SEC Petition Evaluation Report
Petition SEC-00020

Report Rev # 0

Report Submittal Date: 10-20-2005

Petition Administrative Summary											
Petition Under Evaluation											
Petition #		Petition Type		Submittal Date			DOE/AWE Facility Name				
SEC-00020		83.13		01-03-2005			Pacific Proving Ground (PPG)				
Feasible to Estimate Doses with Sufficient Accuracy?											
Single Class				Multiple Classes				Determination Established for All Classes			
Yes		No	X	Yes		No		Yes	X	No	

Initial Class Definition
All scientists and scientific couriers employed at Enewetak Atoll during Operation HARDTACK I, from July 1, 1958 through August 31, 1958.

Proposed Class Definition
All employees of DOE, DOE contractors, or subcontractors employed at the PPG from 1946 through 1962.

Related Petition Summary Information			
SEC Petition Tracking #(s)	Petition Type	DOE/AWE Facility Name	Petition Status
None			

Related Evaluation Report Information	
Report Title	DOE/AWE Facility Name
None	

ORAU Lead Technical Evaluator:	**Signature on File** *Monica Harrison-Maples*	**10/20/2005** *Date*
Lead Technical Evaluator:	**Signature on File** *LaVon Rutherford*	**10/20/2005** *Date*
Reviewed By:	**Signature on File** *James W. Neton*	**10/20/2005** *Date*
Approved By:	**Signature on File** *Larry J. Elliott*	**10/20/2005** *Date*

Evaluation Summary

This evaluation report by the National Institute for Occupational Safety and Health (NIOSH) covers a class of employees proposed for addition to the Special Exposure Cohort (SEC) in Petition SEC00020, qualified on April 11, 2005. Although the petition requested NIOSH to consider all scientists and scientific couriers located at the Enewetak Atoll, a location within the Pacific Proving Grounds (PPG), during Operation HARDTACK I from July 1 through August 31, 1958, this evaluation covers all employees of Department of Energy (DOE), DOE contractors, or subcontractors employed at the PPG from 1946 through 1962.

In this evaluation report, NIOSH provides its findings on the feasibility of estimating radiation doses of members of this class with sufficient accuracy (i.e., the feasibility of dose reconstruction) and on related matters, as required for NIOSH evaluations of SEC petitions under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA) and title 42 of the Code of Federal Regulations (CFR), Part 83, *Procedures for Designating Classes of Employees as Members of the Special Exposure Cohort Under the Energy Employees Occupational Illness Compensation Program Act of 2000 (*42 CFR pt. 83). This report will be considered by the Advisory Board on Radiation and Worker Health and by the Secretary of Health and Human Services (HHS). The Secretary of HHS will make final decisions concerning whether or not to add one or more classes to the SEC in response to the petition addressed by this report.

Feasibility of Dose Reconstruction

The feasibility determination for the class of employees covered by this evaluation report is governed by, section 83.13(c)(1) of 42 CFR pt. 83. Under this regulation, NIOSH must establish whether or not it has access to sufficient information to either estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred under plausible circumstances by any member of the class, or to estimate the radiation doses of members of the class more precisely than a maximum dose estimate. If NIOSH has access to information sufficient for either case, then dose reconstruction is feasible.

NIOSH has established in this evaluation 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 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.

Health Endangerment

The health endangerment determination for the class of employees covered by this evaluation report is governed by EEOCIPA and 42 C.F.R. Part 83.13(c)(3). Under these requirements, if it is not feasible to estimate with sufficient accuracy radiation doses for members of the class, NIOSH must also make a determination whether or not there is a reasonable likelihood that such radiation doses may have endangered the health of members of the class. The regulation requires NIOSH to assume that any duration of unprotected exposure may have endangered the health of members of a class when it has been established that the class may have been exposed to radiation during a discrete incident likely to have involved levels of exposure similarly high to those occurring during nuclear criticality incidents.

If the occurrence of such an exceptionally high level exposure has not been established, then NIOSH is required to specify that health was endangered for those workers who were employed for a number of work days aggregating at least 250 work days within the parameters established for the class or in combination with work days within the parameters established for one or more other classes of employees in the SEC (excluding aggregate work day requirements).

The NIOSH evaluation did not identify any evidence from the petitioners or from other resources that would establish that the class was exposed to radiation during a discrete incident likely to have involved exceptionally high level exposures, as described above. Consequently, NIOSH has specified that health was endangered for those workers covered by this evaluation who were employed for a number of work days aggregating at least 250 work days within the parameters established for this class or in combination with work days within the parameters established for one or more other classes of employees in the SEC.

Proposed Class Definition

This evaluation defines a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy and whose health may have been endangered by such radiation doses. This class includes all employees of DOE, DOE contractors, or subcontractors employed at the PPG from 1946 through 1962 for a number of work days aggregating at least 250 work days occurring either solely under this employment or in combination with work days within the parameters (excluding aggregate work day requirements) established for other classes of employees included in the SEC.

1.0 Purpose

The purpose of this report is to provide an evaluation of the feasibility of reconstructing the dose for the employees proposed as a class in SEC petition 00020. The petition covered scientists and scientific couriers, radiation safety monitors, and construction workers who were Atomic Energy Commission (AEC) employees, contractors, or subcontractors at the Pacific Proving Ground (PPG) from January 1946 through December 1962. The evaluation was initially based on the petition, SEC00020 which defines a class limited to "scientists and scientific couriers located at the Enewetak Atoll, a location within the Pacific Proving Grounds (PPG), during Operation HARDTACK I from July 1 through August 31, 1958." The evaluation class definition is being extended to include personnel for whom NIOSH has identified a plausible scenario for ingestion or inhalation of radiological particles in the air due to the re-suspension of fallout and a lack of internal monitoring data.

This evaluation was conducted in accordance with the requirements of 42 C.F.R. Part 83 and the guidance contained in the National Institute for Occupational Safety and Health (NIOSH) Internal Procedures for Special Exposure Cohort (SEC) Evaluations, OCAS-PR-004. It provides information and analyses germane to considering a petition for adding a class of employees to the SEC. It does not provide any determinations concerning the feasibility of dose reconstruction that necessarily apply in the particular case of any individual energy employee who might require a dose reconstruction from NIOSH.

2.0 Introduction

Energy Employees Occupational Illness Compensation Program Act (EEOICPA) and 42 C.F.R. Part 83 requires NIOSH to evaluate qualified petitions requesting Department of Health and Human Services (HHS) to add a class of employees to the SEC. The evaluation is intended to provide a fair, science-based determination of whether or not it is feasible to estimate with sufficient accuracy the radiation doses of the class of employees through NIOSH dose reconstructions[1]. If it is not feasible, the evaluation is further required to make a determination with respect to the health endangerment of the class of employees.

NIOSH is required to document the evaluation in a report, which is provided to the petitioners and to the President's Advisory Board on Radiation and Worker Health (the Board). The Board will consider the NIOSH evaluation report, together with the petition and any comments of the petitioner(s), to make recommendations to the Secretary of HHS on whether or not to add one or more classes of employees to the SEC. Once NIOSH has received and considered the advice of the Board, the Director of NIOSH will propose decisions on behalf of HHS. The Secretary of HHS will make final decisions, taking into account the NIOSH evaluation, the advice of the Board, and the proposed decision issued by NIOSH. As part of this final decision process, the petitioner(s) may seek a review of certain types of proposed decisions issued by NIOSH.[2]

This NIOSH report provides a summary of the methods and findings of the NIOSH SEC petition evaluation for all employees of DOE, DOE contractors, or subcontractors employed at the PPG from 1946 through 1962.

[1] NIOSH dose reconstructions under EEOICPA are performed using the methods promulgated under 42 CFR Part 82 and the detailed implementation guidelines available at www.cdc.gov/niosh/ocas.
[2] See 42 CFR Part 83 for a full description of the procedures summarized here. Additional internal procedures are available at www.cdc.gov/niosh/ocas.

3.0 Initial Class Definition and Petition Basis

The initial class definition, as specified within SEC Petition SEC00020, which qualified on April 11, 2005, requested HHS to consider the addition of a class of employees including the scientists and scientific couriers employed at Enewetak Atoll during Operation HARDTACK I, from July 1 through August 31, 1958 to the SEC.

Of the evidence provided by the petitioners, the following evidence met the criteria in the rule to provide support of their belief that dose reconstruction would not be feasible for this proposed class of employees, to qualify the submission as a petition to receive consideration by NIOSH, the Board, and HHS:

- As of the time of qualification, no data or documentation had been located indicating any results or program to monitor for internal exposure due to ingested or inhaled radioactive material. The petitioner provided a declaration that there was no monitoring for internal exposures due to ingested or inhaled radioactive material.

The petitioners supplied an affidavit in support of this basis.

4.0 Data Resources

NIOSH identified and reviewed multiple data resources to determine the availability of information relevant to determining the feasibility of dose reconstruction for the class of employees covered by the evaluation. This included determining the availability of information on personal monitoring, area monitoring, testing processes, and radiation source materials for the period of time from 1946 through 1962 at PPG. The following sections identify the resources identified and reviewed.

4.1 Previous Dose Reconstructions

NIOSH reviewed its dose reconstruction database, NIOSH OCAS Claims Tracking System (NOCTS), to identify dose reconstruction cases under EEOICPA that might provide information relevant to the petition evaluation. Table 1 below provides a results summary of this review for the 1946 through 1962 time frame.

.

Table 1: PPG Claims Submitted Under Dose Reconstruction Rule for 1946-1962

Description	Total
Number of cases submitted for energy employees who meet the revised class definition employment period criteria.	65
Number of dose reconstructions completed for energy employees who were employed at PPG during the years identified in the revised class definition.	3
Number of cases for which internal dosimetry records were obtained for the identified years in the revised class definition.	0
Number of cases for which external dosimetry records were obtained for the identified years in the revised class definition.	57

NIOSH reviewed each case to determine whether internal and/or external personal monitoring records for the employee or any other monitoring records for the employee were available. While there was an external monitoring program and most claimants have been determined to have external monitoring records, no records of inhalation or ingestion monitoring for these individuals associated with potential internal exposure received at the PPG were available to NIOSH. References to individual internal monitoring were made in several historical reports on specific test series. Records of the computer aided telephone interviews with many of the claimants were reviewed as well, for any information that might identify monitoring practices and record locations. The interviews provided some information that might be useful for dose reconstructions (i.e., work locations, hours worked, and hazards encountered) and most of the claimants indicated that they wore a film badge.

NOCTS currently indicates that a total of 65 cases requiring dose reconstruction (as of September 28, 2005) have been received for the PPG facility. Four of those cases have been held by Department of Labor for some form of clarification, which makes them unavailable to NIOSH at this time. Of the available cases received to date, dose reconstruction has been completed for 3 claims (4.9% of the available active claims).

4.2 NIOSH and ORAU Research Documents

A search of the NIOSH site research database was conducted for documentation relating to PPG and the resulting 6 documents were evaluated for pertinence to this petition. In addition, multiple publicly accessible websites were searched including the Internal Dose Monitoring website of Lawrence Livermore National Laboratory, the Defense Threat Reduction Agency (DTRA) website, and the Department of Energy Environment, Safety and Health webpage regarding the Marshall Islands. The Marshall Islands Document Collection was searched for all documents pertaining to the various atmospheric nuclear testing operations performed at the PPG.

These documents contained event histories, summary external monitoring dosimetry results (film badge summary readings of gamma exposure), the Department of Defense (DOD) Consolidated Dosimetry Report, final reports of various task groups assigned specific responsibilities within the JTF organizations conducting the testing, contractor environmental survey reports, and standard operating procedures.

The information from these documents relevant to the class is summarized and evaluated in sections 5.0, 6.0, and 7.0 of this report.

4.3 Documentation and/or affidavits provided by the petitioners

In qualifying and evaluating the petition, NIOSH reviewed the following documents submitted or referenced by the petitioners:

1) Affidavit of petitioner, received March 7, 2005.
2) Excerpts from the book “The Leukemias: Epidemiologic Aspects” by Martha S. Linet, 1985, received January 3, 2005.

These documents were reviewed as to the relevance to the petitioning class. The information from these documents, relevant to the petitioning class, has been summarized in sections 5.0 and 7.0 of this report.

5.0 Summary of Available Monitoring Data

Each of the test series had a radiation safety (radsafe) program established, incorporating procedures developed in accordance with lessons learned from previous test series (DNA 6041F). These programs focused primarily on personal monitoring of external radiation exposure. Internal exposure was to be controlled through avoidance and detection as indicated in operational radiological safety procedures. A substantial bioassay program was not implemented for participants of the operation. There was no program for whole body or chest counting, and there was only a brief mention, located in the Albuquerque Operations manager's report (ALO 58-2), of limited use of nasal smears, for which NIOSH has been unable to locate the associated data.

