United States General Accounting Office

GAO

Report to the Honorable Alan Cranston, U.S. Senate

November 1985

OPERATION CROSSROADS

Personnel Radiation Exposure Estimates Should Be Improved

GAO/RCED-86-15

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GAO

United States
General Accounting Office
Washington, D.C. 20548

Comptroller General
of the United States

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November 8, 1985

The Honorable Alan Cranston
Ranking Minority Member
Committee on Veterans' Affairs
United States Senate

Dear Senator Cranston:

On August 3, 1984, you asked us to review certain issues concerning radiation safety activities during the 1946 nuclear test--Operation Crossroads. The report found that certain adjustments in the calculation of Crossroads participants' radiation exposure estimates may be necessary because (1) no allowance was made for inaccuracies associated with the film badges worn by participants to measure external radiation exposure, (2) comprehensive personnel decontamination procedures were lacking or not followed, and (3) no estimates were made for radiation exposure through ingestion or open wounds and the estimate for inhalation may be in error by a factor of 5 or 10.

As arranged with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of the report. At that time we will send copies to interested parties and make copies available to others upon request.

Sincerely yours,

Charles A. Bowsher

Charles A. Bowsher
Comptroller General
of the United States

Executive Summary

Many of the 42,000 military participants in the 1946 atmospheric nuclear weapons test, known as Operation Crossroads, were subjected to varying amounts of radiation exposure. Documents recently discovered by concerned private citizens raise questions about the accuracy of the Defense Nuclear Agency's (DNA) radiation exposure estimates. The Veterans Administration uses these estimates in adjudicating former participants' radiation-related disability claims.

Because of specific Congressional concerns, GAO reviewed certain issues regarding the radiation exposure of Crossroads participants, such as the

- reliability of the personnel film badges used to measure radiation,
- adequacy of the personnel decontamination procedures, and
- accuracy of DNA's radiation dose reconstruction.

Background

Crossroads consisted of two nuclear bomb detonations in the Pacific Bikini Island lagoon from July 1 to August 10, 1946. After each detonation, a task force of approximately 42,000 military personnel and civilian scientists entered the lagoon and examined the damage to and radiation intensities on target ships.

Given the responsibility by the Secretary of Defense to estimate radiation doses for atmospheric nuclear weapons test participants, DNA—in October 1984—issued its report on Operation Crossroads, concluding that personnel had not been overexposed to radiation. DNA's position is based on radiation data recorded on film badges worn by about 6,300 of the 42,000 Crossroads participants and reconstructed external and internal radiation dose estimates for the participants. (See pp. 15 to 16.)

Results in Brief

Crossroads personnel were exposed to four specific radiation types—internal alpha, internal and external beta, and external gamma (see pp. 36 and 37). GAO found that DNA's calculation of exposure estimates for each radiation type may need adjustment because

- film badges were not reliable for measuring both external gamma and beta radiation, as intended, and were not worn by all Crossroads participants;
- personnel decontamination procedures did not provide adequate protection for Crossroads personnel throughout the operation; and

- DNA's dose reconstruction analysis for internal alpha and beta radiation has not properly estimated the possible personnel exposure from three potential pathways—inhalation, ingestion, and open wounds.

Principal Findings

Reliability of Film Badges

DNA's radiation exposure estimates have made no allowance for inaccuracies attributable to film (in badges) or its processing. GAO found and DNA acknowledges that the recorded film badge readings would have had an overall inaccuracy of approximately $\pm$ 30 percent because of inaccuracies in the film.

Further inaccuracies normally occur during film processing and reading. While it was not possible to calculate actual Crossroads inaccuracies, GAO found that a mid-1950's U.S. National Bureau of Standards test showed that readings by several laboratories of film badges similar to those at Crossroads, exposed to known amounts of radiation, were inaccurate by as much as $\pm$ 100 percent. GAO believes it is unlikely that the film badge readings performed under harsh Crossroads conditions would have been more accurate than those in laboratories.

DNA recognizes the film badges at Crossroads were incapable of accurately recording external beta because the portion of the film intended for that measurement actually recorded both external gamma and beta. Although DNA assigned doses to personnel believing the badges overestimated external beta radiation, GAO found cases in which beta exposure may have been underestimated or not estimated at all.

Adequacy of Personnel Decontamination Procedures

Because DNA believes adequate personnel decontamination procedures existed from the beginning at Crossroads, its radiation exposure estimates do not recognize the possibility that personnel may have retained radioactivity on their bodies and clothes after working on contaminated target ships. In contrast GAO believes this possibility exists because decontamination procedures were evolving at Crossroads. For example, the earliest evidence that GAO found of personnel being required to shower or change clothes after returning from contaminated target ships was in procedures issued on July 31, 1946, 6 days after the second

detonation. Moreover, even after comprehensive decontamination procedures were instituted, some violations were reported. Thus, Crossroads participants were probably exposed to more radiation than accounted for by DNA.

Accuracy of Internal Exposure Dose Reconstruction

Internal radiation exposure was not measured at Operation Crossroads. DNA has estimated the exposure from inhaling radioactive materials but used a constant ratio between alpha, beta, and gamma radiation that may have underestimated alpha radiation by a factor of from 5 to 10. Moreover, DNA has not evaluated internal radiation exposure from ingestion and open wounds. DNA believed, incorrectly, a prohibition against food consumption aboard target ships effectively precluded ingestion and did not know how to calculate for open wounds.

Recommendations

GAO recommends that the Secretary of Defense direct DNA to adjust, where feasible, the Crossroads participants' exposure estimates in the following manner:

- develop a range for each film badge reading that recognizes film and film processing inaccuracies; reassess the accuracy of the external beta iation dose information for those who wore film badges and, because ll wore film badges, perform a dose reconstruction for external beta ation;
- estimate the extent to which personnel received radiation exposure from a lack or violation of comprehensive decontamination procedures;
- reevaluate and disclose the possible errors or uncertainties associated with its analysis of internal radiation exposure by inhalation and analyze possible internal radiation exposure through ingestion or open wounds.

In addition, where any of the preceding actions have been determined not to be feasible, GAO recommends that the Secretary of Defense require DNA to document the reasons for each such determination so that the military services can provide this information to the Veterans Administration and the affected veterans.

Agency Comments

The Department of Defense generally disagreed with the report's findings, conclusions, and recommendations. However, GAO's analysis of its

comments showed that the Department (1) provided incorrect or unsupported statements, (2) misinterpreted certain Crossroads-related documents, or (3) presented information inconsistent with DNA's historical report on Operation Crossroads and other material. For these reasons, GAO continues to believe that the Department can improve radiation exposure estimates for Crossroads personnel by effectively addressing and implementing GAO's recommendations. (See p. 56 for GAO's evaluation of the Department's positions on the issues discussed in the report and see appendix IV for GAO's detailed evaluation of the Department's comments.) The Veterans Administration stated that the report's recommendations for calculating radiation doses for Crossroads participants should also be applied to participants in all other atmospheric nuclear tests (see app. III).

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Abbreviations

DNA	Defense Nuclear Agency
DOD	Department of Defense
GAO	General Accounting Office
JTF	joint task force
NTPR	nuclear test personnel review
RCED	Resources, Community, and Economic Development Division
VA	Veterans Administration

Chapter 1

Introduction

Following the end of World War II, questions remained among American military experts regarding the tactical effects of the nuclear bomb. These experts reasoned that only by testing the nuclear bomb under simulated war conditions could these questions be answered. With this in mind, the United States initiated nuclear weapons testing in the Pacific Ocean during 1946. The first such test, known as Operation Crossroads, consisted of two detonations—one above the water's surface and the other underwater.

This operation involved the largest number of participants—almost 42,000 Army and Navy personnel and civilian scientists—for any of the atmospheric nuclear weapons tests conducted by the United States.[1] It lasted from July 1 to August 10, 1946, when efforts by participating personnel to board and decontaminate the unmanned naval ships used as a target for the two bomb tests were officially terminated. About 6,300 Crossroads participants were issued a radiation dose film badge[2] during one or more days of the operation. However, no one wore a film badge every day.

Lacking complete radiation dose information on each Crossroads participant, the Defense Nuclear Agency (DNA)—under direction from the Department of Defense (DOD)—has since statistically reconstructed doses from available data. DNA provides these reconstructed doses, along with available film badge readings, to the particular military service that, in turn, assigns a radiation exposure to its applicable personnel. When requested by the Veterans Administration (VA), the particular military service provides these radiation exposure estimates to that agency for use in adjudicating veterans' service-connected disability claims.

In May 1983 hearings before the Subcommittee on Oversight and Investigations, House Committee on Veterans' Affairs, concerns—based largely on information once belonging to the late Radiological Safety Officer for Operation Crossroads—were raised questioning the accuracy of DNA's radiation dose estimates for that operation. With approximately 500 claims on file at the VA related to Operation Crossroads, any

[1]Nuclear tests conducted prior to November 1962, whether atmospheric or underwater, are considered a part of the United States' atmospheric nuclear weapons testing program because of their potential release of radiation into the atmosphere. Since November 1962 all nuclear tests conducted in the United States have been underground with most of them at the Nevada Test Site.

[2]A film badge is a small piece of film encased in a metal or plastic container and used to measure radiation.

inaccuracy in DNA's dose estimates could potentially affect the adjudication of a large number of veterans' claims.[3] Consequently, on August 3, 1984, the Ranking Minority Member on the Senate Committee on Veterans' Affairs and, subsequently, on August 14, 1984, the Chairman, House Committee on Veterans' Affairs, asked us to evaluate selected aspects of radiation safety during that 1946 nuclear test operation.

