	May 20	May 22	May 24	May 26	May 28	May 30	Jun 1
Jun 1																								0.08
May 30																							0.14	0.33
May 28																						0.53	0.93	1.12
May 26																					0.60	2.13	2.53	2.72
May 24																				0	0.60	2.13	2.53	2.72
May 22																			0	0	0.60	2.13	2.53	2.72
May 20																		0	0	0	0.60	2.13	2.53	2.72
May 18																	0	0	0	0	0.60	2.13	2.53	2.72
May 16																0	0	0	0	0	0.60	2.13	2.53	2.72
May 14															0	0.01	0.01	0.01	0.01	0.01	0.61	2.14	2.54	2.73
May 12														0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.62	2.15	2.55	2.74
May 10													0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.63	2.16	2.56	2.75
May 8												0.02	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.65	2.18	2.58	2.77
May 6											0.02	0.06	0.07	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.69	2.22	2.62	2.81
May 4										0.02	0.06	0.10	0.11	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.73	2.26	2.66	2.85
May 2									0.03	0.07	0.11	0.15	0.16	0.17	0.17	0.18	0.18	0.18	0.18	0.18	0.78	2.31	2.71	2.90
Apr 30								0.03	0.08	0.12	0.16	0.20	0.21	0.22	0.22	0.23	0.23	0.23	0.23	0.23	0.83	2.36	2.76	2.95
Apr 28							0.02	0.08	0.13	0.17	0.21	0.25	0.26	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.88	2.41	2.81	3.00
Apr 26						0.02	0.08	0.14	0.19	0.23	0.27	0.31	0.32	0.34	0.33	0.33	0.34	0.34	0.34	0.34	0.94	2.47	2.87	3.06
Apr 24					0.04	0.10	0.16	0.22	0.27	0.31	0.35	0.39	0.40	0.42	0.41	0.41	0.42	0.42	0.42	0.42	1.02	2.55	2.95	3.14
Apr 22				0.03	0.09	0.15	0.21	0.27	0.32	0.36	0.40	0.44	0.45	0.46	0.46	0.47	0.47	0.47	0.47	0.47	1.07	2.60	3.00	3.19
Apr 20			0.01	0.08	0.14	0.20	0.26	0.32	0.37	0.41	0.45	0.49	0.50	0.51	0.51	0.52	0.52	0.52	0.52	0.52	1.12	2.65	3.05	3.24
Apr 18		0.01	0.04	0.11	0.17	0.23	0.29	0.35	0.40	0.44	0.48	0.52	0.53	0.54	0.54	0.55	0.55	0.55	0.55	0.55	1.15	2.68	3.08	3.27
Apr 16	0.03	0.07	0.10	0.17	0.23	0.29	0.35	0.41	0.46	0.50	0.54	0.58	0.59	0.60	0.60	0.61	0.61	0.61	0.61	0.61	1.21	2.74	3.14	3.33
Apr 14	0.14	0.18	0.21	0.28	0.34	0.40	0.46	0.52	0.57	0.61	0.65	0.69	0.70	0.71	0.71	0.72	0.72	0.72	0.72	0.72	1.32	2.85	3.25	3.44
Apr 12	0.35	0.39	0.42	0.49	0.55	0.61	0.67	0.73	0.78	0.82	0.86	0.90	0.91	0.92	0.92	0.93	0.93	0.93	0.93	0.93	1.53	3.06	3.46	3.65
Apr 10	0.75	0.79	0.82	0.89	0.95	1.01	1.07	1.13	1.18	1.22	1.26	1.30	1.31	1.32	1.32	1.33	1.33	1.33	1.33	1.33	1.93	3.46	3.86	4.05
Apr 8	0.98	1.02	1.05	1.12	1.18	1.24	1.30	1.36	1.41	1.45	1.49	1.53	1.55	1.55	1.56	1.56	1.56	1.56	1.56	1.56	2.16	3.69	4.09	4.28

Figure 6-1. Cumulative dose (rem) for personnel on Parry Island due to Operation Greenhouse fallout (Example: personnel arriving April 26 and departing May 26 received a dose of 0.94 rem) (DNA 1983).

ARRIVAL DATE ENEWETAK ISLAND (APRIL → MAY → JUNE)