TABLE 5.1 SUMMARY OF MONITORING DATA FOR PPG

	Available Data	Qualifications on data
External Dosimetry Data	Considerable personal monitoring data and area monitoring data are available for gamma.	Protective covering on badges potentially shielded out betas. Reports of defective seal on badges for DOMINIC I.
Neutron Dosimetry Data	Experimental studies were conducted to explore neutron generation and measurement	Experiments did not include information on the exposure of test participants.
Internal Dosimetry Data	None located in publicly accessible records. Based on conversations with SAIC, who is responsible for DTRA dose reconstructions, the urine and air data for evaluation of internal exposures are not available.	As noted by the National Research Council (NRC) (NRC 2003) suitable monitoring data to estimate intakes of radionuclides generally were not obtained. Other than a number of urine samples analyzed during Operation CROSSROADS, bioassays were rare among personnel.
Environmental Sampling Data	Reports of radioactivity results in sea water, lagoon water sampling, beta activity in plankton, and surveys of plant, fish and invertebrate samples from all around the PPG were completed by University of Washington. Public Health Service sampled air, rain, and fallout at locations in and surrounding the PPG.	
Air Sampling Data	Sampling protocols differed for the different test series, but were collected according to operational plan, i.e. for HARDTACK I samples were collected daily or 48 hours after detonation. No occupational air data has been retrieved to date. Some offsite monitoring data is available.	Some samples were only counted once and activity values were extrapolated to the end of the collection.

An example of the type of data that is typically seen in test reports, are described below.

Sample type	Number of samples
Sea water	463
Rain water	29
Fresh water	2
Alpha swipes	60
Nasal smears	200
Food	15

Soil	13
Urine (tritium)	20
Marine specimens	6
Plant specimens	3

This information was taken from a report of the Albuquerque Operations Manager (ALO 58-2). The report references that the samples were counted during HARDTACK I, but no data from these samples have been located as of the date of this evaluation report. The number of samples varied with each test shot, but no data from the test shots have been located at this time.

Since 1946, personnel from the School of Fisheries, University of Washington have studied the effects of nuclear detonations and the ensuing radioactivity on the marine and terrestrial environments throughout the Central Pacific (UW). A collection of reports and publications about these activities and a collection of several thousand samples from these periods are reportedly kept at the School of Fisheries. The basic field program was the collection of terrestrial, lagoon, and ocean samples that represented the major components of the ecosystem. Some of the identification and measurement of the radionuclides in the samples was done in the field to provide guidance to the on-going field program, but most of the samples were analyzed in the home laboratory where the facilities were available for more sensitive detection and measurement and longer sample counting times could be accommodated. This data, which might be available from the University of Washington, may be useful for calculating ingestion from swimming in the lagoons and eating marine life (UW and UW 40).

Since its inception in 1978, the Nuclear Test Personnel Review (NTPR) program has provided radiation dose information and data to veterans who participated in U.S. atmospheric nuclear tests, served with the American occupation forces in Hiroshima and Nagasaki, Japan, or were prisoners of war in Japan at the conclusion of World War II. The program is administered by the Defense Threat Reduction Agency (DTRA), which is the Department of Defense (DOD) Executive Agent for the NTPR Program. NIOSH contacted Science Applications International Corporation (SAIC), the contractor retained by DTRA to complete dose reconstructions for veterans meeting the criteria identified above, to determine the availability of urine and air sample data for test shots conducted at PPG. SAIC technical experts indicated that the 2600 urine samples identified for CROSSROADS were unavailable. SAIC also indicated few, if any, air sample data, are available.

There is no NIOSH Technical Basis Document (TBD) for PPG but the TBD for Nevada Test Site (NTS) has information pertinent to this evaluation. More extensive atmospheric testing was conducted at the NTS than at PPG. The NTS nuclear weapons testing monitoring results are a useful source of information on the deposition of specific radionuclides resulting from nuclear weapons testing.

6.0 Summary of Radiological Operations Relevant to the Initial Class

This summary is based in part on a review of individual project task reports for each test series. This information was confirmed, in part, by a review of the Defense Nuclear Agency report, *"For the Record- A History of the Nuclear Test Personnel Review Program, 1978-1986"* (DNA 6041F).

Between 1945 and 1962, the U.S. Atomic Energy Commission (AEC) conducted 235 atmospheric nuclear weapon tests at sites in the U.S. and in the Pacific and Atlantic oceans. In the Pacific, 29 atolls and 5 islands spread over 770,000 mi^2 with a total land area of about 70 mi^2 comprise the Marshall Islands. Enewetak Atoll, Bikini Atoll, Johnston Island and Christmas Island in the Marshall Islands together, are the AEC's Enewetak Proving Ground, later known as the Pacific Proving Ground (PPG). The table below identifies the test series, the year they occurred, the number of detonations, and the various types of detonations.

Pacific Test Series Name	Year Conducted	No. of Detonations	Type of Detonation
Crossroads	1946	2	Airburst/Underwater
Sandstone	1948	3	All Tower
Greenhouse	1951	4	All Tower
Ivy	1952	2	Surface/ Airburst
Castle	1954	6	Surface/ Barge
Redwing	1956	17	Surface, Airdrop, Barge, and Tower
Hardtack I	1958	35	Various
Dominic	1962	36	Airdrop

Note: For more detail on each test see Appendix A

All of the test series were conducted by organizations designated as a Joint Task Force (JTF), made up of military personnel from the four services, federal civilian personnel, and contractor personnel.

From the beginning of the tests, military leadership recognized the need for a substantial, qualified, military radsafe organization. After CROSSROADS, the radiation safety plans established an organization to provide radsafe expertise and services to commanders of the separate components of the task force, who were responsible for personnel safety within their commands. Personnel were trained in radiological safety. Standards governing permissible exposure were established.

The principal source of exposure to DOE, DOE contractors, or subcontractors, or AWE employees employed by the AEC or AEC contractors or subcontractors at the PPG from 1946 through 1962 would have been external exposure from gamma rays following detonation, fallout, the activation of debris (i.e. photo tower steel), contamination and immersion. Beta exposure would occur from cloud immersion and direct contact with fallout. Neutron exposure would have been a concern near the blast. The principal potential source of internal radiation doses for members of the class would have been inhalation or ingestion due to contamination caused by the fallout from the nuclear detonations.

Operation CROSSROADS was the first atmospheric nuclear weapon test series held in the Marshall Islands starting in 1946. From the beginning of the nuclear testing, Radiological Safety Plans focused on detection and avoidance of radiation (DNA 6032F). The plans included the establishment of exclusion areas, operational limits, and contamination controls (including donning and doffing clothing upon egress from potentially contaminated areas). Systematic reconnaissance was to begin shortly after each detonation with aerial and surface surveys, including water samples, soil samples, and marine life samples. Radsafe monitors were assigned to monitor and limit the radiation exposure of work parties. Over 225 monitors were used for each of the two CROSSROADS detonations. The Operational Plan set the maximum allowable dose for exposure over a long period at 0.1 roentgens (R) per 24 hours. In addition, no individual was allowed to have a total exposure of over 50 or 60 R in 2 weeks. If an individual received 10 R in 1 day or 60 R in 2 weeks, he was to be withdrawn from active participation in the operation. There is no record indicating that this action was ever required (DNA 6032F).

About 15 percent of the JTF 1 personnel were issued at least one of the 18,875 film-badge dosimeters during CROSSROADS. Approximately 6,596 personnel were on islands or ships that had no potential for radiation exposure. Personnel anticipated to be at greatest radiological risk were badged, and a percentage of each group working in less contaminated areas was badged. The maximum accumulated exposure recorded was 3.72 R. Beginning with REDWING, film badges were issued to all individuals upon their arrival at the PPG to determine gamma radiation exposure (DNA 6032F; DNA 6041F).

Due to the presence of alpha emitters, including plutonium, a program to urine test personnel thought to have been exposed was implemented to determine whether any had taken these substances into their bodies. The water-testing laboratory on the ship Haven was converted for testing urine. By 15 August 1946, 2600 samples had been tested. The men doing the work had to use instruments that were on hand and develop techniques as they worked. The widespread presence of radioactive material led to high background counts and made it difficult to determine whether an individual had low levels of alpha emitters in his urine (DNA 6032 F).

The radiological safety approach used for CROSSROADS was duplicated for all tests after CROSSROADS. A radsafe annex to the Operation Plan, outlining the radiological safety regulations for the operation was issued prior to each test series. Exposure limits changed as more knowledge was gained from the tests. Air sampling was performed, but this was designed to establish fallout patterns rather than monitoring occupational internal exposure. According to SAIC, few of these air sampling data are available and NIOSH has not had the opportunity to examine them. Urine samples were collected for CROSSROADS but NIOSH has been unable to retrieve the data. After CROSSROADS, urine sampling was performed for special cases, such as after the occurrence of fallout a short time after zero hour of the DOG shot test during Operation GREENHOUSE. There were 125 urine samples analyzed, but these data are not available to NIOSH.

Appendix A of this report provides more detail concerning each of the tests and radiological operations performed at the PPG.

7.0 Evaluation of Feasibility of Dose Reconstruction

The feasibility determination for the class of employees covered by this evaluation report is governed by 42 CFR § 83.13(c) (1). Under this regulation, NIOSH must establish whether or not it has access to sufficient information to either estimate the maximum radiation dose that could have been incurred under plausible circumstances by any member of the class, or to estimate the radiation doses of members of the class more precisely than a maximum dose estimate. If NIOSH were to have access to the information sufficient for either case, then dose reconstruction would be feasible.

In making determinations of feasibility, NIOSH begins by evaluating whether current or completed NIOSH dose reconstructions demonstrate the feasibility of estimating with sufficient accuracy the potential radiation doses of the class. If not, NIOSH systematically evaluates the sufficiency of different types of monitoring data and process and source or source term data, which together or individually might assure NIOSH that it can estimate either the maximum doses members of the class might have incurred, or more precise quantities that reflect the variability of exposures experienced by groups or individual members of the class. This approach is specified in the SEC Petition Evaluation Internal Procedures (OCAS-PR-004) available at www.cdc.gov/niosh/ocas.

As documented in Section 4.1, NIOSH has not completed any dose reconstructions nor collected information in the process of dose reconstruction that fully demonstrates the feasibility of estimating the radiation doses of the class. As indicated in section 5.0, another government organization, DTRA has completed dose reconstructions for veterans associated with the nuclear weapons testing program at PPG.

The feasibility evaluation that follows examines the methods used for dose reconstruction under DTRA and the availability of information necessary for reconstructing internal and external radiation doses of members of the class.

7.1 NTPR Dose Reconstructions

As identified in section 5.0, a method for completing dose reconstructions for veterans who participated in U.S. atmospheric nuclear tests was developed by DTRA for the NTPR program, which serves veterans who participated in U.S. atmospheric nuclear tests, served with the American occupation forces in Hiroshima and Nagasaki, Japan, or were prisoners of war in Japan at the conclusion of World War II. The primary purpose of the NTPR Program is to provide participation data and radiation dose information to veterans. In theory, the technical work of this program could be used to support dose reconstructions for all employees of DOE, DOE contractors, or subcontractors employed at the PPG from 1946 through 1962. Since the veterans and members of the proposed class worked in the same locations or close proximity, they were subject to similar exposures. Therefore, the models developed for determining dose to veterans could be used for the class members.

However, in 2003, the National Research Council (NRC) reviewed the NTPR program, issuing a report, "A Review of the Dose Reconstruction Program of the Defense Threat Reduction Agency" (NRC 2003). The review was prompted by a GAO report to Congress (2000) and examined the methods of the program and a random sample of completed dose reconstructions from the program to determine:

- Whether or not the reconstruction of sample doses is accurate.
- Whether or not the reconstructed doses are accurately reported.
- Whether or not the assumptions made regarding radiation exposure based on sampled doses are credible.
- Whether or not the data from nuclear tests used as a part of the reconstruction of sampled doses are accurate.

The final report outlined several conclusions and recommended improvements relating to various aspects of the NTPR dose reconstruction process.

NIOSH has examined the models used for the NTPR program, conclusions and recommendations by the NRC (NRC 2003), and DTRA's corrective action plan (DOD 2004). The technical issues associated with internal and external exposures identified by the NRC were evaluated to determine whether the data or technical products of the NTPR program could be used to support dose reconstructions for the EEOICPA claims and whether the issues identified by the NRC can be resolved in a timely manner.

<u>Internal Dose Issues</u>

The internal dose reconstruction process established by DTRA starts by determining the activity ratio of hundreds of radionuclides produced by the weapon detonation. Since the time of the detonation is well documented, the decay of these radionuclides and the subsequent affect of that decay on the activity ratio are readily determined. DTRA assumes that the radionuclides are well mixed in the cloud produced by the detonation and subsequently, that the fallout is well mixed. This information is used to determine the radiation level per unit ground contamination. With that determination, and the calculation of a resuspension factor, the integrated airborne exposure is related to the external radiation exposure.