Operation Crossroads

Operation Crossroads consisted of two 23-kiloton nuclear bombs detonated within the Bikini Island lagoon in the Pacific during the summer of 1946. The first detonation—termed Test Able—involved dropping the nuclear bomb from a plane and exploding it at an altitude of 520 feet. The second detonation—termed Test Baker—involved suspending the nuclear bomb by cable approximately 90 feet underneath a medium-sized landing ship and exploding it by remote control. Each detonation used, as its target, an array of about 80 unmanned naval ships. After each detonation a joint task force of Army and Navy personnel and civilian scientists—stationed aboard support ships more than 10 nautical miles from the center of the blast—reentered the Bikini Island lagoon and examined the damage inflicted and the radiation intensities existing on the target ships. Approximately 42,000 personnel, 240 ships (target and support), and 160 aircraft participated in Operation Crossroads. About 200 goats, 200 pigs, and 5,000 rats were also distributed throughout the target fleet so that the effects of each of the 2 nuclear bombs on animals could be studied.[4]

Test Able

The Test Able detonation occurred on July 1, 1946. When the bomb exploded, according to a radiological defense manual published after Operation Crossroads, a brilliant flash of light occurred, lasting a few millionths of a second, followed by a seething mass of gases, heated to a glow, which grew rapidly into a large ball of fire. A shock wave traveled from the center of the burst, visible on the water looking like a tremendous shimmer traveling in all directions. As the glow of the ball of fire died out, a great white mushroom cloud of smoke, fission products, unfissioned particles, and dust developed and rose to a height of 30,000 to 40,000 feet.

[3]None of the 500 claims related to Operation Crossroads has, as of June 1985, been approved.

[4]In addition to the test animals, military equipment—including aircraft parts, ammunition, radar, petroleum, tanks, field stoves, clothing, and medical equipment—was also positioned on the various target ships to study the effects of the detonations.

As the cloud began to move downwind and dissipate, drone aircraft were directed into the cloud and drone ships were directed into the target area to take radiological samples. Approximately 2 hours after the detonation, manned Navy gunboats—which were used because of their speed and maneuverability—also reentered the lagoon to measure radiation around the target ships. Once radiation levels were determined, boarding teams and salvage units began boarding ships— approximately 4 hours after the detonation—and assessing damage where the radiation levels were low. Before the day's end the lagoon was declared radiologically safe and the entire task force had reentered and anchored in the southern part of the lagoon.

Damage inflicted by Test Able consisted of five ships sunk and six ships seriously damaged. In general, according to one of the official Crossroads reports prepared after that operation, the bomb would have been lethal for any crewmen in the open within a range of 1,300 yards and for those behind armor at about half that distance. Instantaneous exposure to the bomb's heat, blast, and initial radiation would have been the only cause of personnel deaths because the mushroom cloud created by the bomb carried most of the residual radioactive fallout downwind.

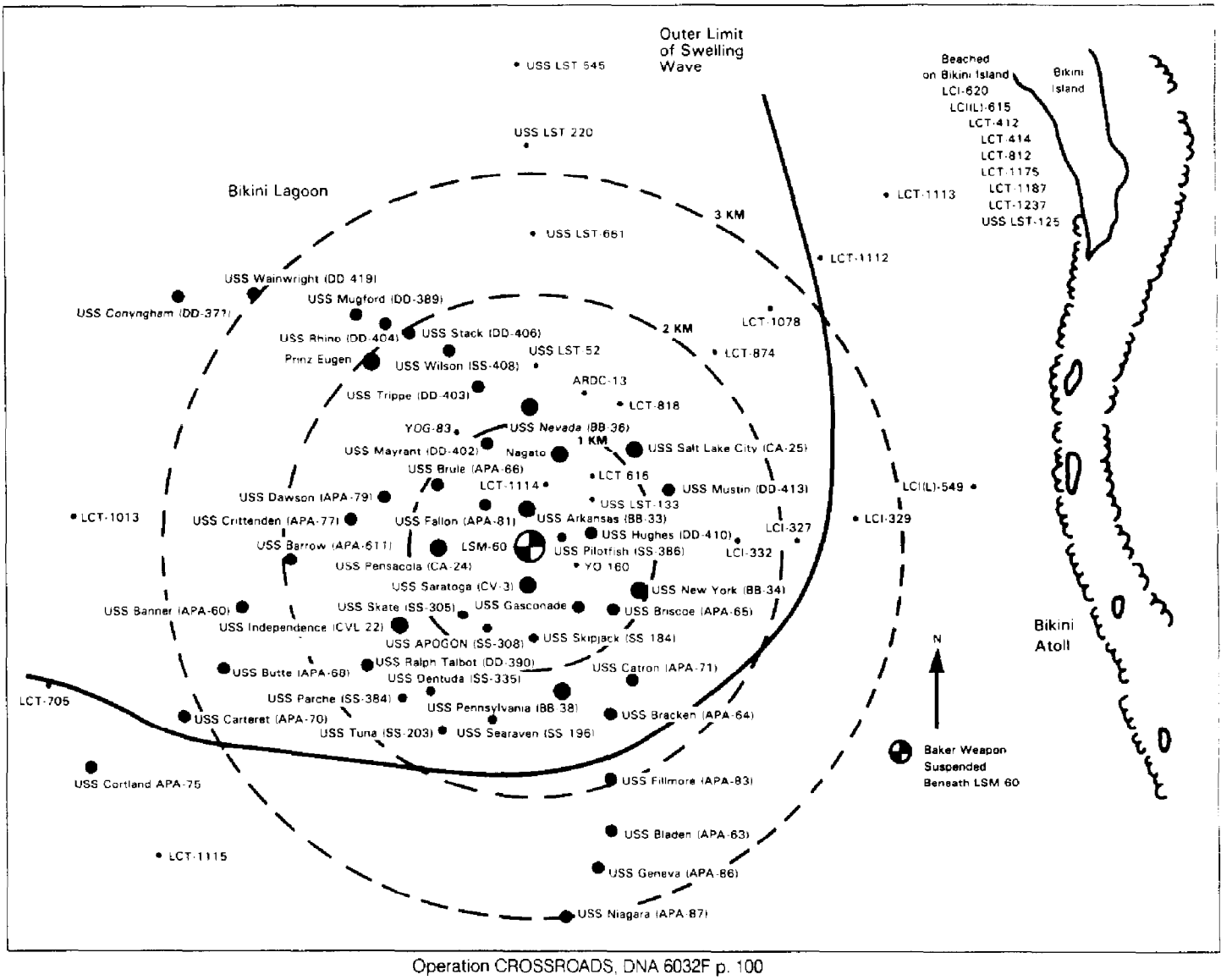
Test Baker

Following completion of the Test Able damage assessment, the Test Baker detonation occurred on July 25, 1946. Unlike the first test shot, part of the lagoon water erupted in the Test Baker blast. After an initial flash, according to a radiological defense manual published after Operation Crossroads, a huge column of water nearly a half a mile across rose 5,000 to 6,000 feet in the air. At its zenith a mushroom cloud of gas and spray developed. As the column of water collapsed back into the lagoon, a swelling wave of water and mist roughly 1,000 feet high spread out in all directions, immersing the target ships (see fig. 1.1 for Test Baker's target ship locations).

Reentry into the lagoon proceeded as it had with Test Able by first sending in drone aircraft and boats to take radiological samples. From then on, however, post-Test Baker operations proceeded quite differently. Commencing about 2 hours after the detonation, low radiation readings allowed teams to board a few of the ships on the outer rim of the target array. However, intense radiation was discovered closer to the target center so further boarding and salvage efforts were abandoned that day. By day's end, almost the entire lagoon remained off limits.

Damage inflicted by Test Baker consisted of eight ships sunk and eight immobilized or seriously damaged. According to official Crossroads reports, had crews been aboard the target ships, they probably would have fared worse during Test Baker than Test Able. Unlike the first detonation, Test Baker threw large masses of highly radioactive water onto the decks and into the hulls of the target ships, making them highly radioactive. In all, one of the official Crossroads reports estimated that topside personnel within 700 yards would have received lethal radiation doses within 30 seconds to a minute; personnel within 1,700 yards would have received lethal doses within 7 minutes; and those within 2,500 yards would have received lethal doses within 3 hours.

Figure 1.1: Target Ship Locations for Crossroads, Test Baker



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With intense radiation persisting in the water and on the target ships, the joint task force devoted most of its efforts during the first week after Test Baker to the retrieval of animals and the resurfacing of target

submarines submerged for the test. Commencing August 1, the joint task force began full-scale decontamination of the target ships. After first hosing down the ships with foam and salt water, nearly 2,000 Navy personnel began boarding the target ships on a daily basis to scrape, scrub, and wash the ships down to acceptable radiological dose levels. These decontamination efforts continued through August 10, 1946, when, on that day, the Crossroads Radiological Safety Officer received evidence of the probable widespread presence of plutonium on the target ships.[5] If deposited in the body, a microscopic amount of plutonium could prove lethal. Upon learning of the probable presence of plutonium, the joint task force commander immediately halted the decontamination efforts.

With that turn of events, Operation Crossroads came to an abrupt end. Support ships, that had spent more than one day in Bikini lagoon after Test Baker, were ordered to undergo decontamination, as necessary, by sandblasting hulls and by flushing salt-water systems from September 1946 to May 1947, to meet radiological clearance standards. Conversely, the target ships used during the operation met various fates. In addition to the eight ships sunk during Test Baker, six were sunk at Bikini lagoon after Test Baker because of extensive structural damage. Forty-two others, from August to September 1946, were towed to Kwajalein Island—largest of the Marshall Islands—to off-load ammunition and were subsequently sunk while 22 other target ships, from September 1946 to June 1948, were either sailed or towed back to the United States for decontamination experiments. Most of these 22 target ships were later sunk because they were not considered fit for continued use or decontamination proved unsuccessful.