	16	18	20	22	24	26	28	30	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1
1																								0.11
30																							0.17	0.42
28																						0.66	1.17	1.42
26																					0.84	2.80	3.31	3.56
24																				0	0.84	2.80	3.31	3.56
22																			0	0	0.84	2.80	3.31	3.56
20																		0	0	0	0.84	2.80	3.31	3.56
18																	0	0	0	0	0.84	2.80	3.31	3.56
16																0	0	0	0	0	0.84	2.80	3.31	3.56
14															0	0	0	0	0	0	0.84	2.80	3.31	3.56
12														0	0	0	0	0	0	0	0.84	2.80	3.31	3.56
10													0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.85	2.81	3.32	3.57
8												0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.86	2.82	3.33	3.58
6											0.01	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.88	2.84	3.35	3.60
4										0.01	0.03	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.90	2.86	3.37	3.62
2									0.01	0.03	0.05	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.92	2.88	3.39	3.64
30								0.01	0.03	0.05	0.07	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.94	2.90	3.41	3.66
28							0.02	0.04	0.06	0.08	0.10	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.97	2.93	3.44	3.69
26						0.02	0.05	0.07	0.09	0.11	0.13	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	1.00	2.96	3.47	3.72
24					0.01	0.05	0.08	0.10	0.12	0.14	0.16	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	1.03	2.99	3.50	3.75
22				0.01	0.03	0.07	0.10	0.12	0.14	0.16	0.18	0.20	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	1.05	3.01	3.52	3.77
20			0.01	0.03	0.05	0.09	0.12	0.14	0.16	0.18	0.20	0.22	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	1.07	3.03	3.54	3.79
18		0.01	0.03	0.05	0.07	0.11	0.14	0.16	0.18	0.20	0.22	0.24	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	1.09	3.05	3.56	3.81
16	0.02	0.04	0.06	0.08	0.10	0.14	0.17	0.19	0.21	0.23	0.25	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	1.12	3.08	3.59	3.84
14	0.06	0.08	0.10	0.12	0.14	0.18	0.21	0.23	0.25	0.27	0.29	0.31	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	1.16	3.12	3.63	3.88
12	0.15	0.17	0.19	0.21	0.23	0.27	0.30	0.32	0.34	0.36	0.38	0.40	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	1.25	3.21	3.72	3.97
10	0.33	0.35	0.37	0.39	0.41	0.45	0.48	0.50	0.52	0.54	0.56	0.58	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	1.43	3.39	3.90	4.15
8	0.41	0.43	0.45	0.47	0.49	0.53	0.56	0.58	0.60	0.62	0.64	0.66	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	1.51	3.47	3.98	4.23

APRIL → ← MAY → JUNE

DEPARTURE DATE

Figure 6-2. Cumulative dose (rem) for personnel on Enewetak Island due to Operation Greenhouse fallout (Example: personnel arriving April 28 and departing May 26 received dose of 0.97 rem) (DNA 1983).

ARRIVAL DATE JAPTAN ISLAND

Arrival	APRIL								MAY															JUNE
	16	18	20	22	24	26	28	30	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1
JUNE 1																								0.08
MAY 30																							0,14	0.33
28																						0.53	0.93	1.12
26																					0.60	2.13	2.53	2.72
24																				0	0.60	2.13	2.53	2.72
22																			0	0	0.60	2.13	2.53	2.72
20																		0	0	0	0.60	2.13	2.53	2.72
18																	0	0	0	0	0.60	2.13	2.53	2.72
16																0	0	0	0	0	0.60	2.13	2.53	2.72
14															0	0	0	0	0	0	0.60	2.13	2.53	2.72
12														0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.61	2.14	2.54	2.73
10													0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.62	2.15	2.55	2.74
8												0.02	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.65	2.18	2.58	2.77
6											0.02	0.05	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.68	2.21	2.61	2.80
4										0.02	0.06	0.09	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.72	2.25	2.65	2.84
2									0.03	0.08	0.12	0.15	0.17	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.78	2.31	2.71	2.90
APRIL 30								0.03	0.08	0.13	0.17	0.20	0.22	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.83	2.36	2.76	2.95
28							0.03	0.09	0.14	0.19	0.23	0.26	0.28	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.89	2.42	2.82	3.01
26						0.03	0.10	0.16	0.21	0.26	0.30	0.33	0.35	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.96	2.49	2.89	3.08
24					0.04	0.10	0.17	0.23	0.28	0.33	0.37	0.40	0.42	0.43	0.43	0.43	0.43	0.43	0.43	0.43	1.03	2.56	2.96	3.15
22				0.03	0.10	0.16	0.23	0.29	0.34	0.39	0.43	0.46	0.48	0.49	0.49	0.49	0.49	0.49	0.49	0.49	1.09	2.62	3.02	3.21
20			0.02	0.08	0.15	0.21	0.28	0.34	0.39	0.44	0.48	0.51	0.53	0.54	0.54	0.54	0.54	0.54	0.54	0.54	1.14	2.67	3.07	3.26
18		0.02	0.07	0.13	0.20	0.26	0.33	0.39	0.44	0.49	0.53	0.56	0.58	0.59	0.59	0.59	0.59	0.59	0.59	0.59	1.19	2.72	3.12	3.31
16	0.03	0.08	0.13	0.19	0.26	0.32	0.39	0.45	0.50	0.55	0.59	0.62	0.64	0.65	0.65	0.65	0.65	0.65	0.65	0.65	1.25	2.78	3.18	3.37
14	0.16	0.21	0.26	0.32	0.39	0.45	0.52	0.58	0.63	0.68	0.72	0.75	0.77	0.78	0.78	0.78	0.78	0.78	0.78	0.78	1.38	2.91	3.31	3.50
12	0.39	0.44	0.49	0.55	0.62	0.68	0.75	0.81	0.86	0.91	0.95	0.98	1.00	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.61	3.14	3.54	3.73
10	0.91	0.96	1.01	1.07	1.14	1.20	1.27	1.33	1.38	1.43	1.47	1.50	1.52	1.53	1.53	1.53	1.53	1.53	1.53	1.53	2.13	3.66	4.06	4.25
8	1.14	1.19	1.24	1.30	1.37	1.43	1.50	1.56	1,61	1.66	1.70	1.73	1.75	1.76	1.76	1.76	1.76	1.76	1.76	1.76	2.36	3.89	4.29	4.48