The NRC review raised a number of issues associated with the methods used by DTRA to estimate inhalation dose. They summarized these issues in two tables. One table identified issues that potentially overestimated internal doses. These issues were not evaluated in this SEC evaluation. The second table identified issues that potentially underestimated the inhalation dose. That table is reproduced below. The table number is the number in the NRC report.

TABLE V.C.7 Summary of Assumptions Used to Estimate Inhalation Doses in NTPR Program That Have Substantial Uncertainty That Is Not Taken into Account or Should Tend to Result in Underestimates of Dose

Dose coefficients (organ-specific equivalent doses per unit activity of radionuclides inhaled) • Uncertainties in dose coefficients due to uncertainties in dosimetric and biokinetic models are not taken into account. • Uncertainty in dose coefficients for alpha-emitting radionuclides due to uncertainty in biological effectiveness of alpha particles is not taken into account. • Dose coefficients for organs of GI tract from inhalation of plutonium may be underestimated when inhaled materials are respirable (AMAD, 1 μm).
Methods used to estimate inhalation exposures (intakes of radionuclides in air) • Sources of error and uncertainty in methods of estimating radionuclide concentrations in deposited fallout based on measured external photon exposures have not been evaluated, and reliability of methods is unknown. The assumption of no fractionation (except for removal of noble gases) should result in substantial underestimates of concentrations of refractory radionuclides (such as plutonium), and the method of calculating external exposure rates per unit concentration of radionuclides on a surface probably is not valid for fallout deposited on ships in Pacific and should result in underestimates of concentrations in these cases. • Resuspension factor used to estimate radionuclide concentrations in descending fallout may result in underestimates of exposure when exposure did not occur during entire period of fallout. • Presence of fallout deposited more than a few months before exposure usually is ignored, especially late in period of atomic testing at NTS, when buildup of plutonium and longer-lived fission products from many prior shots was extensive. • Effect of blast wave from detonations at NTS on resuspension of substantial fraction of previously deposited fallout over large areas generally is ignored. • In some dose reconstructions for veterans who filed claim for compensation for cancer in internal organs and received substantial external dose, inhalation dose of zero was assigned even though inhalation exposure almost certainly occurred. • Resuspension factors applied to fallout deposited on ships in Pacific, especially below decks, may be too low. • Inhalation dose during time spent indoors on residence islands in Pacific is assumed to be zero; some inhalation doses below decks on ships also may be underestimated.

The NRC concluded generally that the methods used in the NTPR program to estimate inhalation doses to atomic veterans do not consistently provide credible upper bounds.

Most of the issues dealing with uncertainty are similar to issues NIOSH has already or is currently dealing with in the EEOICPA program. Of the issues identified by the NRC, NIOSH considers the following issue most significant with respect to the feasibility of dose reconstruction for non-military personnel under EEOICPA:

"*Sources of error and uncertainty in methods of estimating radionuclide concentrations in deposited fallout based on measured external photon exposures have not been evaluated, and reliability of methods is unknown. The assumption of no fractionation (except for removal of noble gases) should result in substantial underestimates of concentrations of refractory radionuclides (such as plutonium).*"

DTRA and the Veterans Administration, with the support of the National Council on Radiation Protection, issued a report to Congress dated June 3, 2004 (DOD 2004) that identified a plan of action to correct the deficiencies identified by the NRC. The corrective actions identified for this issue included: potential modification of existing models; developing new models; and review by the Veterans Advisory Board on Dose Reconstruction. In the report, the plan indicated that this issue would be resolved within two years (i.e., June 2006) following submission of the report to Congress.

In order for NIOSH to consider using the DTRA model for inhalation dose, the model must be able to establish credible upper bounds. Therefore, the issues identified by the NRC that question the ability to establish upper bounds would have to be resolved and the model would have to be validated, as recommended by the NRC.

<u>External Dose Issues</u>

The NTPR program primarily uses film badge monitoring data or radiation surveys with field instruments to determine external dose. If the person wore a film badge and the data could be located, the external gamma dose is generally based on those data. If no acceptable film badge data are available or if the film badge data do not cover all potential exposures, the external dose for these exposures are based on a "scientific" dose reconstruction that relies on survey data.

The NRC review identified the following issues associated with the external dose reconstructions performed by NTPR:

1) Although the methods used to estimate *average* doses to participants in various units are generally valid, many participants did not wear film badges all the times that they might have been exposed, so *individual* doses are often highly uncertain.
2) Upper bounds of doses from external exposure to gamma radiation are often underestimated because of questionable assumptions about a person's locations and durations of exposure.
3) Skin and eye doses from exposure to beta particles do not always seem to be credible upper bounds, and skin doses from radioactive particles on the skin do not seem to have been taken into account.
4) Upper bounds of doses from external exposure to neutrons are always underestimated by a factor of about 3–5, but few participants received much neutron exposure.

The issues identified above are similar to issues that NIOSH has dealt with in the EEOICPA dose reconstruction process. NIOSH expects it could apply uncertainty factors to ensure a reasonable estimate of the external dose. In addition, the dose could be bounded by making claimant favorable assumptions to overcome data gaps. For example, when locations of employees are not clear the dose reconstructor could assign the employee the dose from the highest exposed group.

<u>Conclusion</u>

Based on issues identified by the NRC that questioned the ability to establish an upper bound dose reconstruction, NIOSH has determined that the DTRA dose reconstruction approach could not be used at this time for completing dose reconstructions for the proposed class. Although the DTRA models might support the ability to estimate inhalation doses in the future, it is not certain that the issues identified by the NRC will be resolved in a reasonable period of time to support dose reconstruction for EEOICPA claims.

7.2 Internal Radiation Exposure

The principal potential source of internal radiation doses for members of the class would have been inhalation or ingestion due to contamination caused by the fallout from the nuclear detonations. The fallout patterns were part of the scientific investigations conducted as part of the testing program and were well investigated and documented in multiple reports, including those of Program 40, the PHS offsite monitoring program, the Radsafe organization, the Armed Forces Special Weapons Project, and the Scientific Task Group.

It has been estimated that as much as 80 percent of the radioactive debris from a land surface burst falls out within the first day following the detonation. Detonations on the surface of seawater generate particles consisting mainly of salt and water drops that are smaller and lighter than the fallout particles from a land-surface detonation and as such, water bursts produce less early fallout. The initial radiation of an underwater detonation is absorbed by the large quantities of water surrounding the detonation point. The intense heat vaporizes the water and forms a bubble beneath the surface that expands as the energy works against the mass of water. The expansion continues until the energy is expended, at which point the bubble begins to collapse as it rises toward the surface. Depending on the depth of the burst and the size of the bubble, it may break the surface of the water near its fully expanded size or smaller. Some radioactive products are vented into the air as the bubble breaks the surface, but most of the device debris remains trapped in the volume of water that collapses on the bubble (the radioactive pool).

The water-surface detonations at Enewetak and Bikini atolls, being mostly over relatively shallow lagoon waters (barge shots) or on the very little dry land probably formed a complex combination of land-surface and water particle size characteristics.

Fallout associated with some of the detonations, both on the land surface and in the water, was a potential source of internal exposure. The possibility existed for inhalation and ingestion of radiological particles during a fallout event as well as exposure to re-suspended fallout remnants at some later date. Radiological particles on the land surface could potentially have been disturbed and re-suspended by wind, personnel traffic through contamination areas, construction activities disturbing contaminated soil, or by decontamination efforts, and been inhaled or ingested by personnel operating in the contaminated areas.

<u>Inhalation</u>

As indicated in section 6.0, limited urinalysis was reportedly done for certain test shots or series, but NIOSH has been unable to obtain those records. Some air monitoring was performed, but the only data available are offsite monitoring data. No occupational air sampling data are available. Air monitoring was performed to address fallout patterns rather than occupational internal exposure. While there is an indication that some nasal smears were performed, no data are available to NIOSH at this time from these smears. No evidence has been located to indicate that any lung or whole body counting or personal air monitoring was done as a part of the radsafe operations or procedures for the PPG.

Although it might be possible to calculate the maximum plausible radionuclide deposition from the detonations, because there are so many variables (e.g., size and type of bomb, detonation height, geographical conditions, weather conditions, etc.), each test would have to be evaluated individually to determine the maximum exposed individual or group for that test. This would require access to potentially sensitive information specific to each nuclear device together with extensive information on employee locations and activities. NIOSH cannot determine on a timely basis, with respect to this petition evaluation, the feasibility of a source and process-based dose reconstruction effort.

Therefore, based on the lack of any internal monitoring data or area monitoring data and due to the significant variability in parameters that would affect actual deposition of radionuclides, NIOSH has determined that it is not feasible to estimate inhalation-related radiation doses for the class of employees covered by this report.

Ingestion

Fallout and residual contamination from underwater detonations in the lagoon waters would have been a potential source of internal exposure as the lagoon was both a water source and location of recreational swimming for personnel between shots. Generally, the circulation pattern of a lagoon is more restricted than the ocean. The northeast winds move the surface waters from east to west and in so doing there is upwelling on the east side of the lagoon to replace the westward flowing surface water. A circulation pattern is established in which surface water moves westward and then sinks, and the bottom waters move eastward and up-well.

As has been noted earlier in this report, the lagoon waters were tested for contamination as both a water source and a recreation location. Beach swimming areas were closed on more than one occasion due to higher than acceptable levels of contamination. Reports from the Laboratory of Radiation Biology on beta activity at Rongelap Atoll indicate the ingestion of radiological material as part of the drinking water or recreational swimming would have been minimal (CASTLE 1954). In addition, the NRC reviewed various bounding ingestion scenarios when reviewing the NTPR program and came to the conclusion that doses to specific organs and tissues due to ingestion of radionuclides probably were low, compared with doses from external exposure, except in rare cases.

NIOSH has not considered ingestion of potentially contaminated local foodstuffs. The practice of eating locally grown produce or seafood was prohibited by regulation and there has been no claim of ingestion of such by the petitioner, nor within any documentation received to date.

As indicated in section 5.0, data may be available from the University of Washington, School of Fisheries that would support determining potential ingestion dose. However, at this time, no internal monitoring data that would support estimations of ingestion dose have been located. Since there is a lack of sufficient information to estimate inhalation-related doses to complete dose reconstructions for this class of employees, NIOSH has not completed evaluating the sufficiency of ingestion monitoring data.

7.2 External Radiation Exposure

External radiation exposure was the primary radiological concern for the planners and management of the nuclear atmospheric test operations in the PPG. The potential existed for external radiation exposure from fallout, the activation of debris (i.e. photo tower steel), contamination and immersion. The external exposure was monitored primarily through the use of film badges and radiation monitoring equipment.

As discussed in the subsections of Section 6.0, specific to each test series, a film badge program was used to maintain exposure information on personnel living and operating in the PPG during the operations. Beginning with REDWING, film badges were issued to all individuals upon their arrival at the PPG to determine gamma radiation exposure (S-56/239 p. 95). The configuration of the film badges would require the application of models to derive associated upper limit beta exposure estimates, as the badges would have shielded out significant amounts of beta radiation. In addition to the film badges, self-reading pocket dosimeters were issued for entrance to RADEX areas. The summary exposure data on individuals is available for this evaluation. Monitoring was performed for work parties entering radiological exclusion (RADEX) areas, with clearly specified stay times and dose limits.

Based on the available data, NIOSH can utilize the film badge monitoring data or radiation surveys with field instruments to determine external dose. If the person wore a film badge and the data could be located, the external dose can be based on this data with correction factors applied for beta dose and uncertainty. If no acceptable film badge data are available, maximum credible exposure scenarios could be developed for individuals given the roles, responsibilities, and location associated with the task unit they were assigned to and exposure rate information for various work assignments. Again, correction factors for beta dose and uncertainty would be applied, as necessary.

Neutrons

The highest potential source of neutron exposure would have been the detonation events and accessing the detonation locations for recovery of monitoring equipment. Neutron exposure to personnel should not have been substantial during the period covered by this evaluation. This conclusion is consistent with that of the NRC. Personnel were evacuated beyond the range of both blast effects and neutron exposure from the detonations. Access controls were implemented for the detonation sites following the detonations as discussed in section 6.0 of this report. No neutron monitoring data were located, but since internal doses cannot be estimated to complete dose reconstructions for this class of employees, NIOSH did not complete an evaluation of the feasibility of estimating neutron doses.

7.3 Occupational Medical Exposures

Occupational medical exposures to X-rays, when such screening X-rays are a condition of employment, are also included in EEOICPA dose reconstructions. It is not clear during the proposed class time period whether individuals at the PPG site were required to have pre-employment, annual, and termination chest X-ray examinations. However, NIOSH could make claimant-favorable assumptions, as needed, on the frequency requirements of occupational medical X-rays and the type of X-ray equipment that may have been used.

In addition, NIOSH has issued a Technical Information Bulletin (TIB), ORAU-OTIB-0006, *Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures* that can be used to assign dose from these procedures. Therefore, NIOSH concludes it is feasible to determine the maximum potential occupational medical exposures.