Responsibilities of DNA

Operation Crossroads was the first peacetime atmospheric nuclear weapons test. Between 1945 and 1962 the United States carried out 235 such tests, principally in Nevada and the Pacific Ocean. An estimated 200,000 American military personnel and civilians were involved in these nuclear tests, and more than half received some level of radiation exposure. Responding to a possible correlation between these nuclear tests and subsequent health problems among test participants, DOD in

[5]Only one of the many types of radiation instruments used at Operation Crossroads was initially capable of accurately measuring plutonium but that instrument type failed because of the influence of humidity and mishandling. Thus, the presence of plutonium was largely determined from paint, wood, and metal samples taken from the target ships and analyzed in a laboratory on Kwajalein Island. On pages 35 to 41 of the report, we evaluate DNA's analysis of possible internal radiation exposure from plutonium and other radioactive elements at Crossroads.

December 1977 began a program of wide-ranging actions with DNA serving as administrator.

DNA, in turn, established a nuclear test personnel review (NTPR) program that has included (1) compiling a roster of the American military personnel and civilians involved in the atmospheric nuclear tests, (2) developing a historical report of each atmospheric nuclear test that involved American military personnel and civilians, (3) providing estimates of atmospheric test radiation doses—both as a comparison with film badge readings and as a substitute for them in cases where badges were not worn or readings were not recorded, and (4) providing assistance to the veteran, the VA, and others by researching and providing as complete data as possible on individual participation and radiation doses.

In October 1984 DNA issued its historical report on Operation Crossroads. The report indicated that the two nuclear bomb tests produced four types of radiation that posed a potential hazard to Crossroads participants: internal alpha, internal and external beta, and external gamma radiation.[6] At Operation Crossroads no standard existed for internal alpha and beta radiation, and external beta radiation was set at 5 times the level for gamma. Regarding gamma, all aspects of Operation Crossroads were planned at allowing personnel to be exposed to no more than 0.1 roentgen of gamma radiation per day and, in cases where the daily exposure standard was exceeded, to no more than 60 roentgens of gamma radiation in 2 weeks.[7] If this had occurred, which according to DNA's historical report it did not, an individual was to be withdrawn from active participation in the operation. In 1946 the military arbitrarily estimated that up to 60 roentgens of gamma radiation in 2 weeks could be tolerated without any harmful effects. Today, the permissible exposure dose for radiation workers is 5 rem per year.[8] According to

[6]Alpha radiation is difficult to detect and its effect is lasting for years. It has a range of only a few inches in air and is incapable of penetrating clothing or even the outer layer of unbroken skin. However, alpha radiation is a primary hazard when absorbed internally. Beta radiation may travel several feet in the air before being absorbed. In more dense material, such as body tissue, beta radiation may travel up to half an inch. Clothing normally provides adequate protection from beta radiation. Therefore, beta radiation is a hazard only when beta-emitting materials are either in direct contact with the skin or absorbed internally. Gamma radiation is electromagnetic radiation originating in the nuclei of certain radioactive elements and accompanying many nuclear reactions. Gamma rays can travel great distances through air and can penetrate a considerable thickness of material.

[7]A roentgen is a unit that expresses the amount of ionization—a process of adding electrons to, or knocking electrons from, atoms or molecules—that gamma radiation produces in air.

[8]A rem is a unit that expresses biological effects. Exposure to 1 roentgen of gamma radiation is approximately equivalent to 1 rem.

DNA's historical report, the Crossroads participant with the highest accumulated recorded exposure—from 6 separate film badge readings—received 3.72 rem. For the months of July and August 1946, the historical report listed the following individual film badge readings.

Table 1.1: Actual Crossroads Film Badge Readings

	July		August	
Gamma radiation (rems)	Number of badges	Percent	Number of badges	Percent
0	2,843	75.5	3,947	59.2
.001-.1	689	18.3	2,139	32.1
.101-1.0	232	6.1	570	8.6
1.001-2.0	3	.1	8	.1
Total	**3,767**	**100.0**	**6,664**	**100.0**

According to the historical report, about 15 percent, or 6,300, of the joint task force personnel were issued a film badge during 1 or more days of the operation. Lacking complete radiation exposure data on each Crossroads participant throughout the duration of the operation, the historical report indicated that DNA has reconstructed personnel exposure doses.

Specifically, in two additional reports, DNA has reconstructed personnel exposure to external gamma radiation for those individuals who were exposed to this radiation type but wore no film badge and to internal radiation that film badges were incapable of measuring.[9] The first report was issued in April 1985 and, according to DNA, the latter report is awaiting printing and is expected to be issued in December 1985.

In the first additional report, entitled Analysis of Radiation Exposure for Naval Units of Operation Crossroads, DNA has evaluated the external gamma radiation received by personnel from contamination existing in the Bikini lagoon water and aboard the support and target ships. According to the report, by tracking a crew's activity at Operation Crossroads against the radiological environment and time in that environment, a reconstructed gamma radiation exposure can be developed that can be used in conjunction with actual film badge readings. The

[9]DNA has elected not to perform a dose reconstruction for external beta radiation believing, instead, that it is acceptable to use the external beta radiation doses recorded on film badges worn.

report, in summary, has concluded that the reconstructed radiation doses for the various target and support ships' crews at Crossroads ranged from zero to 1.7 rem of radiation.[10] Of those, about 93 percent received less than 0.5 rem.

In the other additional report, entitled Internal Dose Assessment--Operation Crossroads, DNA evaluated the internal contamination received by personnel who boarded target ships after Test Baker and inhaled radiation particles deposited on the ships and later resuspended into the air by some disturbance of the surface. In this report DNA calculated internal radiation doses by evaluating breathing rate, use of respiratory breathing devices, and radioactivity resuspended in the air. The report concluded that the total dose delivered to the body over a 50-year perio commencing with the intake of the radioactive materials would have been less than 0.1 rem.[11]

Objectives, Scope, and Methodology

Prior to the issuance of DNA's historical report, concerned private citizens—in May 1983 hearings before the Subcommittee on Oversight and Investigations, House Committee on Veterans' Affairs—presented an analysis based largely on information once belonging to the late Radiological Safety Officer for Operation Crossroads. That analysis challenged preliminary statements being made by DNA of generally low radiation doses at Operation Crossroads by offering information about the extent of contamination aboard target ships, the crude monitoring devices available, and the extent and potential dangers of inhalation of radioactive materials. Therefore, on August 3, 1984, the Ranking Minority Member on the Senate Committee on Veterans' Affairs and, subsequently, on August 14, 1984, the Chairman of the House Committee on Veterans' Affairs asked us to review four issues regarding Operation Crossroads. Those issues concerned the

- reliability of the radiation dose film badges used,
- adequacy of the personnel decontamination procedures,
- appropriateness of the military response to recommendations made by the Radiological Safety Officer regarding safety issues, and

[10]According to DNA, the Crossroads participant mentioned on p. 15 received a higher exposure dose because his work as a radiation safety monitor required him to board various Crossroads target shi to evaluate the radiological conditions.

[11]At Operation Crossroads no standard for internal radiation exposure existed. Today, internal radi tion exposure standards are based on the type of radioactive element taken into the body and the particular body organ affected. For example, the maximum permissible body burden to the liver for plutonium 239 is 0.4 microcuries.

- accuracy of DNA's dose reconstruction efforts.

We performed our review between August 1984 and May 1985. In initiating our review of these four issues, we analyzed the information in the collection of documents once belonging to the late Crossroads Radiological Safety Officer, compared it against information in the possession of DNA, and found that this collection of documents provided little information not already belonging to DNA. We also researched information pertinent to Operation Crossroads at such locations as the National Archives, Federal Records Center, Department of the Navy, and U.S. Department of Energy. In addition, we obtained information from outside sources such as the National Association of Atomic Veterans, International Alliance of Atomic Veterans, Federation of American Scientists, and International Radiation Research and Training Institute. Further, we interviewed officials with DNA, the Army, the Navy, and members of the late Radiological Safety Officer's family.

To evaluate the reliability of the radiation dose film badges used, we reviewed the historical report prepared by DNA on Operation Crossroads and DNA's supporting documentation. We also interviewed recognized experts in film badge dosimetry including officials with the U.S. National Bureau of Standards, U.S. Nuclear Regulatory Commission, and Reynolds Electrical and Engineering Company, a private contractor that provides dosimetry service to the U.S. Department of Energy at the Nevada Nuclear Test Site. Further, we researched and analyzed available information on film badge reliability—circa Operation Crossroads to the present—from such sources as the National Library of Medicine and U.S. Department of Energy.

To assess the adequacy of the personnel decontamination procedures, we analyzed those procedures established by the military before, during, and after Operation Crossroads. We also reviewed movie films and photographs taken during Operation Crossroads to help determine what, if any, protective clothing was worn and what procedures were followed by crews working on contaminated target ships.

To ascertain the appropriateness of the military response to recommendations made by the Crossroads Radiological Safety Officer either to improve personnel decontamination procedures or to keep personnel exposures at a minimum, we analyzed—from official records of DNA and the coliection of documents once belonging to the late Radiological Safety Officer—the reasonableness and timeliness of the military action

taken. When no action was taken, we analyzed the military's justification.

To evaluate the accuracy of DNA's dose reconstruction efforts, we reviewed those reports prepared under contract for DNA that reconstructed Crossroads personnel radiation exposures and interviewed contractor personnel from Science Applications International, Inc. who were responsible for those reports. We also researched available information—including the official records of DNA and the collection of documents once belonging to the late Radiological Safety Officer—to assess the validity of the assumptions used in the contractor reports. We did not evaluate report methodology since DNA has asked the National Academy of Sciences to provide a peer review of that methodology. The results of their work will be available in late 1985. Finally, we interviewed VA officials who periodically request dose reconstruction estimates from the various military services for use in adjudicating veterans' claims for service-connected disability.

We did not evaluate the merits of conducting an epidemiological study of the long-term adverse health effects of exposure to ionizing radiation for former Crossroads participants. Congress assigned the task of conducting such a study, if determined to be scientifically feasible, to the VA. We made our review in accordance with generally accepted government auditing standards.