DEPARTURE DATE

Figure 6-3. Cumulative dose (rem) for personnel on Japtan Island due to Operation Greenhouse fallout (Example: personnel arriving April 28 and departing May 26 received dose of 0.89 rem) (DNA 1983).

The assigned fallout exposures in the Navy medical records for personnel who were aboard ships for the entire test period are shown in Table 6-6.

Table 6-6. Operation Greenhouse fallout exposures for personnel aboard ships for the entire test period.[a]

Ship	Exposure (R)
USS *Curtiss* (*AV-4*)	1.043
CTG 3.3 Staff (USS *Curtiss*)	1.043
USS *Cabildo* (*LSD-16*)	0.700–1.100[b]
USS *Sproston* (*DDE-577*)	1.000
USS *Walker* (*DDE-517*)	0.433
USS *LST-859*	0.334
Boat pool	0.700–2.100[b]

a. For dose reconstruction, 1 R is assumed to be equivalent to 1 rem.
b. For dose reconstruction, apply the higher value.

6.3 INSTRUCTIONS TO DOSE RECONSTRUCTORS

6.3.1 Penetrating Dose Determination

Before 1955, covered employees who were not badged should be assigned the 95th-percentile doses in Attachment A. If the employee had recorded dose, the dose reconstructor should compare that recorded dose with the empirical 95th-percentile doses in Attachment A and assign the larger of the two. If the covered employee was not at the PPG for the entire period of an operation, the 95th-percentile dose for that operation should be prorated based on the ratio of the time the covered employee was on site during the active operation and the total period for the entire operation. This prorated 95th-percentile dose should be compared with the recorded dose for the operation and the higher of the two should be assigned. The recorded dose for the operation should not be prorated before the comparison with the prorated 95th percentile dose.

Operations at the PPG were always confined within a calendar year but never lasted for an entire year (i.e., 12 months). Operations typically started after the end of February of a given year and ended before the end of November of the same year. Some operations lasted only a few months in a given year. For purposes of comparing and prorating recorded and 95th-percentile doses, only the dose that was recorded during the active months of the operation should be compared with the 95th-percentile dose. Any dose that was recorded before or after the active operation months should be added to the higher of the operations recorded dose, or the 95th-percentile dose.

These doses should be converted to organ doses using exposure (R) dose conversion factors (DCFs) and be applied as constants.

6.3.2 Nonpenetrating Dose Determination

Shallow or beta dose is determined for susceptible cancers (e.g., skin, breast, testes, penis, and lips) by multiplying the penetrating dose (Section 6.3.1) by the appropriate beta-to-gamma ratio (Section 6.1). The use of the efficiency method in Section 6.1 is allowed for cases where a best estimate is not required. These doses should be assigned as constants.

6.3.3 Penetrating and Nonpenetrating Doses from Fallout

For cases where occupation on the various islands and ships (for April 8, 1951, through May 14, 1951) is documented in the dosimetry records and the covered employee stay times are known, additional penetrating dose should be assigned (1) in accordance with Figures 6-1, 6-2, and 6-3, or (2) in accordance with Table 6-5. The additional dose should be added to the dose as derived in Section 6.3.1. This new summed penetrating dose should then be multiplied by the appropriate beta-to-gamma ratio in Section 6.1 to determine the beta dose for susceptible cancers. The derived penetrating dose should be assigned as a constant. The nonpenetrating dose that was derived from fresh fallout should be applied as a constant and the nonpenetrating dose that was derived from weathered fallout should be applied as a lognormal distribution with a GSD of 2.41. Nonpenetrating dose should be evaluated in accordance with the ORAUT-OTIB-0017, *Interpretation of Dosimetry Data for Assignment of Shallow Dose* (ORAUT 2005), in relation to organ DCFs and other modifying factors. Penetrating dose should be evaluated in accordance with OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* (NIOSH 2007), in relation to organ DCFs. For penetrating dose, anterior-posterior geometry, a comparison with rotational geometry for bone surfaces, red bone marrow, esophagus, and lung should be considered as potentially favorable to the claimant with isotropic geometry assumed for cases requiring a best estimate. The penetrating dose derived from Figures 6-1, 6-2, and 6-3 should be converted to organ doses using the *H*(10)* DCFs from NIOSH (2007) while the penetrating dose derived from Table 6-5 should be converted to organ dose using the exposure (R) DCFs.