7.4 Summary of Feasibility Findings

This report evaluated the feasibility of completing dose reconstructions for all employees of DOE, DOE contractors, or subcontractors employed at the PPG from 1946 through 1962. NIOSH finds that the external monitoring records and operational histories available are sufficient to complete external dose reconstructions for these employees, with the exception of neutron exposure, which was not fully evaluated. Existing NIOSH procedures could be used to estimate possible occupational medical exposures. However, NIOSH lacks access to source term data, bioassay data or internal monitoring data to estimate internal doses associated with potential inhalation of radionuclides. Methods used by the NTPR program for military employees cannot be considered for application to dose reconstructions under EEOICPA until issues identified by the NRC are resolved. Hence, NIOSH finds that it is not feasible to estimate with sufficient accuracy internal radiation doses for the class of employees defined in this report.

The table below summarizes the results of the feasibility findings for each exposure source:

TABLE 7.3.1 FEASIBILITY FINDINGS

Source of Exposure	Maximum Exposure can be determined	Maximum Exposure cannot be determined
Internal		X
- Ingestion	Not evaluated	
- Inhalation		X
External	X	
- Gamma	X	
- Beta	X	
- Neutron	Not evaluated	
Occupational Medical X-ray	X	

8.0 Evaluation of Health Endangerment

The health endangerment determination for the class of employees covered by this evaluation report is governed by EEOICPA and 42 C.F.R. Pt. 83.13(c)(3). Under these requirements, if it is not feasible to estimate with sufficient accuracy radiation doses for members of the class, NIOSH must also make a determination whether or not there is a reasonable likelihood that such radiation doses may have endangered the health of members of the class. The regulation requires NIOSH to assume that any duration of unprotected exposure may have endangered the health of members of a class when it has been established that the class may have been exposed to radiation during a discrete incident likely to have involved levels of exposure similarly high to those occurring during nuclear criticality incidents.

If the occurrence of such an exceptionally high level exposure has not been established, then NIOSH is required to specify that health was endangered for those workers who were employed for a number of work days aggregating at least 250 work days within the parameters established for the class or in combination with work days within the parameters established for one or more other classes of employees in the SEC.

NIOSH has determined that it is not feasible to estimate with sufficient accuracy radiation doses from potential internal exposures. Internal doses from these exposures may have endangered the health of some members of the class, based on the facts that there was likely to have been some inhalation exposure to plutonium and other alpha-emitting radionuclides and the lack of reliable information to establish plausible maximum limits to this exposure.

The NIOSH evaluation did not identify any evidence from the petitioners or from other resources that would establish that the class was exposed to radiation during a discrete incident or similar conditions resulting from the failure of radiation exposure controls and likely to have produced levels of exposure similarly high to those occurring during nuclear criticality incidents. Although the testing program involved controlled nuclear criticality events, NIOSH is not aware of any report of personnel exposure to exceptionally high levels of radiation, comparable to that resulting from nuclear criticality incidents, during any of the nuclear atmospheric test series at the PPG. If such exposures occurred, it is almost certain they would have been documented, given the highly organized radsafe operations and given the careful monitoring of external radiation exposures. The evidence reviewed in this evaluation indicates that some workers in the class may have accumulated substantial chronic exposures through episodic intake of radionuclides. Consequently, NIOSH is specifying that health was endangered for those workers covered by this evaluation who were employed for a number of work days aggregating at least 250 work days within the parameters established for this class or in combination with work days within the parameters established for one or more other classes of employees in the SEC.

9.0 Proposed Class Definition

This evaluation defines a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy and whose health may have been endangered by such radiation doses. This class includes all employees of DOE, DOE contractors, or subcontractors employed at the PPG from 1946 through 1962 for a number of work days aggregating at least 250 work days occurring either solely under this employment or in combination with work days within the parameters (excluding aggregate work day requirements) established for other classes of employees included in the SEC.

10.0 References

ALO 58-2
Office of Test Operations Albuquerque Operations; “Report of the Manager; Operation Hardtack, Phase I”

CASTLE 1954
Defense Atomic Support Agency; “Operation Castle, Radiological Safety, Final Report, Volume 1, Extracted Version,” 1954

DNA 6032F
Defense Nuclear Agency (DNA); “Operation Crossroads 1946” L. Berkhouse, J.H. Hallowell, F.W. McMullan, S.E. Davis, C.B. Jones, M.J. Osborne, F.R. Gladeck, E.J. Martin; DNA 6032F, 1 May 1984

DNA 6033F
Defense Nuclear Agency (DNA); “Operation Sandstone: 1948” L. Berkhouse, S.E. Davis, F.R. Gladeck, J.H. Hallowell , C.B. Jones, E.J. Martin, F.W. McMullan, M.J. Osborne, W.E. Rogers; DNA 6033F, 19 December 1983

DNA 6034F
Defense Nuclear Agency (DNA); “Operation Greenhouse 1951” L. Berkhouse, S.E. Davis, F.R. Gladeck, J.H. Hallowell , C.B. Jones, E.J. Martin, F.W. McMullan, M.J. Osborne; DNA 6034F, 15 June 1983

DNA 6035F
Defense Nuclear Agency (DNA); “Castle Series, 1954” Edwin J. Martin, Richard H. Rowland; DNA 6035F, 1 April 1982

DNA 6036F
Defense Nuclear Agency (DNA); “Operation Ivy: 1952” L. Berkhouse, S. Davis, M.K. Doyle, F.R. Gladeck, J.H. Hallowell, C.B. Jones, E.J. Martin, F.W. McMullan, R.H. Miller, M.J. Osborne, R. Pozega, W.E. Rogers, R.H. Rowland, C.F. Shelton; DNA 6036F, 1 December 1982

DNA 6037F
Defense Nuclear Agency (DNA); “Operation Redwing: 1956” L. Berkhouse, S. Bruce-Henderson, S. Davis, H. DeSantis, P. Dean, M.K. Doyle, F.R. Gladeck, J.H. Hallowell, E.J. Martin, F.W. McMullan, R.H. Miller, D.S. Patterson, W.E. Rogers, R.H. Rowland, C.F. Shelton, P. Sturman; DNA 6037F, 1 August 1982

DNA 6038F
Defense Nuclear Agency (DNA); “Operation Hardtack I 1958” L. Berkhouse, F.S. Calhoun, F.R. Gladeck, K.G. Gould, J.H. Hallowell, E.J. Martin, F.W. McMullan, R.A. Miller, M.J. Osborn, C.F. Shelton; DNA 6038F, 1 December, 1982

DNA 6040F
Defense Nuclear Agency (DNA); “Operation Dominic I-1962” L. Berkhouse, S.E. Davis, F.R. Gladeck, J.H. Hallowell, C.B. Jones, E.J. Martin, R.A. Miller, F.W. McMullan, M.J. Osborne; DNA 6040F, 1 February 1983

DNA 6041F
Defense Nuclear Agency (DNA); Johnson, Abby A.; Goetz, Jerald L.; McRaney, William K.; “For the Record-A History of the Nuclear Test Personnel Review Program, 1978-1986” DNA 6041F, 1 August 1986.

DNA JTF
"Radiological Safety Final Report Operation Hardtack" Vol. II

DOD 2004
Department of Defense (DOD); "Radiation Dose Reconstruction Program of the Department of Defense Report to Congress" June 2004

HAI
Deines, Ann C.; Goldman, David I.; Harris, Ruth R.; Kells, Laura J.; "Marshall Islands Chronology 1944 to 1990" 11 January 1990

HPJa
Simon, S.L., Robison, W.L.; "A Compilation of Nuclear Weapons Test Detonation Data for U.S. Pacific Ocean Tests" Health Physics 73(1):258-264;1997

NVOO 209
US DOE Nevada Operations Office; "United States Nuclear Tests July 1945 through September 1992" DOE/NV—209-REV 15, December 2000

NRC 2003
National Research Council, "A Review of the Dose Reconstruction Program of the Defense Threat Reduction Agency" 2003

PHS 1958
Public Health Service; "Report of the Public Health Service Off-Site Radiological Monitoring Data Operation Hardtack Phase I 1958"

S-56/239
Task Group 7.2 Joint Task Force Seven; "Commander Task Group 7.2 Joint Task Force Seven Final Report; Operation REDWING" 31 July 1956

TG 7.1
Task Group 7.1; "Operation HARDTACK April-October 1958: Report of the Commander Task Group 7.1" May 29, 1959

TG 7.4
Task Group 7.4 Enewetak, MI; "Operation HARDTACK Final Report" 1958

TG 7.5
Minkkinen, C., Schlacks, H.P., Goeke, R.H., Weaver, C.L, "Task Group 7.5 Radiological Safety Support Operation Hardtack, Phase I" OTO-58-3, April 1959

TKBS-0008-02
ORAU Team, Rollins, E.; "Technical Basis Document for the Nevada Test Site – Site Description" ORAU-TKBS-0008-2, February 2, 2004

UCRL-51612
Lawrence Livermore Laboratory UC/Livermore; Noshkin, V.E.; Wong, K.M.; Eagle, R.J.; Gatrousis, C.; "Transuranics at Pacific Atolls I. Concentrations in the Waters at Enewetak and Bikini" June 26, 1974

UW
Donaldson, L.R.; “Annual Report of the Laboratory of Radiation Biology, University of Washington, July 1, 1959-June 30, 1960” July 12, 1960

UW 40
Project 40 Laboratory of Radiation Biology University of Washington; Donaldson, Lauren R., “Summary of Operational Phases for Project 40 of Operation Hardtack” March 20, 1958.

WT 89
Cooney, James P., Graves, Alvin C.;“Operation Greenhouse Scientific Director’s Report of Atomic Weapon Tests at Enewetak, 1951 Annex 9.3 Radiological Safety”; WT-89 July, 1951

WT 1359
“Report of the Commander, Task Group 7.1, Operation REDWING” August 1956

APPENDIX A
The Pacific Proving Ground and Atmospheric Testing

1.0 Introduction

Between 1945 and 1962, the U.S. Atomic Energy Commission (AEC) conducted 235 atmospheric nuclear weapon tests at sites in the US and in the Pacific and Atlantic oceans. In the Pacific, 29 atolls and 5 islands spread over 770,000 mi^2 with a total land area of about 70 mi^2 comprise the Marshall Islands. Enewetak Atoll, Bikini Atoll, Johnston Island and Christmas Island in the Marshall Islands together, are the AEC's Enewetak Proving Ground, later known as the Pacific Proving Ground (PPG).

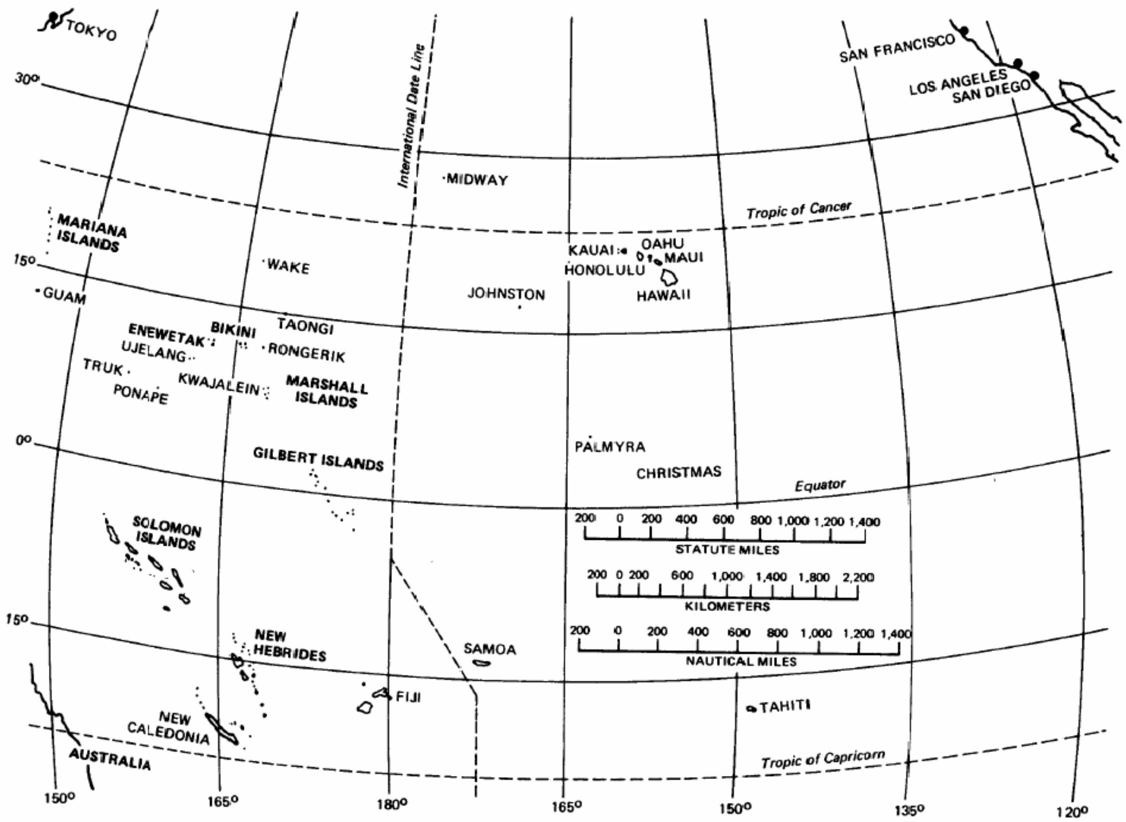

FIGURE 1 THE PACIFIC PROVING GROUND

2.0 Enewetak and Bikini Atolls

Enewetak Atoll

Enewetak Atoll is a coral cap set on truncated, submerged volcanic peaks that rise from the ocean floor. Coral and sand have gradually built up narrow islands into a ring-like formation with open ocean on the outside and a relatively sheltered lagoon on the inside. The atoll is an elliptical shaped collection of about 47 coral islands strung along the reef and has a total land area of 2.75 mi^2 enclosing a lagoon 23 miles in diameter, and with three passages that permit access to the lagoon from the sea.