Chapter 2

Evaluation of Selected Aspects of Radiation Safety During Operation Crossroads

Operation Crossroads represented the first and largest—in terms of participants—of the post-World War II atmospheric nuclear tests conducted by the United States. Because of that, certain things happened during that operation that were not anticipated. For instance, the military did not anticipate the extent of radioactive contamination after Test Baker.[1] As a result more Navy personnel boarded and attempted to decontaminate the target ships after that test than had been contemplated. Unfortunately, most did so without being issued a film badge to measure their radiation exposure.

Addressing the specific issues asked us by the Ranking Minority Member on the Senate Committee on Veterans' Affairs and the Chairman, House Committee on Veterans' Affairs, we found that certain adjustments in DNA's calculation of radiation exposure estimates may be necessary because of the following:

- Readings, from the film badges used, may have either overstated or understated the actual gamma radiation received by as much as 100 percent.
- Personnel decontamination procedures seemed to evolve at Operation Crossroads from a very simplistic approach to radiation protection to comprehensive procedures that were not instituted until more than 2 weeks after the second nuclear test, and because of that, more radiation exposure than has been estimated probably occurred.
- DNA's analysis of internal radiation exposure by inhalation could have underestimated alpha radiation by a factor of 5 or even 10. DNA also has not evaluated internal radiation exposure received through ingestion or through open wounds.
- Exposure from external beta radiation may, in many cases, have been underestimated or not estimated at all.

Moreover, at the time of our review, DNA had not required the military services to disclose error ranges associated with reconstructed radiation exposure estimates reported to the VA. As a result, we found that while the Army has been reporting this error range, the Navy has not. Subsequently, DNA has published for review and comment in the Federal Register, dated May 9, 1985, new minimum standards requiring all military

[1]Generally, Test Baker was concluded to be much more radiologically hazardous than Test Able because large masses of highly radioactive water were thrown onto the decks and into the hulls of the target ships. Thus, the issues discussed in this chapter pertain primarily to post-Test Baker operations.

services to report to the VA a most-probable, reconstructed gamma radiation exposure estimate, with error range or limits, if available. However, we noted that the military services have not been reporting, and the proposed minimum standards would not require them to report, the inaccuracies associated with individual film badge readings.[2]

Crossroads Film Badges Provided Only an Estimation of Gamma Radiation Exposure

Film badges are widely used to detect radiation essentially because they are small and light, provide a permanent record of exposure amount, and have no complicated circuits to become unadjusted. A film badge also has some drawbacks. Typically, according to the technical literature on the subject, inaccuracies (1) exist in the ability, or sensitivity, of the film to measure radiation and (2) occur in the processing of the film—unless processing conditions are carefully controlled.

DNA has not recognized such inaccuracies in the film badges worn at Operation Crossroads. On the other hand, DNA acknowledges—in a report prepared on film badges used throughout the atmospheric nuclear weapons testing program—and national research laboratory studies have shown that film badges provide only an approximate estimate of gamma radiation exposure. For example, these studies estimate that actual exposures may be understated or overstated by as much as 100 percent because of inaccuracies in the film (used in the badges) and in film processing. That means that an actual exposure to 1 rem of radiation could be recorded by the film as .5 rem or 2.0 rem.[3]

General Film Badge Design and Accuracy

A film badge consists of a small piece of film usually encased in a metal or plastic container that can be pinned to clothing. The film, which is similar to photographic film, is wrapped in paper or other material to prevent light from exposing it. In addition, the container may be sealed or placed in a plastic bag to protect it from water.

The film in the badge reacts to radiation in much the same manner as ordinary photographic film reacts to light. As the radiation is absorbed by the film, it produces a chemical change that causes the film to

[2]The Navy and the Army also provide the VA with external beta radiation dose information (if any is recorded on the film badge worn) and, once DNA's internal dose assessment report is finalized, will be providing the VA with internal alpha and beta radiation dose information. This internal radiation dose information will be provided both for veterans with claims now on file with the VA and for veterans who submit claims in the future.

[3]A reported reading that is 100 percent high is 2 times the actual exposure and a reported reading that is 100 percent low is one half the actual exposure.

blacken. The extent of the blackening of the developed film is a measure of the accumulated dose or total amount of radiation to which it has been exposed. To determine the recorded dosage, an instrument called a densitometer is used to compare the blackening with that of film of the same type that has been exposed to known amounts of radiation.

Errors generally occur, however, in almost every step of the film badge cycle, starting with the manufacturing of the film through film development. To begin with, each film used must have a uniform thickness to accurately record radiation exposure. The thickness of the film is dependent on the chemical coating, or emulsion, applied to the cellulose base.

In spite of care in manufacture, emulsion thickness can vary in and between film batches. The variance between batches, however, can be somewhat compensated for by exposing one film from each batch to a known amount of radiation and comparing the film exposure against an expected value. On the other hand, variance of emulsion thickness within a single batch is all but impossible to compensate for short of testing each film. The variance within a single batch of film reflects that batch of film's inaccuracy, or insensitivity, to measure radiation.

In addition to film inaccuracy, the developing process can cause errors in measuring radiation. To properly develop a film, according to a radiological defense manual published after Operation Crossroads, it must be placed in a processing solution at a specific temperature for a specific amount of time. Both temperature and time affect the final blackening, or density, of the film that, when read with the densitometer, is the basis for determining exposure. Each Fahrenheit degree variation in the recommended temperature of the processing solution may result in as much as a 6-percent variation in the exposure reading. In addition, each minute variation in the recommended time the film is in the processing solution may introduce as much as a 10-percent variation in an exposure reading. Because the time in the processing solution needs to be carefully controlled, the film must be rinsed immediately upon removal from the developing solution. This final step is also very critical and, if not done, can additionally affect the accuracy of the film badge developing.

Beyond the generally known technical inaccuracies associated with film badges, other factors may result in differences between the exposure

recorded by a film badge and the actual exposure a person receives.[4] One of the more significant factors is the positioning of the badge in relation to the source of radiation. For example, if a film badge is worn on a shirt pocket and the source of radiation is a ship's deck, the radiation exposure to the waist area would be more than double of that to the chest—if the person were standing. In addition, if the radiation source is located behind the person, the body may absorb most of the exposure before it reaches the badge. While these factors do affect the accuracy of personnel exposure, there is no adjustment for them because it is practically impossible to determine their extent.

Estimated Accuracy of Film Badges Used at Operation Crossroads

The film badges used at Operation Crossroads were intended to measure gamma radiation between .05 to 2.0 rem of radiation.[5] This means that gamma radiation in excess of 2.0 rem would not be measured since the film could not exceed a 2.0 rem reading. Conversely, the film would not measure any gamma radiation below .05 rem—one half the daily exposure limit established for the operation. Thus, if an individual, for example, wore separate film badges exposed to .04 rem on one day, .02 rem on a second day, and .03 rem on a third day, each of the film badges could have read zero. At Operation Crossroads, 9 films during the months of July and August 1946 were found to have reached their maximum of 2.0 rem, and 6,790 films were found to have zero readings. According to the technical advisor in the environmental sciences department of the Reynolds Electrical and Engineering Company, assigning the minimum detectable amount—.05 rem—to each Crossroads film badge that read zero may be prudent.[6]

Beyond knowing the designated measurement range, little information exists on Crossroads film badge accuracy. On the basis of available

[4]Environmental conditions, such as light, heat, and humidity, will also affect film accuracy. Light and heat will further blacken the film and, thereby, overestimate the radiation exposure, whereas humidity without water condensing on the film will cause the film to fade and, thereby, underestimate the radiation exposure. In the Bikini Island lagoon, the climate is generally warm and humid. Temperature changes are slight, ranging from 70° to 90° Fahrenheit.

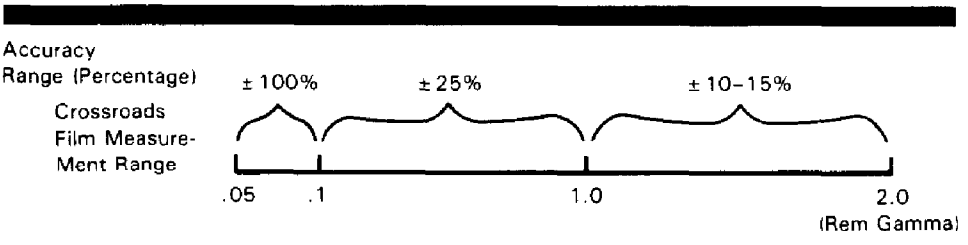
[5]Crossroads film badges were also designed to measure external beta radiation but provided readings of questionable accuracy for this radiation type. See page 41 for a discussion of external beta radiation.

[6]Approximately 8,000 film badges issued from August 31 to December 31, 1946, at Kwajalein Island—where ammunition was being unloaded from target ships—are on file at the Reynolds Electrical and Engineering Company in Las Vegas, Nevada. According to officials of this company, the remaining Crossroads film badges have not been located, and those on file include none of the film badges that reached their maximum at 2.0 rem of radiation. If these 2.0 rem film badges were on file, according to a dosimetry expert with the U.S. National Bureau of Standards, they could be reread, using state-of-the-art dosimetry equipment, and a more exact gamma radiation dose assigned to them.

Crossroads records, it appears that the Crossroads personnel responsible for developing and reading the film badges were aware of the proper procedures. However, we could not determine whether those procedures had actually been followed.

Without information on the accuracy of Crossroads film badges, we noted that DNA—in a report prepared on film badges used throughout the atmospheric nuclear weapons testing program—has assigned these film badges an estimated overall accuracy factor of ± 30 percent. DNA's assistant NTPR program manager told us this overall accuracy percentage is based on the educated judgment of the technical advisor in the environmental sciences department of the Reynolds Electrical and Engineering Company (an expert involved in film badge dosimetry for over 30 years). This overall percentage reflects that the film badges used at Operation Crossroads were probably accurate within 100 percent at the .05 to .1 rem range, within ± 25 percent at the .101 to 1.0 rem range, and within ±10 to 15 percent at the 1.001 to 2.0 rem range. The following line graph shows this breakdown.