7.0 SUMMARY

This site profile provides guidance for dose reconstruction for non-SEC cancers and those presumptive cancer claims that involve less than 250 days (or 83 days if assignment was continuous duty) of employment for EEOICPA claimants who worked at the PPG. NIOSH finds that the external monitoring records and operational histories available with the methods in this TBD are sufficient to complete photon and beta external dose reconstructions for these employees. For participants with available X-ray records that are linked to a covered DOE site, dose reconstructors should use existing NIOSH TBDs and procedures to estimate possible occupational medical exposures. Occupational medical exposures for participants who were hired on location or who do not have available X-ray records linked to a covered site (e.g., NTS, LANL, LLNL, etc.) should be evaluated in accordance with ORAUT-OTIB-0079 (ORAUT 2017). Coworker doses should be assigned to workers at the 95th-percentile level as described in Section 6.3.1 in lieu of other environmental or recorded doses. NIOSH lacks access to source term data, bioassay data, or internal monitoring data to estimate internal doses associated with potential inhalation of radionuclides.

8.0 ATTRIBUTIONS AND ANNOTATIONS

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

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GLOSSARY

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

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

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

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

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

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

nonpenetrating dose
Dose from beta and lower energy photon (X-ray and gamma) radiation that does not penetrate the skin. It is often determined from the open window dose minus the shielded window dose. See *dose*.

penetrating dose
Dose from moderate to higher energy photons and neutrons that penetrates the outer layers of the skin. See *dose*.

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

radioactive
Of, caused by, or exhibiting radioactivity.

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

radiograph

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

rem

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

roentgen (R)

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

shallow dose equivalent

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

skin dose

See *shallow dose equivalent*.

uncertainty

Standard deviation of the mean of a set of measurements. The standard error reduces to the standard deviation of the measurement when there is only one determination. See *accuracy*, *confidence interval or level*, and *error*. Also called standard error.

X-ray

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

X-ray radiation

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

ATTACHMENT A
COWORKER EXTERNAL DOSE

LIST OF TABLES

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ATTACHMENT A
COWORKER EXTERNAL DOSE (continued)

Revision 01 of this site profile used range-tabulated data tables to determine 95th-percentile values for use with external dose assignment for energy employees. This revised attachment describes the analysis of the actual individual dosimetry records (hardcopy reports were entered into an electronic format) from PPG operations. The following assumptions and approaches were used:

1. About 57,000 dose data entries were completed. Where possible, data for individuals associated with the military were excluded by the data entry staff.
2. About 2,500 data entries were duplicates and were removed from the analysis.
3. About 5,800 blank entries were not converted to zero or considered in the analysis.
4. Values between zero and the censoring limit (~40 mrem) were imputed using the methods from ORAUT-RPRT-0071, External Dose Coworker Methodology (ORAUT 2015).
5. In some instances – especially for data associated with Operation Castle – the sum of individual dosimeter values for an employee was greater than the summary dose for that employee. In those cases, the greater value from the summation process was used as the dose for the operation.

The values for each operation (or periods between operations) were analyzed separately. The results are summarized in Table A-1 and shown for each operation and time period in Figures A-1 through A-10. In each figure, the number of individuals analyzed is given, along with the empirical 95th-percentile dose value and a 95th-percentile value derived from a lognormal fit of the data. The parameters defining the lognormal fit are given in each figure.

Not all datasets were good fits to a lognormal distribution. It is likely that the data (especially as seen with Operations Castle, Redwing, Hardtack-I, and Greenhouse) follow a hybrid lognormal distribution. In these instances, exposures follow (1) a lognormal component in the lower range where the effect of dose limits is less pronounced and (2) a normal distribution in the higher range where the effects of a dose limit is strong (DOE 1990). This is illustrated in the figures for these operations where the plot of the actual data is lower than the fitted lognormal plot. Because a lognormal fit is not appropriate for these datasets, the empirical 95th-percentile value for a given operational period should be used for coworker data comparison. The datasets and R code used in this coworker analysis are available in ORAUT (2018).

ATTACHMENT A
COWORKER EXTERNAL DOSE (continued)

Table A-1. Summary of external coworker dose analysis using ORAUT-RPRT-0071 methodology vs. Defense Nuclear Agency (DNA) data.

Operation	Year	Number of results	Empirical 95th percentile (rem)	Lognormal derived 95th percentile (rem)	DNA number of results	DNA 95th percentile (rem)
Crossroads	1946	6,059	0.347	0.337	10,431	0.365
Sandstone	1948	262	1.710	1.450	119	2.348
Ivy	1952–1953	1,512	1.680	1.709	367	1.238
Castle	1954	2,273	4.890	6.760	2,175	2.117
Period 55	1955	1,480	1.470	1.653	Not applicable	Not applicable
Redwing	1956	996	6.076	9.194	3,847	3.969
Period 57	1957	1,356	0.495	0.515	Not applicable	Not applicable
Hardtack-I	1958	7,320	3.794	11.160	5,067	1.707
Greenhouse	1961	3,524	6.230	13.400	551	1.813
Dominic-I	1962	3,130	0.289	0.365	4,620	0.558