Enewetak Island, the largest in the atoll, lies on the southeastern edge and is only 4 km long and 1 km wide. Northeast of Enewetak Island is Parry Island, which was the operational headquarters for many of the test series. These two islands are immediately south and east of Deep Entrance and account for about 30 percent of the atoll's land area.

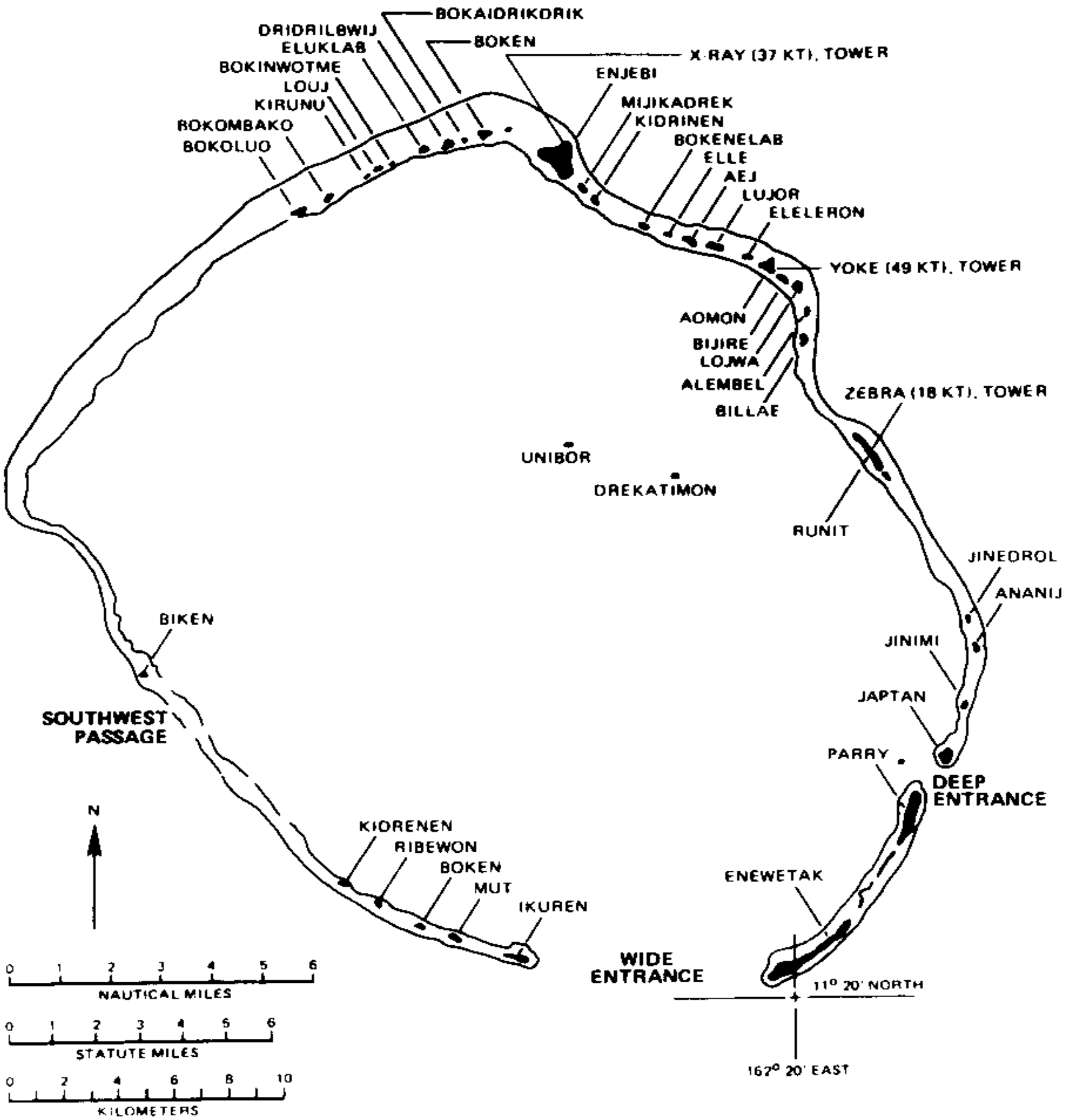

FIGURE 2 ENEWETAK ATOLL

BIKINI ATOLL

Bikini Atoll, similar to Enewetak Atoll, is a coral cap set on truncated, submerged volcanic peaks that rise from the ocean floor. It consists of 27 small islands that encircle a broad lagoon 25 miles long and 15 miles wide, with a maximum depth of about 200 feet. It has a total land area of 2.72 square miles. The land area is concentrated in the eastern islands, from Bikini to Eneu and the southern islands, from Enidrik to Aerokoj. At Bikini, ocean water flows in over northern and eastern reefs and flows out of the western portion of Eneu Channel. Water exchanges over the western reefs with the tides, ocean water flowing in and mixing with the flood and lagoon water flowing out with the ebb. The net rate of flushing of Bikini waters is such that onehalf of the lagoon waters is replaced by ocean water in 22 days and the original volume will account for only 10 percent of the lagoon volume after 2-1/2 months (DNA 6032F)

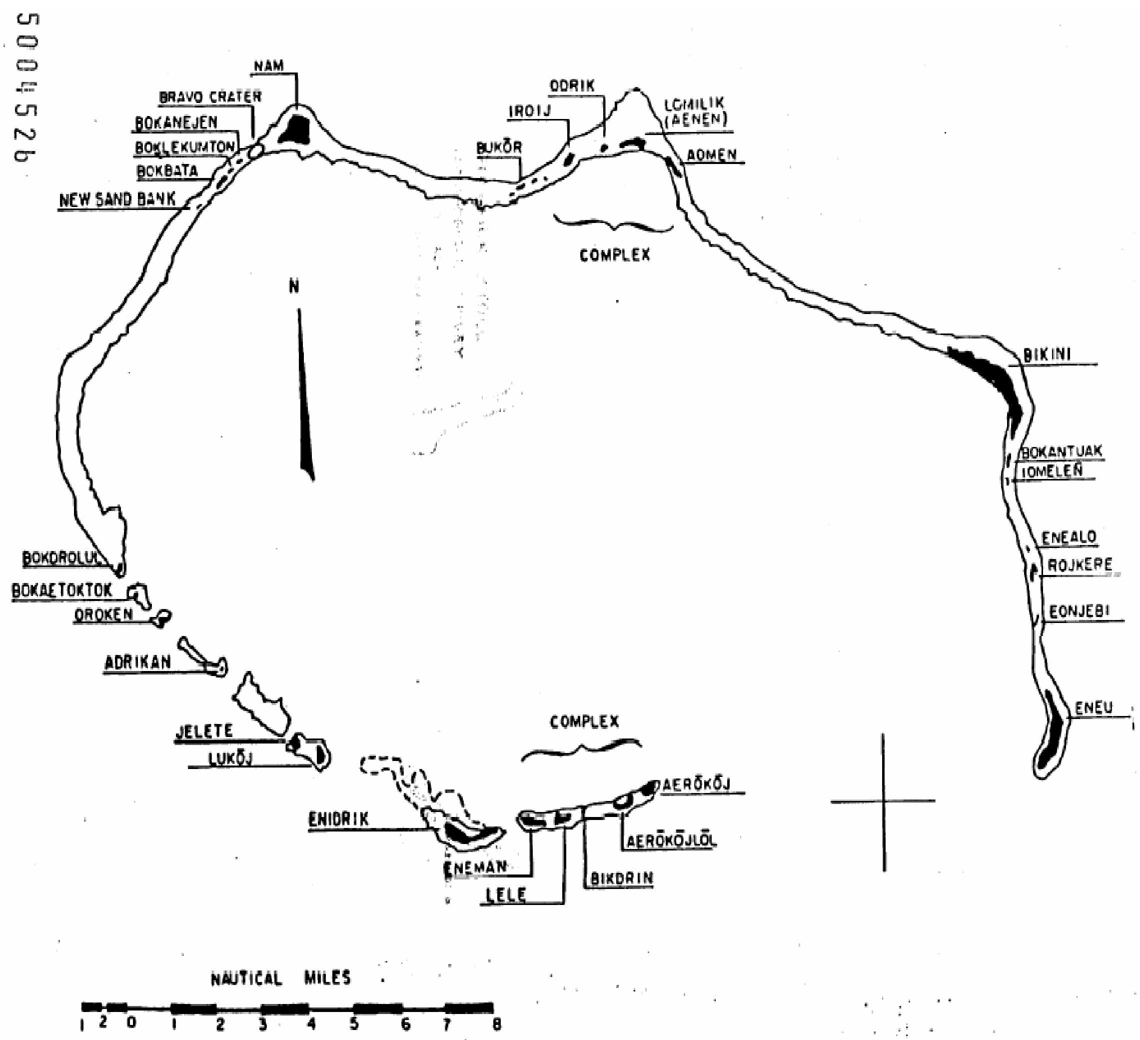

FIGURE 3 BIKINI ATOLL

3.0 PACIFIC TEST SERIES

All of the test series were conducted by organizations designated as Joint Task Force (JTF), made up of military personnel from the four services, federal civilian personnel, and contractor personnel.

The CROSSROADS test series was conducted by JTF 1, SANDSTONE was conducted by JTF 7, GREENHOUSE by JTF 3, and IVY by JTF 132. Before IVY, each task force was deactivated after its series was finished. The AEC continued to develop weapons, but the continuity of testing operations in the Pacific and the various roles in those operations was broken after each series. The discontinuity of the planning and command organization potentially had a significant impact on the method of record keeping and retention of those records. The inefficiencies of establishing new task forces with each test series was recognized near the end of GREENHOUSE , but JTF 3 was considered too large and expensive for long-term operation. By CASTLE, JTF 7 was established and conducted CASTLE, REDWING, and HARDTACK I.

The JTFs were divided into functional and service branch-oriented task groups. The scientific task group was the center of the operations and primarily staffed the work parties responsible for the retrieval of experimental results from contaminated locations.

For all of the test series following CROSSROADS, activity was necessary preceding the detonations to meet the requirements of the experimental programs because the islands of the atolls were not arranged in a pattern that facilitated the placement of instruments. Causeways were built, earth was moved, facilities were constructed, etc. In addition, the facilities had to be maintained between test series, including utilities, and base support elsewhere on the atolls. Construction to prepare for the various missions of the different test series was always a possibility.

3.1 CROSSROADS, 1946

Operation CROSSROADS was the first atmospheric nuclear weapon test series held in the Marshall Islands. The series consisted of two detonations, each with a yield of 23 KT. The devices used in the CROSSROADS tests were similar in design to the Trinity device and the weapon detonated over Nagasaki, Japan.

TABLE 1 CROSSROAD DETONATIONS AT BIKINI ATOLL

Name	Date (1946)	Type of Detonation
ABLE	1 July	Airburst at 520 feet
BAKER	25 July	Underwater at a depth of 90 feet

The series was to study the effects of nuclear weapons on ships, equipment, and material. A target fleet of more than 90 vessels was assembled in Bikini Lagoon as a target. This target fleet consisted of older U.S. capital ships, three captured German and Japanese ships, surplus U.S. cruisers, destroyers and submarines, and a large number of auxiliary and amphibious vessels. Military equipment was arrayed on some of the ships as well as amphibious craft that were beached on Bikini Island. Technical experiments were also conducted to study nuclear weapon explosion phenomena. Some experiments included the use of live animals.

The support fleet of more than 150 ships provided quarters, experimental stations, and workshops for most of the 42,000 men that conducted the tests. Additional personnel were located on nearby atolls such as Enewetak and Kwajalein. The islands of the Bikini Atoll were used primarily as recreation and instrumentation sites.