Figure 2.1: Estimated Crossroads Film Inaccuracy



DNA's assistant NTPR program manager further explained that these percentages represent the accuracy associated only with the film. This official said the matter of also estimating an accuracy associated with Crossroads film badge processing had been discussed but was not considered calculable.

Because data on Crossroads film badges are scarce, we reviewed other pertinent information relative to Crossroads film accuracy. We noted, for instance, that a radiological defense manual published shortly after Operation Crossroads stated that film accuracy within a single batch of films may vary by ±20 percent. We also obtained information relative to the accuracy of Crossroads film badge processing by analyzing film badge processing under controlled laboratory conditions.

In this regard, we found that numerous studies and tests have been conducted to determine the accuracy of commercial and federal film badge

dosimetry services. These tests were conducted by exposing films to known amounts of gamma radiation then sending them to different labs that developed and assigned readings to them.[7] The readings were then compared to the known exposures.

The earliest such test we reviewed was conducted in 1953, almost 7 years after Operation Crossroads, by the U.S. National Bureau of Standards. The test involved 15 national laboratories or contractors, most of which were funded by the Atomic Energy Commission, one of the predecessor agencies to the Department of Energy.

The national laboratories and contractors knew they were being tested for their film processing accuracy. The 15 participants were sent a total of 320 films exposed in the 0 to 2.0 rem range to develop and assign gamma radiation readings. Of these, the national laboratories or contractors assigned readings to 152 of them higher than the actual exposure and to 142 of them lower than the actual exposure. In addition, 15 of the 142 films with lower readings were assigned a zero dose even though an actual exposure existed on each of the 15 films, some reaching as high as .1 rem. Only 26 film readings matched the actual exposure. A summary of the 294 inaccurate film readings is presented in table 2.1.

Table 2.1: Number of Film Readings Higher or Lower by Percentage Rate

	Total	100 percent or more	50 to 99 percent	1 to 49 percent
High	**152**	36	50	66
Low	**142**	40	22	80

Another test conducted in 1963 by the Universities of Pennsylvania and Wisconsin tested 12 commercial facilities. However, this time the participants were unaware that they were being tested. The test methodology was similar to the test previously discussed and the actual film exposures ranged from .02 to 8.0 rem for the 715 films exposed. Readings higher than the actual exposure were assigned to 274 and readings lower than the actual exposure were assigned to 370. Only 71 films were within 2.5 percent of the correct exposures. Of the 715 films read in the test, 44 were assigned readings that were more than 100 percent higher

[7]The film used in these tests was not the same name brand as the film used at Operation Crossroads. However, the accuracy of the film was reportedly the same, and the film was exposed to about the same range or level of radiation that reportedly existed at Operation Crossroads.

than the actual exposures and 109 were assigned readings that were 10(percent less than the actual exposures.[8]

At Operation Crossroads, mixed high and low energy levels of radiation existed.[9] Each of the two tests, that we reviewed, indicated that exposure to mixed high and low radiation levels is the most difficult to accurately determine and is generally understated. For instance, the test conducted by the U.S. National Bureau of Standards showed that 22 of 28 exposures to mixed radiation levels were understated and the other test conducted by the Universities of Pennsylvania and Wisconsin showed that about 97 of 128 exposures to mixed radiation were understated, with about 40 of the 97 being understated by more than one half the actual exposure.

Observations

While film badges have been used since the 1940's, inherent factors have affected their accuracy. These factors have tended to make film badge dosimetry an inexact science. Even under carefully controlled laboratory conditions, film badge dosimetry has been in error, because of inaccuracies associated with the film and its processing, by $\pm$ 100 percent or more in assigning gamma radiation doses. By contrast, Crossroads dosimetry was conducted almost 40 years ago under harsh field conditions. Therefore, it is unlikely that dosimetry results from Crossroads were more accurate than the more recent test results obtained under controlled conditions.

Personnel Decontamination Procedures Seemed to Evolve at Operation Crossroads

Personnel working in radioactive areas sometimes pick up radioactive particles on their bodies and their clothes. Recognizing that, the joint task force attempted to establish personnel decontamination procedures that would minimize both the spread of this radioactivity and the potential personnel exposure to it.

Because DNA believes these decontamination procedures adequately protected Crossroads personnel, its radiation exposure estimates do not recognize the possibility that individuals retained radioactivity on their bodies or their clothes upon their return from work on target ships. We

[8]Our analysis of the test is based on bar graphs contained in a study reporting the test results.

[9]Radiation consists of particles that can travel at a wide range of speeds, or energies. The different radiation energies arise from the radioactive decay of the various fission products that are produced by the detonation of a nuclear bomb. Low energy radiation is less penetrating than high energy radiation and thus less likely to cause biological damage.

found, however, that radiation protection procedures seemed to evolve at Operation Crossroads from a very simplistic approach to comprehensive personnel decontamination procedures that were not instituted until more than 2 weeks after the second nuclear test. In addition, even after comprehensive personnel decontamination procedures were instituted, some violations were reported. As a result, we believe that more radiation exposure than accounted for probably occurred.

Key Elements to Personnel Decontamination

The objective of personnel decontamination procedures is to assist in safeguarding personnel from radiation exposure by preventative or corrective means.[10] Personnel are instructed to avoid contaminated areas, but this is not always possible. Therefore, when personnel must come in contact with such an area, certain procedures should be followed, including the use of a central change station. Actually, a change station provides two basic purposes. First, it ensures that each individual is properly processed prior to entering and upon leaving a contaminated area. Secondly, it guards against contamination being needlessly spread.

Before entering a contaminated area, an individual should go to the central change station to obtain and put on proper clothing and equipment. The outer garment worn should be washable and nonporous, should cover the body completely, and should be tight-fitting at the ankles, wrists, and neck. In addition, some type of head covering—preferably tight-fitting—should be worn as well as goggles, boots, gloves, and a filter mask.

When in a contaminated area, it is important to personnel decontamination that each individual have a continuous and complete record of his or her exposure. Normally, an instrument, such as geiger counter, is used to provide the continuous record by giving an on-the-spot measure of radiation and a means of detecting and avoiding high radiation areas. Additionally, a film badge or a dosimeter is normally used to record the cumulative exposure received by the individual during the duration of his or her work.

Upon leaving a contaminated area and returning to the central change station, it is necessary to determine if the individual became contaminated and, if so, to take corrective action. At the change station each individual is instructed to remove all clothing and thoroughly wash,

[10]The information contained in this section is based on Crossroads defense manuals published shortly after that operation.

paying particular attention to areas where radioactive particles may lodge—such as the scalp and under nails. Clothing that is heavily contaminated is either disposed of or put aside for however long it is necessary for the radioactivity to decay. Less-contaminated clothing may be laundered and reused. The individual is monitored from head to foot with an instrument sensitive to the type of radiation existing in the contaminated area. If still contaminated, the individual is instructed to repeat the washing process as often as necessary. For persistent radiation, attention by medical personnel may be required. Otherwise, the individual is routed to a change room where clean clothing is made available prior to his or her release.

Personnel Decontamination Procedures Used at Operation Crossroads

The major impetus behind personnel decontamination and personnel safety at Operation Crossroads was the radiological safety section. This section consisted of a Radiological Safety Officer and about 400 personnel who were responsible for ensuring that the participating personnel were protected, to the maximum extent possible, from radiation's harmful effects. Their duties were to monitor radiation in the lagoon and aboard vessels, prepare and process film badges, and conduct a variety of other activities related to radiological safety.

As best as we can determine, in reviewing Crossroads-related information, the Radiological Safety Officer made 10 separate recommendations during Operation Crossroads either to improve personnel decontamination procedures or to keep exposures at a minimum. The majority of these recommendations were implemented by the joint task force. (App. I shows the date recommendations were made and whether they were implemented.)

On the basis of available evidence, however, personnel decontamination procedures seemed to evolve at Operation Crossroads. As more was learned about the radiological hazards, procedures were revised to protect the personnel involved.

For instance, the operation plan prepared prior to Operation Crossroads was intended to provide the necessary guidance for the health and safety of all Crossroads personnel. However, this plan offered only a very simplistic approach to radiation protection. It advocated—for crews reboarding target ships after Test Baker—that a policy of detection and avoidance be followed with no emphasis on personnel decontamination. Although monitors were assigned to provide radiological reconnaissance of each target ship prior to reboarding by the crew and

to detect and post areas where high concentrations of radioactivity were located, the crew was instructed only to restrict its activity and avoid "hot spots" once aboard the target ship.

July 31, 1946, Memorandum

On July 31, 1946—or 6 days after Test Baker—an outline of decontamination procedures was issued for personnel to follow. The procedures instructed all personnel to be fully clothed at all times, when working in contaminated areas, and to have a complete change of clothing and effective showers after each day's work. However, the procedures provided no particular guidance as to what constituted "fully clothed," a "complete change of clothing," or an "effective shower." The procedures also established no central change station to ensure that they were carried out. In addition, the procedures indicated that it was desirable for personnel to wear rubberized gloves and boots. Whether this occurred or, if so, to what degree is unknown.

DNA has, in its possession, thousands of photographs taken during Operation Crossroads and has included two of them, depicting crews working on unidentified target ships, in its historical report on Operation Crossroads. However, DNA could not provide us any photographs, including those in the historical report, that show that crews wore protective clothing in the performance of their decontamination work. (See fig. 2.2 and 2.3 for two pictures taken from DNA's historical report of crews working on target ships. According to the DNA assistant NTPR program manager, both pictures were taken about August 6, 1946.)

In addition, the July 31, 1946, memorandum indicated that all personnel clothing worn during decontamination work was to be laundered before reuse. The memorandum did not make a distinction between clothing that was heavily contaminated and clothing that was not. It seems possible, therefore, that heavily contaminated clothing was not discarded after being worn.