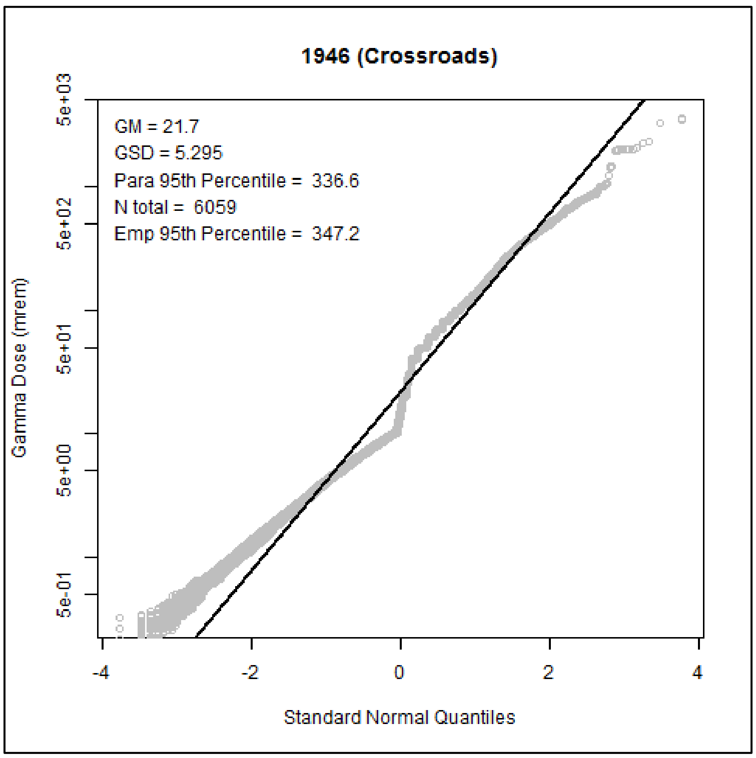

Figure A-1. External coworker dose analysis for Operation Crossroads.

ATTACHMENT A
COWORKER EXTERNAL DOSE (continued)

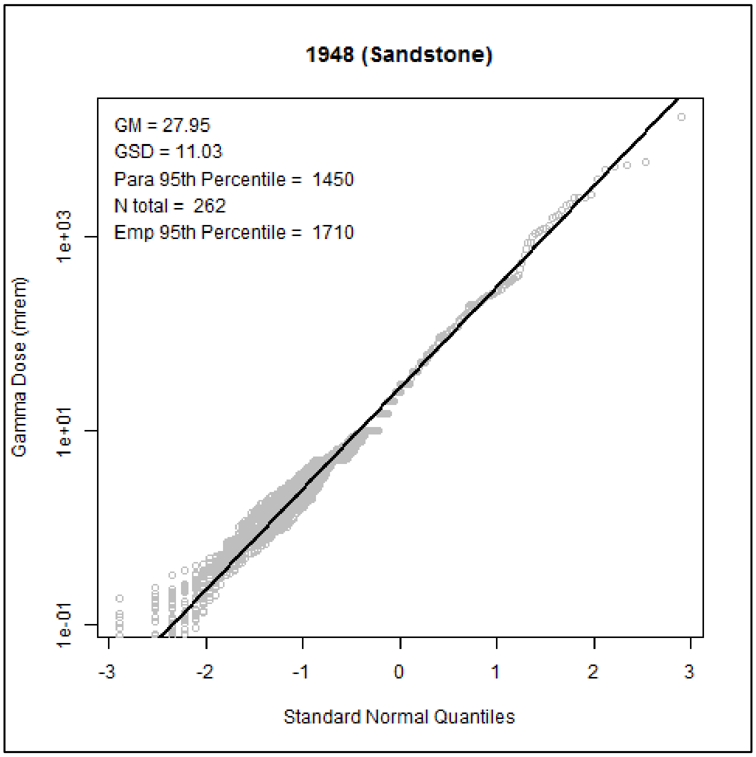

Figure A-2. External coworker dose analysis for Operation Sandstone.