Before the first test, all personnel were evacuated from the target fleet and Bikini Atoll. These men were placed on units of the support fleet, which sortied from Bikini Lagoon and took safe positions at least 10 nmi (18.5 km) east of the atoll. In the ABLE test, the weapon was dropped from a B-29 and burst over the target fleet. In BAKER, the weapon was suspended beneath an auxiliary craft anchored in the midst of the target fleet. (DNA 6032F)

Radiological safety plans to limit personnel exposure were approved in April of 1946 that emphasized detection and avoidance of radiation, and included the establishment of exclusion areas, operational limits, and contamination controls (including donning and doffing clothing upon egress from potentially contaminated areas). Systematic reconnaissance was to begin shortly after each detonation with aerial and surface surveys, including water samples, soil samples, and marine life samples. Radiation safety (radsafe) monitors were assigned to monitor and limit the radiation exposure of work parties. Over 225 monitors were used for each of the two CROSSROADS detonations. As a result of CROSSROADS, military leadership recognized the need for a substantial, qualified, military radsafe organization. The Operational Plan set the maximum allowable dose for exposure over a long period at 0.1 roentgens (R) per 24 hours. In addition, no individual was allowed to have a total exposure of over 50 or 60 R in 2 weeks. If an individual received 10 R in 1 day or 60 R in 2 weeks, he was to be withdrawn from active participation in the operation. Such action was never required.

About 15 percent of the JTF 1 personnel were issued at least one of the 18,875 film-badge dosimeters during CROSSROADS. Approximately 6,596 personnel were on islands or ships that had no potential for radiation exposure. Personnel anticipated to be at greatest radiological risk were badged, and a percentage of each group working in less contaminated areas was badged. The maximum accumulated exposure recorded was 3.72 R.

The table below, summarizing film badge readings (in roentgens) for July and August, (when the largest number of personnel was involved) comes from the Nuclear Test Personnel Review Program report on Operation Crossroads (DNA 6032F).

TABLE 2 SUMMARY OF CROSSROADS FILM BADGE READINGS

	Total badges read	Exposure Range (Gamma)			
		0 R	0.001-0.1 R	0.101-1.0 R	1.001-10.0 R
JULY (%)	3,767 (100)	2,843 (75)	689 (18)	232 (6)	3 (<0.1)
AUGUST %	6,664 (100)	3,947 (59)	2,139 (32)	570 (9)	8 (0.1)

Due to the presence of alpha emitters, including plutonium, a program to urine test personnel thought to have been exposed was implemented to determine whether any had taken these substances into their bodies. The water-testing laboratory on the ship Haven was converted for testing urine. By 15 August 1946, 2600 samples had been tested. The men doing the work had to use instruments that were on hand and develop techniques as they worked. The widespread presence of radioactive material led to high background counts and made it difficult to determine whether an individual had low levels of alpha emitters in his urine (DNA 6032 F).

3.2 SANDSTONE, 1948

Operation SANDSTONE was conducted at Enewetak in the spring of 1948 and consisted of three tower shots, all detonated at a height of 200 feet. It was the second test series carried out at the PPG and was primarily a scientific series conducted by the AEC as a proof-test of second generation nuclear devices. The Los Alamos National Laboratory (LANL) provided technical leadership for the test series with the military providing supplies and support.

The designation of the organization conducting the operation was JTF 7 and like JTF 1 it was military in form but consisted of military, civil service, and contractor personnel. JTF 7 was activated in October 1947.

TABLE 3 SANDSTONE DETONATIONS AT ENEWETAK ATOLL

Name	Date (1948)	Type of Detonation
X-RAY	15 April	Tower
YOKE	1 May	Tower
ZEBRA	15 May	Tower

The radiation safety plans for SANDSTONE established an organization to provide radiation safety (radsafe) expertise and services to commanders of the separate components of the task force, who were responsible for personnel safety within their commands. Personnel were trained in radiological safety. Standards governing permissible exposure were established. The permissible radiological exposure was established at 0.1 roentgen (R) per 24-hour period and a maximum exposure of 3 R for certain approved specific missions. Film badges were issued to persons deemed likely[3] to be exposed to radiation, as well as a group, representative of the task force. An extensive weather forecasting group was established to predict wind directions and areas of potential fallout. Personnel were evacuated from danger areas before each detonation. Reentry to radioactive areas was restricted to personnel required to retrieve important data, and their radiation exposures were monitored.

For SANDSTONE, cloud debris was collected by eight unmanned B-17 drone aircraft. The drones picked up significant amounts of radioactive material on their surfaces, posing potential radiation exposure to ground crews involved in decontamination. Samples collected were highly radioactive and required special handling as they were taken from the aircraft and prepared for shipment to laboratories for analysis.

3.3 GREENHOUSE, 1951

Operation GREENHOUSE was conducted during April and May of 1951, on the northeastern islands of the Enewetak Atoll. The test was conducted by Joint Task Force 3 (JTF3), made up of DOD and AEC personnel. Task force personnel were stationed either on the southern islands of Enewetak, on ships, or at Kwajalein Atoll depending on their mission.

The test series consisted of four tower shots, two at 200 feet and two at 300 feet. These detonations resulted in significant downwind fallout. (DNA 6034F) The purpose of the four GREENHOUSE tests was to continue development of nuclear weapons and the development of thermonuclear weapons.

TABLE 4 GREENHOUSE DETONATIONS AT ENEWETAK ATOLL

Name	Local time	Date (1951)	Type of Detonation
DOG	0634	8 April	Tower – 300 ft
EASY	0627	21 April	Tower – 300 ft
GEORGE	0930	9 May	Tower – 200 ft
ITEM	0617	25 May	Tower – 200 ft

Radiological Safety regulations were issued by the Commander Joint Task Force 3 (CJTF 3). A maximum permissible exposure level was set at 0.1 R per day (0.7 R per week), not to exceed a total of 3.9 R for 13 weeks. CJTF 3 could authorize a total exposure of up to 3 R on any one day in specific cases. When this authorization was made, exposed individuals were prohibited from further exposure to more than 0.1 R per day during the remainder of the operation. (DNA 6034F)

For GREENHOUSE a "radiation area" was defined as any area where the level of radioactivity consistently exceeded 0.005 R per 24 hours. In addition, all radiation areas were routinely monitored at intervals prescribed by the commanding officer on recommendation of the radsafe staff.

As part of the radsafe program, film badges were issued to individuals who possibly could have been exposed to radiation while performing their duties such as visiting any of the islands after the shots, boat

[3] For examples of how decisions concerning who was to be badged were made, see the checkpoint monitors instructions, i.e. the 24 April 1948 instructions for the checkpoint on Enjebi, which instructed that any personnel expected to come closer than 550 yards to surface zero were to be issued film badges (DNA 6033F p. 60).

pool crews, radiation monitors, aircrews, aircraft decontamination personnel, and runway crash crews. In addition, over 75 film badges for each test were distributed among the six participating ships, to be worn from the day of the test and 7 days thereafter. Of the approximately 9,350 men in the test area during all or part of the testing operations, 2,416 were badged one or more times. Film badges for personnel entering radioactive areas normally were issued and turned in daily. Boat pool, air crew, and ship badges generally were issued for a week.

The overall average exposure recorded by these badges was less than 0.5 R. A number of individuals, however, had recorded exposures between 5 and 8 R. Some individuals with these higher exposures were affiliated with the AEC and some were involved with the Air Force long-range radioactive cloud-tracking and sampling program. Of 551 non-military participants, 345 had badge readings less than 1 R, 82 had readings from 1 to 3 R, and 34 had readings over 3 R with a high reading of 8.575 R. (DNA 6034F)

Fallout occurred on the islands of Japtan, Parry, and Enewetak and the six task force ships after three of the four shots in this series. The fallout from the first two shots was heaviest on Japtan and lightest on Enewetak. Enewetak was a base island where personnel from JTF 3 lived throughout the series. Japtan was an island used for recreation, but it also had an Army communication station and a Navy medical research unit. The fallout from shot ITEM, the last shot in this series, was much heavier than the first two. Enewetak Island received heavier fallout from ITEM than Japtan and Parry. Personnel who remained on Enewetak Island for 4 days after ITEM received over 2.45 R. Those who remained for 14 days received over 2.8 R, however, most people departed the test area within a week after the shot.

3.4 IVY, 1952

Test series IVY was held at Enewetak Atoll during November of 1952 and consisted of two detonations, MIKE and KING. MIKE was an experimental device and produced the first thermonuclear detonation. KING was a stockpile weapon, modified to produce a large yield. It was dropped from a B-36 bomber. The energy from KING was generated by the fission of plutonium atoms. These were the largest nuclear explosions to that time.

TABLE 5 IVY DETONATIONS AT ENEWETAK ATOLL

Name	Local time	Date (1952)	Type of Detonation
MIKE	0714	1 Nov	Surface; Eluklab Island
KING	1130	16 Nov	Airburst at 1,480 feet, off Runit Island

Joint Task Force 132 (JTF 132) was the organization that conducted the IVY test series. Approximately 2,300 civilians were part of the task force, most of which operated from Enewetak Atoll and the task force ships based there.

Fallout occurred on JTF 132 ships and on Parry and Enewetak islands following both of the test detonations. Exposure, calculated by the Nuclear Test Personnel Review based on data collected aboard three ships anchored near the islands indicates a maximum cumulative personnel exposure due to this fallout at 0.25 to 0.53 R for personnel continuously at Enewetak Atoll from 4 November to 31 December 1952. This calculation ignores weathering and shielding.

IVY posed some unique problems to JTF132 staff and the AEC because of the predicted large size of the detonations. The MIKE shot was expected to produce a yield far surpassing that of any earlier test, and the concern was that the radioactive fallout would be a more serious problem both to participants and off-island inhabitants. There was concern that a device detonated in the atmosphere might significantly contaminate the lagoon and restrict its use by fleet ships. The shot would be detonated without benefit of near-shot-time, shot-island weather data because of personnel evacuation requirements. Thus, during the 5 hours between evacuation and detonation, unpredicted shifts in forecast favorable winds could increase the potential of exposing the fleet to fallout.

Two other distinct radiation concerns existed:

- Initial radiations emitted by the detonation and thermal effects. This was controlled by completely evacuating personnel to safe distances from the atoll for shot MIKE
- Residual radiation near the detonation site that posed a problem for recovery of scientific instrumentation and other work. Exposure was controlled by a more intensive radsafe monitoring and control effort for those participating in areas close to the detonation locations and by a much enlarged program for protection of personnel remote from ground zero

The task force commander published Operation Order 1-52 which, among other responsibilities, required the task group commanders to establish lists of all personnel required by the nature of their duties to use dosimeters, to require physical examinations of civilian personnel who had to handle radioactive material, or who had to be in the forward areas (i.e. any island or lagoon area north of Parry Island) during or after a detonation and of all radiological monitors.

Task force personnel exposed to nuclear radiation during the IVY test series were primarily involved in operations such as radioactive cloud sampling and data recovery where exposures were expected to occur. Only low-level widespread exposure of support personnel appears to have occurred. Very few men exceeded the task force maximum permissible exposure of 3.9 R. Those that significantly exceeded this limit were involved in two aircraft incidents. Nearly 90 percent of the recorded IVY exposures were less than 1 R.

3.5 CASTLE , 1954

CASTLE was a six-detonation nuclear weapon test series in the spring of 1954. The purpose was to test large yield thermonuclear devices.

TABLE 6 CASTLE DETONATIONS

Name	Date (1954)	Type of Detonation
BRAVO	1 March	Surface; Bikini
ROMEO	27 March	Barge; Bikini
KOON	7 April	Surface; Bikini
UNION	26 April	Barge; Bikini
YANKEE	5 May	Barge; Bikini
NECTAR	14 May	Barge; Enewetak

CASTLE was conducted by JTF 7. Tests were carried out in conjunction with each of the detonations to measure power and efficiency of the devices and to attempt to gauge the military effects of the explosions.

BRAVO event was the largest device ever detonated in atmospheric nuclear testing by the U.S. Government and released large amounts of fallout over a much larger area than anticipated. This resulted in the contamination and exposure of multiple individuals living on distant atolls, stationed at the PPG and participating in the test series, and the personnel of a Japanese fishing vessel known as the Lucky Dragon.

A limited number of JTF 7 personnel received radiation exposures considerably in excess of the initially established CASTLE maximum permissible exposure (MPE). This operational limit was 3.9 R (gamma) within any 13 week period of the operation. Three military personnel had heavily exposed badges with readings from 85 to 95 R. As a result of BRAVO, 21 task force members received beta burns.

The other five CASTLE detonations did not produce significant, unexpected personnel radiation exposures. The radiation exposure for JTF 7 personnel at CASTLE averaged about 1.7 R.