August 8, 1946, Memorandum

An August 8, 1946, memorandum sent by radio from the commander of the Crossroads target ship group to the ships in his command supports the preceding possibility regarding heavily contaminated clothing. This memorandum stated that any contaminated clothing with a geiger counter reading of more than 0.5 rem of radiation per 24 hours should be disposed of at sea and that any contaminated clothing with less than 0.5 rem of radiation per 24-hour reading should be laundered separately

from the ship's normal wash.[11] Prior to the August 8 memorandum, we discovered no evidence that heavily contaminated clothing was segregated.

August 9, 1946, Memorandum

Beginning August 9, 1946, more specific personnel decontamination procedures were instituted. According to DNA's historical report, procedures established on that date for the USS Ajax were typical for the entire joint task force. However, we could not find, and DNA could not provide us, any evidence of the typicality. In addition, another ship—the USS Wharton—issued somewhat different procedures also on August 9, 1946. Therefore, we believe that the procedures for the USS Ajax may have been applicable to only that ship.

The procedures issued for the USS Ajax included personnel proceeding to a central change station on board the ship and donning work clothes prior to leaving and boarding target ships. Upon their return to the USS Ajax, personnel reported to a specific location, washed their own clothes, and then showered twice. After the showers, personnel were monitored and, if free of contamination, were allowed to return to their own compartments on board the ship.

On August 9, 1946, one other ship—the USS Wharton—also issued personnel decontamination procedures for personnel to follow. While the USS Wharton also established a central change station similar to that of the USS Ajax, it did not require decontamination crews to follow the same steps upon their return from work on target ships. Specifically, the crews were not required to wash their own clothing or shower twice. Although the crew was expected to shower, a crew member had the option of taking a shower using a designated bathroom or any other shower space normally used. Because of this second option, it is possible that returning crews could have contaminated other parts of the ship such as handrails and bathrooms. On the other hand, not requiring the crew members of the USS Wharton, as did the USS Ajax, to wash their own potentially contaminated clothes probably avoided an increase in their radiation exposure.

[11] Radiation per 24 hours represents the amount of radiation received, if exposed, for a 24-hour period.

Source: Operation Crossroads, DNA 6032F, p. 113.

Figure 2.2: Work crews use a firehose on the superstructure of an unidentified target ship, Crossroads

Figure 2.3: Work crews scrubbing down an unidentified target submarine, Crossroads

Source: Operation Crossroads, DNA 6032F, p. 112.

August 13, 1946, Memorandum

Subsequent to the August 10, 1946, termination of decontamination efforts at Operation Crossroads, some personnel continued to board contaminated target ships to retrieve scientific equipment and to prepare the target ships for towing to Kwajalein Island. Because of that, an August 13, 1946, memorandum established a central change station on the USS Geneva for the processing of all working parties proceeding to and from work on target ships. On the basis of our review, not until this time—19 days after the detonation of Test Baker—is there evidence that comprehensive personnel decontamination procedures existed throughout the entire task force.

This memorandum itself warned of the danger of support ships becoming contaminated from working parties carrying back radioactive material with them. It indicated that the most likely centers for the spread of contamination were the showers in which the men bathed and the ships laundries in which their contaminated clothes were washed. Therefore, to minimize the radiological hazard, the memorandum stated that a centrally located facility was to be established where working parties would be issued clean clothing before going to work and where they could take showers before putting on their personal clothing and returning to their parent ship.

Post-Bikini Safety Precautions at Kwajalein Island

Following the towing of certain target ships to Kwajalein Island for the off-loading of ammunition, additional safety precautions were issued, o

August 30, 1946, for personnel to follow.[12] While previous memoranda outlined decontamination procedures prior and subsequent to boarding target ships, the August 30, 1946, memorandum advised personnel of the existing radiological hazards and established precautions for personnel to follow while on board target ships. Specifically the August 30, 1946, memorandum offered admonitions, such as

- All personnel should be warned that standing pools of water on the decks, even in supposedly uncontaminated parts of the ship, are potentially serious radiological hazards.
- No dry sweeping or dusting will be done in any part of a target ship due to the danger of inhaling radioactive dust.
- Lunches will under no circumstances be served to men on the target vessels and working parties will not be fed until they have been processed through the change ship.
- No men with open wounds not securely covered and protected by bandages will be permitted to perform work on target ships. In addition, any wound, however small, received while working aboard a target ship should be immediately scrubbed with soap and clean water and the injured person processed through the change ship.
- No personnel shall go below decks on target ships unless wearing an oxygen rescue breathing apparatus or positive pressure mask.

Violation of Safety Precautions at Kwajalein Island

In early 1947 many of the target ships that had been taken to Kwajalein Island for the off-loading of ammunition were prepared for towing back to the United States. During this time the senior radiation safety monitor at Kwajalein Island alleged a general breakdown in radiation safety precautions and, for that reason, refused to board any additional target ships. In a series of letters, the senior radiation safety monitor identified those specific violations of safety precautions that he had witnessed or had been reported to him from January 1947—when he was assigned to Kwajalein Island—to March 1947. They included the following:

- Monthly blood tests were not being performed on crews boarding target ships.
- Crews were boarding target ships without radiation monitors.
- Crews were looting contaminated equipment from target ships.

[12]All of the target ships used at Operation Crossroads had some ammunition on them to simulate wartime conditions. After the operation, it was considered too dangerous to allow this ammunition to remain on these ships. Therefore, about 285 Navy officers and enlisted men were assigned to ammunition off-loading at Kwajalein Island.

- Crews were eating and smoking aboard target ships.
- Crews were not being processed through the change ship.
- Contaminated clothing was not being laundered at the change ship.
- Men were wearing clothing with readings as high as .1 rem of radiation per 24 hours.
- Personnel showing a positive contamination, in urinalysis tests, were not taken off work on target ships.

No evidence exists that the Navy investigated each alleged violation; however, in a June 1947 letter, the Chief of Naval Operations indicated that certain safety violations had occurred. Of the above violations, one of the more unfortunate may have been a failure to perform monthly blood tests. Periodic blood testing was considered necessary in the 1940's to establish a norm for an individual and, thereby, a basis to evaluate any changes that had occurred. We noted that, after these violations of safety precautions had been reported, the Navy—in May 1947—instituted a blood testing survey of all active Navy personnel who had been involved. According to the historical report on Operation Crossroads, however, the results of this survey have not been found.

Observations

Comprehensive decontamination procedures are the cornerstone to protecting personnel from radiation's harmful effects. They help ensure that personnel are properly protected before entering a contaminated area and that, upon their return from that contaminated area, personnel have not retained radioactivity on their bodies or clothes. We found that prior to July 31, 1946—6 days after the date of Test Baker—personnel were not required to shower or change clothes after boarding contaminated target ships. Subsequent to July 31, 1946, decontamination procedures evolved further at Operation Crossroads; and even after comprehensive personnel decontamination procedures were instituted—on August 13, 1946—some violations of safety precautions were reported. Because of these developments, we believe personnel could have received additional radiation exposure beyond that recorded on the film badges they sometimes wore.

Film badges were supposed to be turned in by personnel immediately after returning from work on a contaminated target ship. If this was done and if personnel were not properly processed through a change ship and continued to wear contaminated clothing—as was reported at Kwajalein Island—this would have increased their radiation exposure beyond that recorded on the film badges they had worn.

Internal Alpha and Beta Radiation Exposure Has Not Been Fully Evaluated and External Beta Radiation Exposure May Have Been Under-Estimated or Not Estimated at All

Crossroads personnel were exposed to internal alpha, internal and external beta, and external gamma radiation. While film badges used at Operation Crossroads provided an approximate estimate of gamma radiation, they were incapable of measuring for internal alpha and beta radiation and provided external beta radiation estimates, according to DNA, of questionable accuracy. Thus, DNA has performed a dose assessment, or reconstruction, for internal alpha and beta radiation exposure and used external beta radiation estimates acknowledging that they may be incorrect.

DNA evaluated internal alpha and beta radiation in a draft report entitled Internal Dose Assessment--Operation Crossroads and, in that report, assumed that Crossroads participants could receive internal radiation exposure only by inhaling, or breathing in, radioactive materials. This analysis estimated alpha radiation by using certain information that suggested that a constant ratio existed between this radiation type and beta and gamma radiation. However, subsequent information indicates that the alpha-beta-gamma ratio at Operation Crossroads was not constant and that use of a constant ratio may underestimate alpha radiation by a factor of 5 or even 10.

We found evidence that internal radiation exposure could also have occurred through ingestion—as from eating food or drinking water—or from cuts or open wounds. When we brought this to the attention of the DNA assistant NTPR program manager, he admitted that internal exposure through ingestion was a possibility and subsequently asked DNA's contractor responsible for the internal dose assessment report to estimate for us the amount of exposure a Crossroads participant could have received by this means (see p. 39 for the results). The DNA assistant NTPR program manager also admitted that internal exposure from cuts or open wounds was a possibility but said that this was not discussed in the internal dose assessment report because it is unknown how to calculate for it.

DNA has also used external beta radiation doses from film badge readings, acknowledging those doses are incorrect. DNA officials explained this by indicating they believed the recorded doses tended to overestimate a Crossroads participant's exposure to this type of radiation. Instead, we found that, in many cases, personnel exposure to external beta radiation may have been underestimated or not estimated at all.

Types of Radiation and Their Effect on Man

The two nuclear explosions produced four types of radiation that posed a potential hazard to Crossroads' participants: internal alpha, internal and external beta, and external gamma radiation. When any one of these encounters living tissue, it transfers some of its energy to the target atoms, tearing off some or all of their electrons. This leaves the atoms with a positive electric charge—a process called ionization. This tearing off of the electrons d s the bonds holding together the complex molecules making up liv sue and leaves the tissue damaged to some extent. At low levels of ion, the damage may be minor and may not adversely affect the i dual's health. At higher levels, the reverse is true.