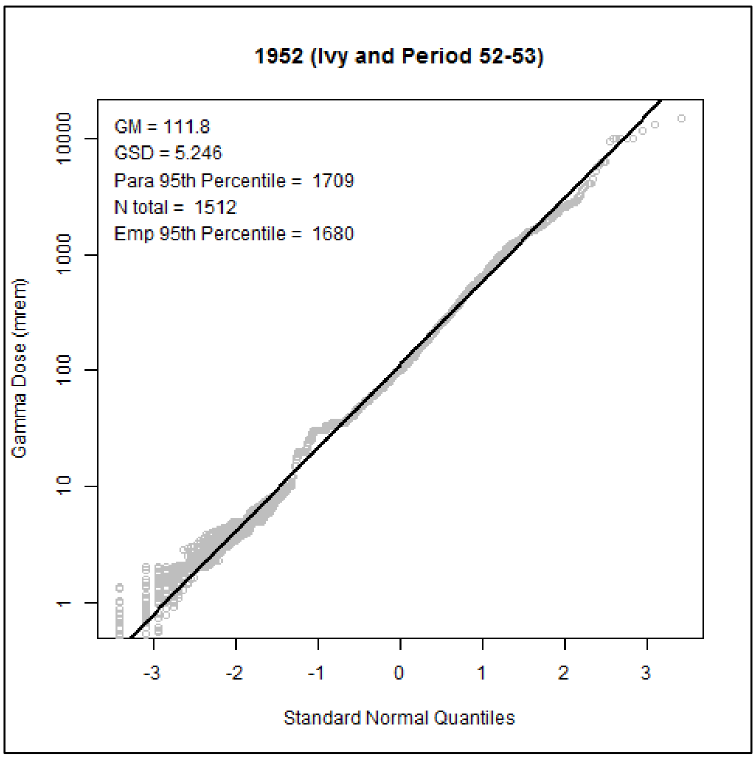

Figure A-3. External coworker dose analysis for Operation Ivy, 1952 to 1953.

ATTACHMENT A
COWORKER EXTERNAL DOSE (continued)

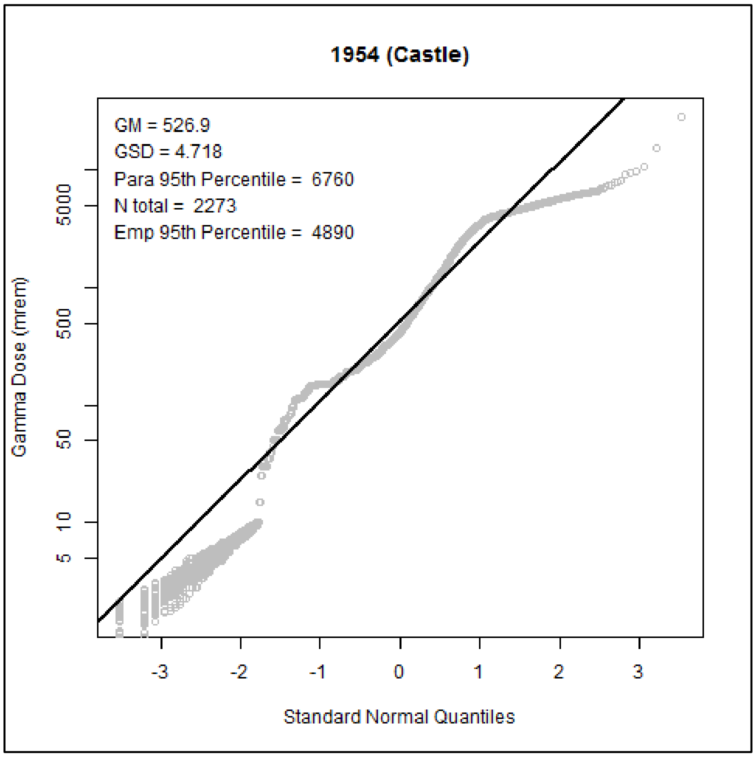

Figure A-4. External coworker dose analysis for Operation Castle.

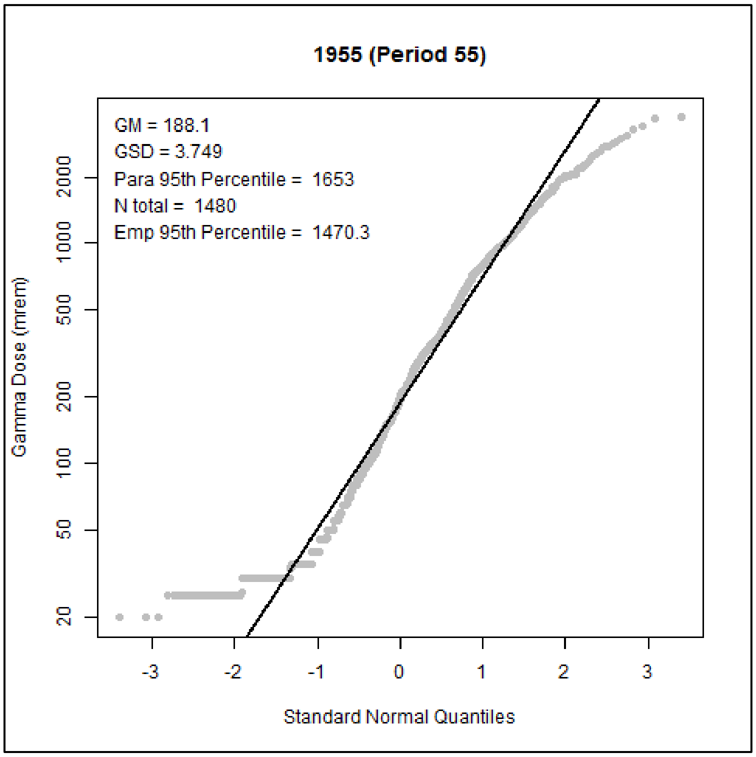

Figure A-5. External coworker dose analysis, 1955.