3.6 REDWING, 1956

REDWING was a 17-detonation nuclear atmospheric test series conducted in May, June, and July of 1956. Detonations were conducted at both Enewetak and Bikini atolls. Enewetak served as a base of operations and was where smaller-yield devices were tested. Bikini was the advance camp where the larger-yield devices were tested.

TABLE 7 REDWING DETONATIONS

Name	Date (1956)	Type of Detonation
LACROSSE	5 May	Surface; Enewetak
CHEROKEE	21 May	Airdrop; Bikini
ZUNI	28 May	Surface; Bikini
YUMA	28 May	Tower; Enewetak
ERIE	31 May	Tower; Enewetak
SEMINOLE	6 June	Surface; Enewetak
FLATHEAD	12 June	Barge; Bikini
BLACKFOOT	12 June	Tower; Enewetak
KICKAPOO	14 June	Tower; Enewetak
OSAGE	16 June	Airdrop; Enewetak
INCA	22 June	Tower; Enewetak
DAKOTA	26 June	Barge; Bikini
MOHAWK	3 July	Tower; Enewetak
APACHE	9 July	Barge; Enewetak
NAVAHO	11 July	Barge; Bikini
TEWA	21 July	Barge; Bikini
HURON	22 July	Barge; Enewetak

The REDWING series' primary objective was to test high-yield thermonuclear devices that could not be tested in Nevada. The development and testing of these fusion devices began in 1950 and had advanced to the stage that one of these, CHEROKEE, was dropped from a B-52 bomber during REDWING. CHEROKEE, although of some scientific interest (all of the other shots tested new weapon developments), was more of a political demonstration to the world of the U.S. ability to deliver these weapons. The drop, as well as detonation LACROSSE, was witnessed by a group of 15 U.S. newsmen, the first such group invited to view a Pacific nuclear test since 1946. In addition to the press observers, 17 invited civil defense officials viewed the detonations.

REDWING was conducted by JTF 7, the same task organization that conducted CASTLE series. JTF 7 was established as a permanent organization in 1953 as the successor to JTF 132, which had conducted the IVY test series in 1952, and existed through 1958 when it conducted HARDTACK I. The structure, roles, and responsibilities of the components of this and previous JTFs with respect to the mission, safety, and security are documented in several reports, directives, and procedures. Numerous technical experiments were carried out in conjunction with each of the 17 detonations to measure the yield and efficiency of the devices. JTF 7 also attempted to gauge the military effects of the explosions.

Because of the isolation of the PPG, JTF 7 gave considerable attention to recreational activity for personnel. Enewetak Island had two movie theaters, a TV station, a hobby shop, a swimming pool and beach areas designated for swimming[4], a skeet range, playing fields, basketball and handball courts, and a service club with snack bar, library, game room, and rooms for adult education classes and clubs. Competitive leagues were organized for many sports. (DNA 6037F)

The operations ran smoothly except for two incidents. The airdropped demonstration test, CHEROKEE, was considerably off target; and the edge of the cloud from the last event fired at Bikini, TEWA, passed over Enewetak, causing fallout there. The missed airdrop caused no exposure of personnel to ionizing radiation as the entire Bikini Atoll had been evacuated, and the miss was in the direction of the open sea, but the TEWA fallout on the Enewetak base camp did lead to the exposure of the personnel there. The incident occurred toward the end of the series when some personnel had already returned to the United States, but the remaining Enewetak personnel received about an additional 1.5 R exposure from this incident. The overall average exposure for the series was approximately 1.7 R. The highest exposures were recorded by Air Force flight officers whose aircraft penetrated the nuclear clouds on scientific missions. (DNA 6037F)

The emphasis on safety was apparent in early planning and stressed throughout REDWING. Radsafe planning proceeded with the concurrence of other agencies (i.e. Department of State for improved offsite monitoring) when required. The radsafe program for REDWING had two primary objectives: 1) the maintenance of personnel radiation exposure at the lowest possible level consistent with medical knowledge of radiation effects and the importance of the test series and 2) avoidance of inadvertent contamination of populated islands or transient shipping. These objectives were consistent with those of all the previous test series.

The radsafe standard for maximum permissible exposure (MPE) was set at 3.9 R for the series. Film badges were provided for all[5] of the participating personnel. Persons likely to be exposed to radiation were often provided with additional badges for more complete recording of exposure. JTF 7 personnel were evacuated from danger areas to Navy vessels before each test and reentry to radioactive areas was restricted to the personnel required to retrieve important data.

3.7 HARDTACK I, 1958

HARDTACK was the operational designation for the U.S. atmospheric nuclear test series in the Pacific and in Nevada in 1958. HARDTACK I was conducted at the Pacific Proving Ground, and was a series in which 35 nuclear devices were detonated[6] in the spring and summer of 1958.

TABLE 8 HARDTACK I DETONATIONS AT ENEWETAK ATOLL

NAME	Date (1958)	Type of Detonation	Location
YUCCA	28 April	Airburst; high altitude	between Bikini and Enewetak
CACTUS	6 May	Surface	Enewetak
FIR	12 May	Barge	Bikini

[4] As noted in the original petition, SEC00020, swimming in the lagoon was an internal exposure concern. The radsafe program routinely monitored the waters of the approved, designated swimming areas. One of the swimming areas was closed for several days following Bikini shots and was closed after NAVAJO for the rest of REDWING. Swimming was prohibited when contaminants were present at greater than $1x10^{-5}$ microcuries per millimeter (sic) depending on the age of the contaminants. (DNA 6037F p. 79)
[5] REDWING was the first test series with universal film badging, as opposed to badging those individuals expected to receive some level of radiation exposure. This may have been, to some degree, a reaction to BRAVO fallout from the CASTLE series.
[6] Of the 35 test shots, 22 were conducted at Enewetak, 10 were conducted at Bikini, 1 was between the two atolls, and two were over Johnston Island. (DNA 6038F)

BUTTERNUT	12 May	Barge	Enewetak
KOA	13 May	Surface	Enewetak
WAHOO	16 May	Underwater	In ocean between Bikini and Enewetak
HOLLY	21 May	Barge	Enewetak
NUTMEG	22 May	Barge	Bikini
YELLOWWOOD	26 May	Barge	Enewetak
MAGNOLIA	27 May	Barge	Enewetak
TOBACCO	30 May	Barge	Enewetak
SYCAMORE	31 May	Barge	Bikini
ROSE	3 June	Barge	Enewetak
UMBRELLA	9 June	Underwater	Enewetak
MAPLE	11 June	Barge	Bikini
ASPEN	15 June	Barge	Bikini
WALNUT	15 June	Barge	Enewetak
LINDEN	18 June	Barge	Enewetak
REDWOOD	28 June	Barge	Bikini
ELDER	28 June	Barge	Enewetak
OAK	29 June	Barge	Enewetak
HICKORY	29 June	Barge	Bikini
SEQUIOA	2 July	Barge	Enewetak
CEDAR	3 July	Barge	Bikini
DOGWOOD	6 July	Barge	Enewetak
POPLAR	12 July	Barge	Bikini
SCAEVOLA	14 July	Barge*	Enewetak
PISONIA	18 July	Barge	Enewetak
JUNIPER	22 July	Barge	Bikini
OLIVE	23 July	Barge	Enewetak
PINE	27 July	Barge	Enewetak
TEAK	31 July	Airburst; high altitude	Johnston Island
QUINCE	6 August	Surface*	Enewetak
ORANGE	11 August	Airburst; high altitude	Johnston Island
FIG	18 August	Surface	Enewetak

*Were reported to be zero yield tests

HARDTACK I had multiple purposes; to assist in the development of nuclear weapons, to improve the understanding of the effects of underwater explosions on Navy ships and materials, and to provide information on nuclear weapons in air and ballistic missile defense. Twenty-two detonations occurred at or near Enewetak Atoll during HARDTACK I, as shown in Table 6.1. The HARDTACK I atmospheric test shots consisted of the unconfined detonation of nuclear devices in the atmosphere, some placed on a platform or a barge on the surface, two flown high into the atmosphere by a rocket, and some detonated underwater.

In planning the HARDTACK test series, emphasis on safety was apparent and stressed throughout the operation. Radiological safety was treated as a command responsibility. Each of the task groups was responsible for establishing self-sufficient radiological safety units to handle routine radiological safety matters and problems unique to the function of the task group itself.

Monitoring and administrative control systems were established to detect and measure radioactivity in the vicinity of the PPG for HARDTACK I. Radiological monitoring and sampling were conducted. Marine surveys were conducted to measure any increase in radioactivity in sea water and marine organisms due to HARDTACK I detonations. All atoll and lagoon areas at or near a detonation site were considered contaminated[7] until cleared for operations by the Radiological Safety Office. Entry control procedures were managed by the Radiological Safety Office. Entry to and exit from RADEX areas was only through established checkpoints. RADEX areas were areas of surface radiological contamination or airborne radiological contamination designated following each detonation for the control of personnel entry and exit. Personnel were not permitted beyond a radsafe checkpoint without an access pass that stated the purpose and precise location of the entry. All vehicles used in RADEX areas were checked through established decontamination stations.

A fallout prediction capability, the Fallout Prediction Unit, and the Fallout Plotting Center were established specifically for HARDTACK I, with fallout stations, monitors, and couriers, an extensive associated weather forecast capability, and weather monitoring stations established around the PPG to support both the forecast operations and the radiological monitoring objectives. Sweeps by U.S. Navy vessels both during and after the test series included taking continuous readings of radioactivity in surface water, sampling of water at various depths, making tows to gather plankton, and catching fish for analysis. Land and marine biological surveys were conducted, including water, plant, and animal samples. In addition, the operation plan directed task group commanders to establish radsafe units within the task groups with adequate special clothing and instrumentation. The task groups were to provide a roster of their personnel for film badge preparation.

A film badge program was used to maintain complete exposure information on all JTF 7 personnel entering the PPG during the operation. Beginning with the previous test series, REDWING, everyone was badged with few exceptions. Beginning 1 April 1958, film badges were issued to all individuals upon their arrival at the PPG. Badges were required to be worn at all times and turned in upon recall, upon exit from any contaminated area, or upon departure from the PPG. The badge was a DuPont 559 film packet (502 and 834 film components) dipped in ceresin wax and then packaged in a rigid polyvinyl chloride case to provide moisture protection. All exposed film badges were developed using the standard techniques employed at Los Alamos Scientific Laboratory (LASL). They were calibrated on a constant time, variable distance range, and the calibration curves were checked for accuracy approximately every 2 weeks. Density of the exposed film was read with the Eberline Film Badge Evaluation and Recording System, FS-3, in conjunction with an IBM-526 Summary Punch.

Self-reading pocket dosimeters, Bendix Model 611, 1 to 5 R range, were also used to obtain quick information on the exposure of an individual while in a contaminated area.

The operational procedures for HARDTACK I specified a MPE limit of 3.75 R (gamma) per consecutive 13-week period with a maximum of 5 R for the operation, with exceptions for emergency and other tactical situations. The operation was defined as the period from 15 days before the first ready date to 15 days after the last shot. A special MPE of 10 R was authorized for crewmembers of air-sampling aircraft. In the event of operational error or emergency, an additional exposure of 10 R would be accepted. Any exposure in excess of 20 R total would be considered as an overexposure for aircrew samplers. Partway through the operation, sample-recovery personnel had their authorized exposure change from 5 R to 10 R. At the same time aircraft maintenance personnel had their maximum exposure raised from 5 R to 8 R.

---

[7] RADEX areas were not strictly defined for alpha contamination. The general definition of full RADEX was an area of greater than 100mr/hr gamma including areas in excess of 10,000 cpm alpha (using a 55 cm^2 probe) and limited RADEX was an area of between 10 and 100 mr/hr gamma, including areas between 1,000 and 10,000 cpm alpha.

Water samples from swimming areas and from the lagoons, where water was distilled for ships, were periodically taken and tested for contamination. No significant radioactivity was found in any of the ships' water samples but a swimming beach at Enewetak island was closed for one day because of fallout from an atmospheric test at Bikini Atoll designated FIR (May 12). Radiochemistry laboratory trailers were located on both Enewetak and Bikini atolls. These facilities did not perform detailed radiochemistry studies; they were for onsite support such as checking potable water and swimming areas to ensure task group personnel safety.

Personnel decontamination was required when radiation levels exceeded 0.007 R/hr (beta plus gamma) or 500 cpm (alpha) (55 cm^2 probe) for outer clothing or 0.001 R/hr (gamma) or 100 cpm (alpha) (55 cm^2 probe) on skin or underclothing. All personnel returning from RADEX areas were monitored at the checkpoints. If contaminated, they were processed through the personnel decontamination station adjacent to the Radsafe Center.