Alpha Radiation

Alpha particles are difficult to detect and their effect is lasting for years. They have a range of only 1 or 2 inches in the air and are incapable of penetrating clothing or even the outer layer of unbroken skin. However, these particles are a primary hazard when absorbed internally.

Once inside, alpha particles are distributed by the body in a manner similar to that of calcium. They are carried to the bones, liver, kidneys, and other parts of the body and deposited. These alpha deposits bombard the tis ıe surrounding them, causing irritation that is not given an oppor nity to heal and thus may lead to malignancy.

Beta Radiation

Beta particles may travel several feet in the air before being absorbed. In more dense material, such as body tissue, some beta particles may travel up to half an inch. Clothing normally provides adequate protection from beta radiation. Therefore, beta radiation is a hazard only when beta-emitting materials are either in direct contact with the skin or absorbed internally.

A large quantity of these particles concentrated on the skin will cause irritations much like burns. In addition, beta particles of high energy can be hazardous to the skin and those body organs and glands close to the outer skin layer such as the eyes and gonads. Beta-emitting substances taken into the body have two consequences—irritation of the walls in

the intestinal tract and the destruction of white blood cells, which decreases resistance to infection.

Gamma Radiation

In general, gamma rays have ranges of hundreds of feet in the air, and they can readily penetrate living and nonliving matter. Because they are highly penetrating, gamma rays pose a significant external exposure hazard. Dense materials, such as lead and steel, are often used as shields against gamma radiation.

Inside the body the ionizing properties of gamma radiation destroy the body cells and upset the normal functions of the body. A high dose of gamma radiation may cause loss of hair. Higher doses may cause nausea and aplastic anemia. As the dosage becomes greater, the bone marrow, spleen, and lymph nodes are affected. The mechanisms that manufacture red and white blood cells are also destroyed. Red and white blood cells not destroyed by gamma radiation are depleted through the normal functioning of the body. If these cells cannot be replaced, the natural medium of conveying nourishment and oxygen to the body cells (red corpuscles) and of combating infection (white corpuscles) is lost, producing anemia and reducing the body's defenses against disease.

Estimating Internal Alpha and Beta Radiation Exposure by Inhalation at Operation Crossroads

In its report Internal Dose Assessment--Operation Crossroads, DNA evaluated the internal contamination that personnel who boarded target ships after Test Baker could have received. According to the report the only contamination possible was by inhaling the nuclear debris deposited on the ships and later resuspended into the air by some disturbance of the surface. The report estimated the total amount of internal alpha radiation on the basis of a September 20, 1946, memorandum from the radiation laboratory at the University of California, Berkeley, that suggested that a constant ratio existed between alpha, beta, and gamma radiation on the contaminated target ships.

On the other hand, we discovered that, in a November 21, 1946, letter, the head of the technical analysis section of the Joint Crossroads Committee[13] commented on the risks involved in estimating alpha radiation on the basis of a constant alpha-beta-gamma ratio for the U.S.S. Rockbridge—one of the more thoroughly studied contaminated support ships returning to the United States. He said that alpha radiation was higher

[13]The Joint Crossroads Committee was established, upon dissolution of the Crossroads joint task force, to prepare and publish the official reports on that operation.

than would have been anticipated from previous information and that the alpha-beta-gamma ratio has been found—through laboratory analyses—to vary at different locations on the ship so that any estimate of alpha radiation could have been underestimated by a factor of 5 or even 10.

Consequently, we spoke with a DNA contractor representative who helped prepare the internal dose assessment report and he admitted that the alpha-beta-gamma ratio at Operation Crossroads may not have been constant. He indicated, however, that laboratory analyses of alpha radiation on Crossroads target and support ships were so few and inexact that it would have been impossible to reconstruct the Crossroads radiological environment for alpha radiation on the basis of the laboratory analyses. Therefore, the DNA contractor representative said that a theoretical model was used instead, showing a constant alpha-beta-gamma relationship.

Without a sufficient number of laboratory analyses, it seems reasonable to use a theoretical model to estimate alpha radiation at Operation Crossroads. However, if this model does not recognize that errors may exist in the use of a constant alpha-beta-gamma ratio, then this model may subsequently understate internal radiation exposure from inhalation for Crossroads personnel.

Internal Alpha and Beta Radiation Exposure by Ingestion Not Estimated

DNA, in its draft internal dose assessment report, did not consider the possibility of ingestion of radioactive materials because, as stated in that report, a prohibition against food consumption aboard target ships would have effectively precluded this possibility. On the other hand, we found evidence to suggest that eating food was permitted for a period of time aboard target ships. Ingestion of radioactive materials could have occurred by personnel with contaminated hands transferring the contamination to the food they were eating.

We found, for instance, that the radiological safety plan for Test Baker, dated July 15, 1946, instructed monitors and personnel accompanying them on radiological reconnaissance to carry their own food and water with them while on a mission. We also noted that the decontamination procedures established for work aboard target ships, dated July 31, 1946, identified that K-rations and water in canteens were to be brought aboard target ships daily.

In addition, ingestion of radioactive materials could have occurred as a result of remanning, or restationing a crew on a full-time basis, on target ships after Operation Crossroads. According to DNA's historical report, 12 target ships were remanned after Test Baker, some as early as July 29, 1946.[14] We noted that, as late as August 15, 1946, however, one ship was not warned of the precautions to follow to prevent ingesting radioactive materials but was simply told the consumption of sea rations was considered safe. On that date this ship was reporting radioactive readings as high as .65 rem of gamma radiation per 24 hours, which was more than 6 times higher than the gamma exposure standard of .1 rem established for the operation.

Moreover, the Radiological Safety Officer, in an August 13, 1946, letter to the commander of the target ship group, commented on the overall spread of radioactive contamination at Operation Crossroads. He said the "contamination of personnel, clothing, hands, and even food can be demonstrated readily in every ship in the JTF-1 (joint task force) in increasing amounts day by day [underscoring added]."

During our review, therefore, we asked DNA officials about the possibility of internal radiation exposure from the ingestion of radioactive materials, and they admitted this could have occurred. At DNA's request the contractor that prepared the internal dose assessment report used a constant alpha-beta-gamma ratio to calculate for us the estimated ingested dose for a crew member reboarding one of the more highly contaminated target ships for a day and eating three meals aboard. This calculation concluded that, for 1 day, the crew member would have received less than 2 percent of the annual internal dose limits recommended by the National Council on Radiation Protection and Measurements.[15]

As part of our work, we did not verify the methodology used in the contractor's calculation. We observed, however, that if a crew member had received 2 percent of his annual dose limit in a day, on the basis of a constant alpha-beta-gamma ratio that could be in error by a factor of 10—as discussed on page 38—then this crew member could have received 20 percent of his annual dose limit in a day. Moreover, crew members who spent several days decontaminating various Crossroads target ships or remained aboard some of the remanned target ships for

[14]Crews remained aboard some of the remanned target ships until the end of 1946.

[15]The National Council on Radiation Protection and Measurements is a private nonprofit organization, chartered by Congress, that publishes reports on all aspects of radiation protection.

as many as 4 months after Operation Crossroads could have received much more than 20 percent of their annual dose limit during the operation.

In discussions on this subject, the assistant NTPR program manager indicated that DNA has recently awarded a contract to further review the issue of internal radiation exposure, including the possibility of ingesting radioactive materials. According to this official, the contract is scheduled for completion at the end of 1985.

Internal Alpha and Beta Radiation Exposure by Open Wounds Not Estimated

Beyond the possibility of inhalation or ingestion, one additional pathway exists by which internal radiation exposure may have occurred. From a review of information on this subject, it is known that radioactive material may also enter the body through cuts or open wounds.

The DNA assistant NTPR program manager told us that possible internal radiation exposure by cuts or open wounds was not discussed in the draft internal dose assessment report for Operation Crossroads because it was unknown how to calculate for it. According to this official, various factors must be considered, such as depth of the cut or wound, degree of contamination of the object that caused the cut or wound, and amount of elapsed time before cleansing of the cut or wound. Because too many uncertainties are involved, the DNA assistant NTPR program manager said DNA chose not to mention the subject, or include any estimate for this type of internal radiation exposure, in its internal dose assessment report.

In our review of personnel decontamination procedures for Operation Crossroads, we noted that it was not until August 30, 1946, about 5 weeks after Test Baker, that personnel were advised that no one with open wounds not securely covered and protected by bandages would be permitted to perform work on target ships. This procedure also required personnel who sustained an abrasion or open wound, while working aboard a target ship, to wash the wound with soap and clean water, return to the change ship, and then report to the dispensary for appropriate treatment. The absence of such a procedure prior to August 30, 1946, could have increased the risk of an individual's intake of radioactive materials.

Observations

Three possible pathways exist by which an individual can receive internal alpha and beta radiation exposure—inhalation, ingestion, or cuts or

open wounds. DNA has analyzed only inhalation and its analysis for inhalation assumes a constant alpha-beta-gamma ratio that could have underestimated alpha radiation by a factor of 5 or even 10. On the basis of our review, DNA admits that internal radiation exposure by ingestion could also have occurred, has provided us the results of a quick review of this pathway, and has awarded a contract for further study of this area. Further, DNA admits that internal radiation exposure by cuts or open wounds could have occurred but that DNA does not know how to calculate for it. Without an analysis of all three exposure pathways that recognizes possible errors or uncertainties associated with that analysis, any estimate of internal radiation exposure for Operation Crossroads may be understated.

Estimating External Beta Radiation Exposure at Operation Crossroads

In its historical report for Operation Crossroads, DNA indicated that recorded beta readings obtained for that operation are of questionable accuracy. Despite this, DNA has not performed a dose reconstruction for external beta radiation but, instead, has assigned the recorded beta readings without change to those personnel wearing film badges. DNA officials told us this was done because these questionable beta doses tended to overestimate a person's exposure to this type of radiation. We believe, instead, that, in many cases, personnel exposure to beta radiation may have been underestimated or not estimated at all.