ATTACHMENT A
COWORKER EXTERNAL DOSE (continued)

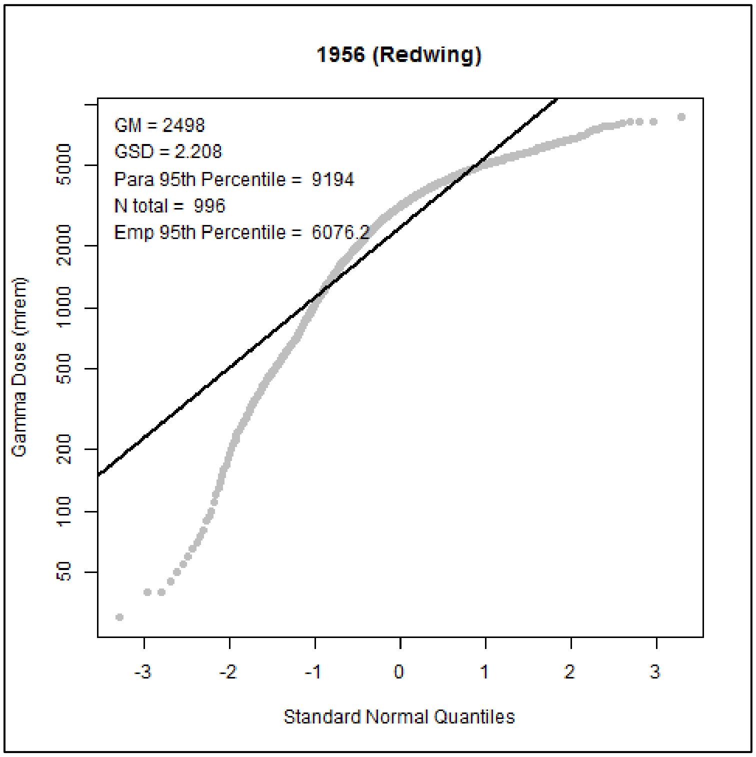

Figure A-6. External coworker dose analysis for Operation Redwing.

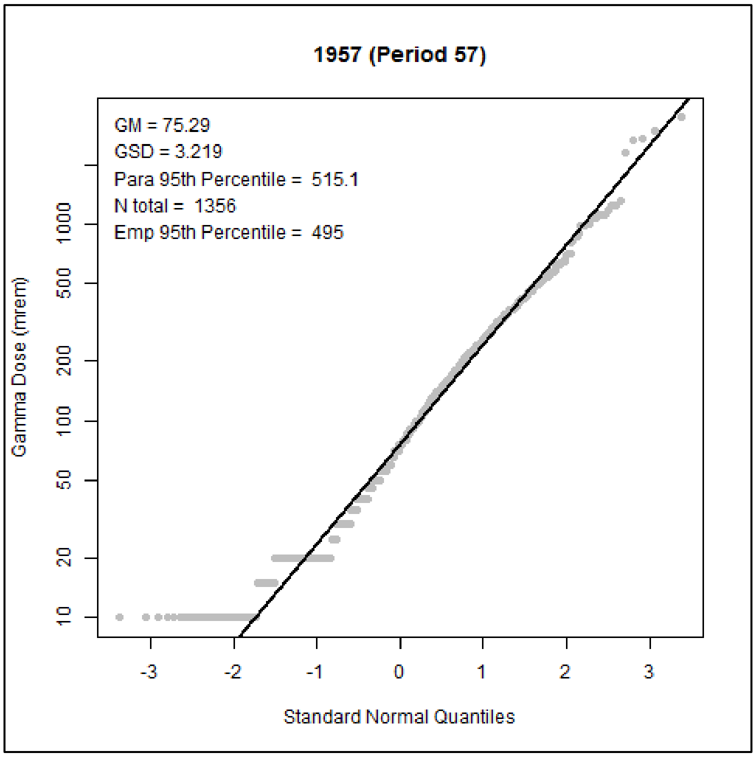

Figure A-7. External coworker dose analysis, 1957.

ATTACHMENT A
COWORKER EXTERNAL DOSE (continued)