During the spring and summer of 1958, the Public Health Service (PHS) operated an "offsite" radiological safety program under an agreement with JTF 7. PHS Officers were stationed on each of the close-in populated atolls of Utirik, Ujelang, Rongelap and Wotho to secure data on radiation levels and collect environmental samples for analysis. In addition, data was obtained for Parry Island and Enewetak Island in the Enewetak Atoll. Parry Island was used as the joint task force headquarters as well as the headquarters and living area for the scientific groups. Enewetak Island was primarily covered with an airfield and its support buildings and equipment, including shops, warehouses, and barracks. Japtan, the third major island in the base area, was across the deep channel from Parry Island and was the site of a radio receiver station and was used as a recreational area. Gamma intensity readings were taken daily using a Radiation Detection Indication And Computation (RADIAC) meter AN/PDR 27F, calibrated against a standard consisting of 7 micrograms of radium. The weighted daily averages of readings for Parry Island are available from 5/06/58 to 7/31/58 (except for 7/12/58). Daily average readings for Enewetak Island are available from 5/19/58 to 7/31/58.

Additionally, PHS carried out a fallout and rain sampling program. Precipitation was collected at six stations in and about the PPG, on Parry Island, Enewetak Island, Rongelap Island, Ujelang Island, Utirik Island and Wotho Island. The samples were collected in weekly composites, the precipitation falling in a collector funnel of 0.4 m^2 in area and retained in a carboy of approximately 19 liters volume. A summary of the collection and processing procedure for these samples is available in the Report of Public Heath Service Off-Site Radiological Monitoring Data (PHS 1958).

Finally, PHS conducted a Marine Biology Survey of the PPG during HARDTACK I. Data is available listing the water sample point coordinates, the water sample readings in dpm (gross beta), the plankton readings in dpm/cc (gross beta), and the external gamma readings of the plankton samples, counted in August and September of 1958.

3.8 DOMINIC I, 1962

DOMINIC I was a series of 36 atmospheric nuclear weapon detonations held in the PPG area from April to November 1962. These detonations and the continental DOMINIC II tests were the last atmospheric nuclear weapon tests conducted by the United States.

As in previous test series in the Pacific, a joint military and civilian organization conducted these tests, Joint Task Force Eight (JTF 8).

TABLE 9 DOMINIC I DETONATIONS

Name	Date (1962)	Type
ADOBE	25 April	Airdrop; S of Christmas Island
AZTEC	27 April	Airdrop; S of Christmas Island
ARKANSAS	2 May	Airdrop; S of Christmas Island
QUESTA	4 May	Airdrop; S of Christmas Island
FRIGATE BIRD	6 May	Airburst; Polaris proof-test, in Christmas Island Danger Area
YUKON	8 May	Airdrop; S of Christmas Island
MESILLA	9 May	Airdrop; S of Christmas Island
MUSKEGON	11 May	Airdrop; S of Christmas Island
SWORDFISH	11 May	Underwater; ASROC proof-test, 370 nmi SW of San Diego
ENCINO	12 May	Airdrop; S of Christmas Island
SWANEE	14 May	Airdrop; S of Christmas Island
CHETCO	19 May	Airdrop; S of Christmas Island
TANANA	25 May	Airdrop; S of Christmas Island
NAMBE	27 May	Airdrop; S of Christmas Island
ALMA	8 June	Airdrop; S of Christmas Island
TRUCKEE	9 June	Airdrop; S of Christmas Island
YESO	10 June	Airdrop; S of Christmas Island
HARLEM	12 June	Airdrop; S of Christmas Island
RINCONADA	15 June	Airdrop; S of Christmas Island
DULCE	17 June	Airdrop; S of Christmas Island
PETIT	19 June	Airdrop; S of Christmas Island
OTOWI	22 June	Airdrop; S of Christmas Island
BIGHORN	27 June	Airdrop; S of Christmas Island
BLUESTONE	30 June	Airdrop; S of Christmas Island
STARFISH	8 July	Airburst; FISHBOWL shot, 400 km over Johnston Island
SUNSET	10 July	Airdrop; S of Christmas Island
PAMLICO	11 July	Airdrop; S of Christmas Island
ANDROSCOGGIN	2 October	Airdrop; Johnston Island Danger Area
BUMPING	6 October	Airdrop; Johnston Island Danger Area
CHAMA	18 October	Airdrop; Johnston Island Danger Area
CHECKMATE	19 October	Airburst; FISHBOWL shot, tens of km over Johnston Island
BLUEGILL	25 October	Airburst; FISHBOWL shot, tens of km over Johnston Island
CALAMITY	27 October	Airdrop; Johnston Island Danger Area
HOUSATONIC	30 October	Airdrop; Johnston Island Danger Area
KINGFISH	1 November	Airburst; FISHBOWL shot, tens of km over Johnston Island
TIGHTROPE	3 November	Airburst; FISHBOWL shot, tens of km over Johnston Island

Most of the DOMINIC I test shots were airdrops, having been dropped from a B-52 bomber. Twenty-four of the airdrops took place from 25 April through 11 July over the ocean just south of Christmas Island. This island is located 1,200 nmi south of Honolulu. Five more airdrops were detonated in October over the open ocean in the vicinity of Johnston Island, 780 nmi west-southwest of Honolulu. These tests were conducted for the purpose of weapon development. Five high-altitude bursts (up to 250 miles) were lofted by rockets from Johnston Island and were for the purpose of studying the effects of nuclear detonations as defensive weapons against ballistic missiles. These detonations were designated the FISHBOWL events. In addition, the Navy conducted two nuclear tests in the open ocean, the first on 4 May about 435 nmi east of Christmas Island and the second on 11 May 370 nmi southwest of San Diego, California. The first, called FRIGATE BIRD, was a missile-launched airburst, a proof test of the Polaris weapon system, launched from the submarine, USS Ethan Allen (SSBN-608). The second, called SWORDFISH, was the test of the Navy ASROC system, a rocket-launched antisubmarine nuclear depth charge.

The Commander of JTF 8 (CJTF 8) was assigned overall responsibility for radiation safety. The Radsafe Branch, located organizationally in the Operations and Plans Office of Headquarters JTF 8, was responsible for overall control of monitoring and decontamination, issuing radsafe supplies and equipment, maintaining RADIAC instruments, procuring all film badges, developing and interpreting exposed badges, and maintaining cumulative radiation exposure records for everyone who was badged. These records were compiled and are supposed to exist in a document referred to as the Consolidated List of Exposures. This branch also managed an extensive offsite radiation surveillance network on 17 remote islands throughout the Pacific. Task groups, which were subordinate to JTF 8, had command responsibility for radiological safety within their organizations.

Film badges were issued to everyone who was stationed on Christmas and Johnston islands and all Navy ships directly involved with the tests. Persons on remote islands monitoring for radiation or conducting experiments were not badged. Of the over 28,000 participants in DOMINIC I, over 25,000 were badged. Badges were issued for extended periods to ensure that all possible exposure was recorded.

Because all but one of the shots (SWORDFISH), were airbursts or airdrops, there was little or no fallout problem and no residual radiation area around the surface zero. Although SWORDFISH produced no fallout, it did create a short-lived radioactive base surge and a pool of radioactive water around the detonation. The base surge dissipated in less than an hour, and the pool dissipated after a few days.

In general, film badge readings were low. Only 842 (3 percent) of the 25,399 badged participants had an exposure greater than 0.5 R. Of these, 56 exposures were over 3.0 R. The established JTF 8 MPE was 3.0 R. Fifty-one military personnel over 3.0 R were associated with cloud sampling (crew, maintenance, sample removal, or decontamination) and were authorized an MPE of 20.0 R before the operation started. The highest total exposure recorded in this group was 17.682 R: this was also the highest for the entire operation. The Navy personnel recording over 3.0 R were on USS Sioux (ATF-75), which was involved in collecting samples of weapon debris from the radioactive pool of water created by the underwater SWORDFISH shot. This group was allowed an MPE of 7.0 R.

Evidence exists that many of the badges worn by personnel during DOMINIC I were defectively sealed and recorded density changes due to moisture, light, and heat in addition to nuclear radiation. **A** 1979-1980 re-evaluation of 1,349 DOMINIC I film badges showed that 45 percent exhibited some damage related to light, heat, and age due to defective wax seals. Environmental damage was observed on 98 percent of the badges, which had a developed density equivalent of over 0.4 R (gamma).

One of the Thor rockets being launched at Johnston Island with a nuclear payload burned on the launch pad. The high explosives in the nuclear warhead detonated, spreading alpha contamination around the launch complex. It took several weeks to decontaminate and rebuild the launch complex. Stringent personnel safety measures were enforced during the cleanup. Reportedly, no one received significant contamination from this accident. (DNA 6040F)

4.0 Nuclear tests and radiation exposures

Nuclear testing by the U.S. consisted mostly of the unconfined detonation of nuclear devices in the atmosphere. Devices might be placed on a platform or a floating barge, placed atop a tower, supported by a balloon, dropped from an airplane, or flown on a rocket. Some were detonated underwater or buried in underground tunnels and shafts.

In theory, personnel could be exposed either by the initial radiation emitted at the time of explosion and for about 1 minute thereafter, or by the residual radiation emitted later. Initial radiation is part of the violent nuclear explosion process itself, and to be close enough for initial radiation exposure could place an observer within the area swept by lethal blast and thermal effects.

The neutron component of initial radiation did indirectly contribute to the possibility of personnel exposure. Neutrons are emitted in large numbers by nuclear weapon detonations. Neutron activation works on sodium, silicon, calcium, manganese, and iron, as well as other common materials. The process affects the metal casing of the device, the test tower, and earth materials. Activation products thus formed are added to the inventory of the radioactive debris produced in the detonation process and could expose personnel in the vicinity of this residual radiation in the performance of their duties.

The overall radioactivity of all the fission products formed decays at a rate that is closely approximated by a rule that states that for each sevenfold increase in time the intensity of the radiation will decrease by a factor of ten. Thus, a radiation rate of 1 R/hr at 1 hour after the burst would be expected to be 0.1 R/hr after 7 hours and 0.01 R/hr after 49 hours. This rule seems to be valid for about 6 months following an explosion, after which the observed decay is somewhat faster than that predicted by this relationship. Activation products, in general, decay at a faster rate than the fission products.

Fission products and activation products, along with un-fissioned uranium or plutonium from the device, constitute the radioactive material in the debris cloud, and this cloud and its fallout are the primary sources of the potential exposure to residual radiation.

In a nuclear airburst in which the central core of intensely hot material, or fireball, does not touch the surface, the device residues (including the fission products, the activation products resulting from neutron interaction with device materials, and un-fissioned uranium and/or plutonium) are vaporized. These vapors condense as the fireball rises and cools, and the particles formed by the condensation are small and smoke-like. They are carried up with the cloud to the altitude at which their rise stops, usually called the cloud stabilization altitude. The spread of this material then depends on the winds and weather. If the burst size is small, the cloud stabilization altitude will be in the lower atmosphere and the material will act like dust and return to the Earth's surface in a matter of weeks. Essentially all debris from bursts with yields equivalent to kilotons of TNT, will be down within 2 months. The areas in which this fallout material will be deposited will appear on maps as bands following the wind's direction. Larger bursts (yields equivalent to megatons of TNT) will have cloud stabilization altitudes in the stratosphere (above about 10 miles in the tropics); the radioactive material from such altitudes will not return to Earth for many months and its distribution will be much wider. Thus, airbursts contribute little potential for radiation exposure to personnel at the testing area, although there may be some residual and short-lived radiation coming from activated surface materials under the burst if the burst altitude is sufficiently low for neutrons to reach the surface.

Surface and near-surface bursts pose larger potential radiation exposure problems. These bursts create more radioactive debris because more material is available for activation within range of the neutrons generated by the explosion. In such explosions the extreme heat vaporizes device materials and activated earth materials as well. These materials cool in the presence of additional material gouged out of the burst crater. This extra material causes the particles formed as the fireball cools to be larger in size, with radioactivity embedded in them or coating their surfaces. The rising cloud will lift these particles to altitudes that will depend on the particle size and shape and the power of the rising air currents in the cloud, which in turn depend on the energy of the burst. The largest particles will fall back into the crater or very near the burst area with the next largest falling nearby. It has been estimated that as much as 80 percent of the radioactive debris from a land-surface burst falls out within the first day following the burst.

Bursts on the surface of seawater generate particles consisting mainly of salt and water droplets that are smaller and lighter than the fallout particles from a land-surface burst. As a consequence, water-surface bursts produce less early fallout than similar devices detonated on land. The large-yield surface bursts in the PPG over relatively shallow lagoon waters or on the very little land surface probably formed a complex combination of land-surface and water-surface detonation particle-size characteristics.

Detonations on towers may be considered as low airbursts or ground bursts, depending upon the relative height of the detonation and its yield. A larger burst will create more fallout than a smaller burst on an equal height tower, not only because of the additional fission products and weapon debris, but also because it will pull up more earth materials, or form a crater. In addition, the materials of the tower itself are a source of easily activated materials. The particles of the tower material may also act as centers for the debris vapors to condense on, to form the larger particles that lead to heavier early fallout. (DNA 6034F)