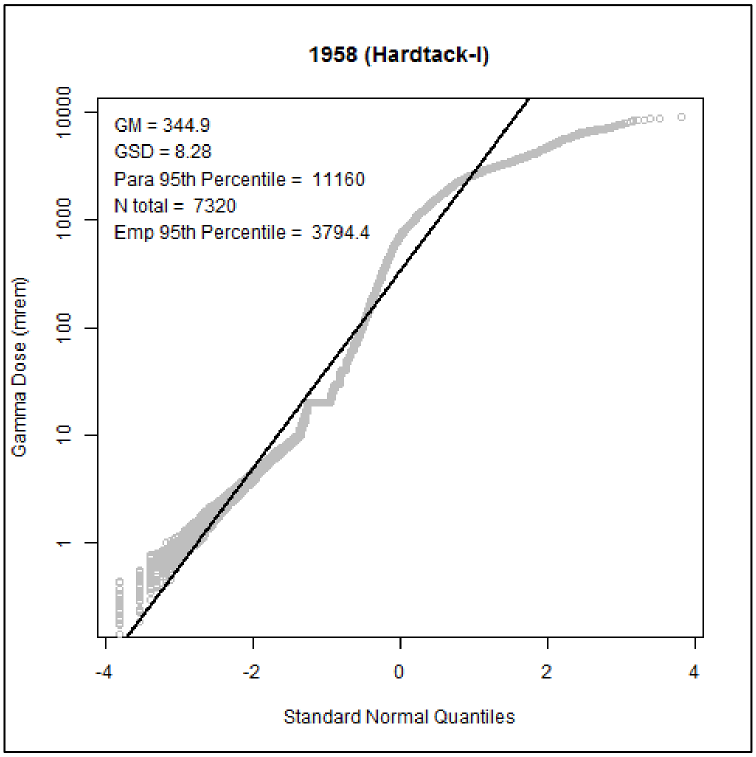

Figure A-8. External coworker dose analysis for Operation Hardtack-I.

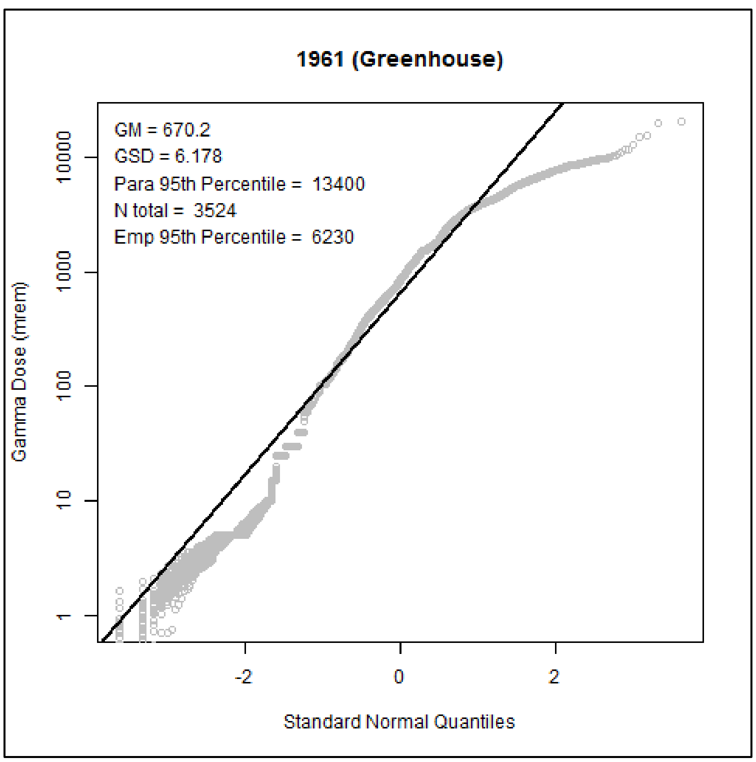

Figure A-9. External coworker dose analysis for Operation Greenhouse.

ATTACHMENT A
COWORKER EXTERNAL DOSE (continued)

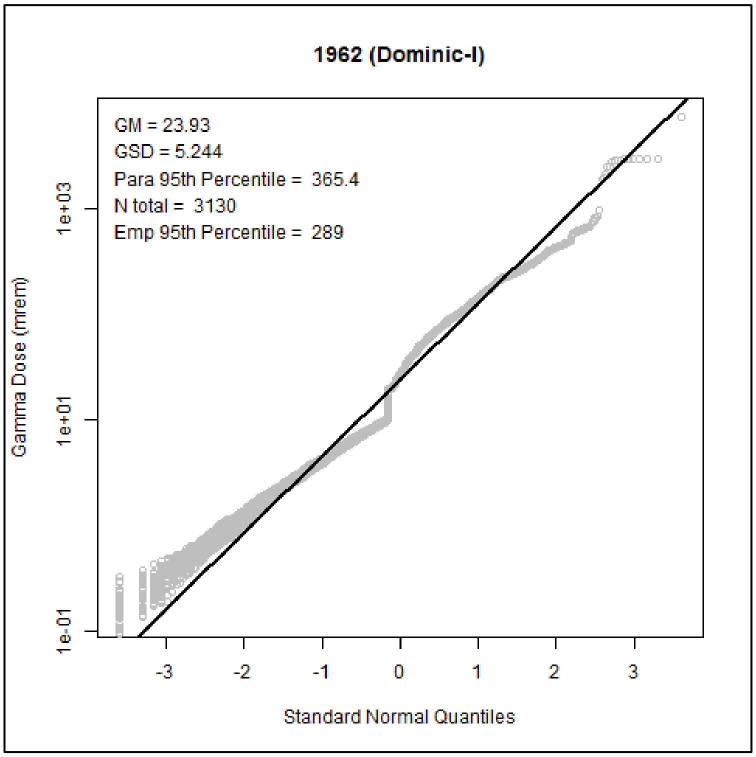

Figure A-10. External coworker dose analysis for Operation Dominic-I.