Each film badge used at Operation Crossroads was fitted with a lead cross that served as a filter. People recording the film badge readings were to measure the film blackening under the lead cross to calculate gamma radiation and the film blackening outside the lead cross to calculate beta radiation. The rationale was that while the lead cross would effectively block beta radiation, it would allow gamma radiation to blacken the film under the cross. On the other hand, the film area outside the lead would be blackened only by beta radiation.

On the basis of information available today, this rationale was incorrect. According to a DNA-recognized expert in film badge dosimetry, for the type of film badge used at Operation Crossroads, gamma radiation would have blackened the film area outside the lead cross as much as the film area under the cross.[16] For this reason DNA believes that any reading of the area outside the lead cross would reflect blackening from

[16]This individual is the technical advisor in the environmental sciences department of the Reynolds Electrical and Engineering Company. He is the same individual who estimated for DNA, in its report being prepared on film badges used throughout the atmospheric nuclear weapons testing program, that Crossroads film badges were accurate to within ± 30 percent.

both gamma and beta radiation and overestimate the recorded beta dosage. (See fig. 2.4.)

However, in examining the original film badge ledgers used at Operation Crossroads, we discovered that, of the first 350 Test Able film badges processed during July 1946, 250 of them were recorded as if the blackening caused by both gamma and beta radiation was less than the blackening caused by gamma radiation alone. (See fig. 2.5.) According to the dosimetry liaison officer in the environmental sciences department of the Reynolds Electrical and Engineering Company, two possible explanations exist for this error. Either the people recording the film badge readings made a miscalculation, or environmental damage—such as from humidity—faded or removed blackening from the film badge. In either event, it seems that beta radiation, for these 250 film badges, may have been underestimated as opposed to the reverse.

Moreover, in examining a computer listing of film badge readings for all Crossroads personnel, we found that, while film badges were seemingly read for beta radiation immediately after Test Baker, it is unclear how long that continued. The following table, derived from that computer listing, shows the number of film badges issued after Test Baker and the number of badges that recorded a beta radiation reading.

Table 2.2: Number of Film Badges Issued With Beta Radiation Readings

	Number	Number with beta radiation readings
7/25 - 7/31/46	1368	483
8/1 - 8/7/46	580	0
8/8 - 8/14/46	1504	1
8/15 - 8/21/46	3368	0
8/22 - 8/28/46	1082	17
8/29 - 8/31/46	130	3

From table 2.2, it is obvious that after July 31, 1946, few film badges were assigned a beta radiation exposure. On the basis of a review of the original film badge ledgers, we found that the reason for this was beta radiation was generally not recorded.

Figure 2.4: Projected Film Badge Darkening Pattern for Beta and Gamma Radiation—by DNA for All Badges

Figure 2.4: Projected Film Badge Darkening Pattern for Beta and Gamma Radiation — by DNA for All Badges

Figure 2.5: Actual Film Badge Darkening Pattern for Beta and Gamma Radiation—Recorded for Many Badges

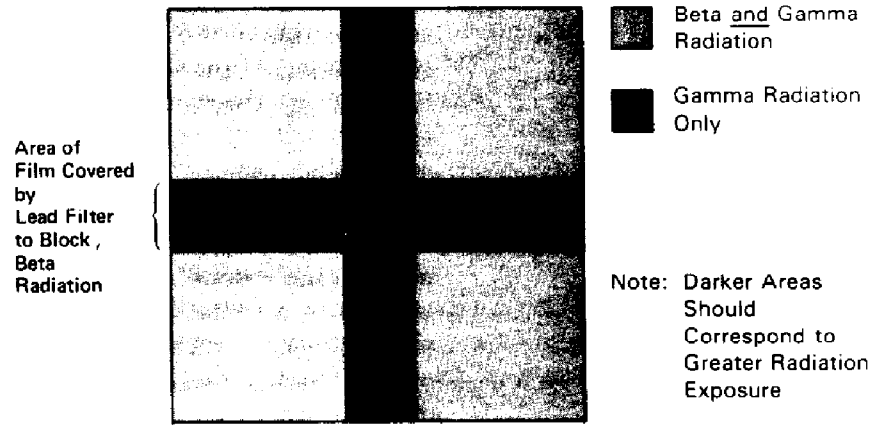


Figure 2.5: Actual Film Badge Darkening Pattern for Beta and Gamma Radiation — Recorded for Many Badges

For instance, in examining one of the original film badge ledgers used at Operation Crossroads, we found that the personnel making the ledger entries determined that some blackening outside the lead existed on almost all of the approximately 1,300 film badges recorded in that ledger. This blackening outside the lead was assigned a value that should then have been converted into a beta radiation dose. However, this value for beta was not converted for any of the film badges recorded in the ledger. Consequently, when the data from this ledger was subsequently transcribed onto keypunch cards for entry on the computer listing, a zero beta radiation dose was apparently assumed and assigned to each film badge.

The dosimetry liaison officer in the environmental sciences department of the Reynolds Electrical and Engineering Company offered us one possible explanation why not one of the film badges having values representing blackening outside the lead was assigned a beta radiation dose. He said that personnel making the film badge ledger entries possibly concluded that all of the blackening outside the lead was caused by environmental damage. The dosimetry liaison officer said, however, that some portion of the blackening could have been due to an actual radiation exposure, and the greater the environmental damage (the degree of blackening), the more actual radiation exposure that could have been hidden.

Observations

On the basis of penetrating ability, generally beta radiation is not externally as hazardous as gamma radiation. However, if it has sufficient energy, beta radiation may penetrate to a depth of one-half inch and affect the skin and those body organs and glands close to the outer layer of skin, such as the eyes and gonads. In addition, beta radiation can augment the damage caused by gamma radiation. Therefore, the presence of beta radiation cannot be ignored. We observed that only a small portion of the Crossroads participants wore film badges leading to recorded external beta radiation readings and these recorded readings may not, in many cases, reflect the amount of beta radiation this small portion of Crossroads personnel received.

The Military Services Have Not Been Required to Disclose Error Ranges Associated With Reconstructed Radiation Exposure Estimates

When a veteran submits a claim to the VA for service-connected disability, the veteran is asked to provide certain information in further support of that claim. In the case of potential radiation disability from participation in the atmospheric nuclear weapons testing program, the veteran is asked to identify the particular weapons test, unit, activities, and known radiation received. The VA, in turn, provides this information to the appropriate military service NTPR program office and asks it to verify the veteran's participation in the particular weapons test and to supply a radiation exposure estimate. This estimate usually represents the external gamma and beta radiation recorded on film badges worn and a reconstructed external gamma radiation dose for those times no film badge was worn. (In addition, an internal alpha and beta radiation estimate will also be supplied once DNA has finalized its assessment of internal radiation exposure, expected in late 1985.) With approximately 500 claims presently on file at the VA relating to Operation Crossroads, it is important that the reported film badge readings and the reconstructed doses for that operation be as factual and complete as possible.[17]

In dose reconstruction a radiological environment must be calculated, and the movement of individuals in that environment must be determined. A combination of the two variables allows an estimate of radiation doses. We noted that the DNA contractor responsible for the dose reconstruction report on external gamma radiation included several uncertainty factors, basically involving the Crossroads radiological environment, in its model calculations. These factors tended to recognize that certain Crossroads radiological data was not precise and should be discussed in terms of an error range, with confidence limits. While we found that the Army[18] has used the highest dose in the error range related to these uncertainty factors in reporting reconstructed radiation exposure estimates to the VA, the Navy has not. Moreover, neither military service has recognized, in the radiation exposure estimates reported to the VA, the inaccuracies associated with film badge readings.

[17]None of these 500 claims related to Operation Crossroads has, as of June 1985, been approved. Of these 500 claims about 480 are Navy claims and about 20 are Army.

[18]Of the approximately 42,000 participants at Operation Crossroads, about 3,300 were Army personnel either stationed aboard support ships and responsible for evaluating the effects of the nuclear bombs on military equipment or stationed at Kwajalein Island as part of the Army Air Corps.

Assumptions and Uncertainty Factors Included in the Dose Reconstruction Model

According to the DNA assistant NTPR program manager, eight high-sided assumptions are included in DNA's Crossroads dose reconstruction model for gamma radiation. These assumptions, which basically involve the movement of Crossroads participants, result in Navy and Army veterans being assigned a dose estimate on the high-side in recognition of areas of uncertainty. The DNA assistant NTPR program manager said that, quite often, these assumptions are contrary to logic or data gained from subsequent studies but are included nevertheless.

For instance, in its dose reconstruction model, DNA assumes that each serviceman (either Navy sailor or Army soldier) was on the bow of the ship, without any shielding from the hull, superstructure or bulkhead, as his support ship passed through contaminated water. It is also assumed that every man aboard ship was at the same location at which a radiation reading of the Bikini lagoon water was taken. In addition, DNA assumed that when a support ship came alongside a contaminated target ship, every man aboard the support ship was on deck at the point closest to the target ship. Thus, if a salvage vessel with 100 men passed alongside a target ship, all 100 men are assumed to have been standing unshielded at the closest point to the target vessel. Using these assumptions results in higher than likely dose estimates.

According to the DNA assistant NTPR program manager, five uncertainty factors are also included in its dose reconstruction model for gamma radiation. Each of these factors was developed by the contractor that devised the model, and each reflects a plus or minus error range associated with the Crossroads radiological environment. These factors are based on such elements as the poor reliability of monitoring instruments, the wide variation of radiation readings, and the lack of uniformity in methods of reporting radioactivity. The factors recognize that certain Crossroads data were not precise and should therefore, be estimated as falling within a particular range—as opposed to being a specific amount. They include (1) contamination aboard target ships after Test Able, (2) contamination in the Bikini lagoon after Test Able, (3) contamination aboard target ships after Test Baker, (4) contamination aboard support ships after Test Baker, and (5) contamination in the Bikini lagoon after Test Baker.

Rationale for the Navy Not Using the Error Ranges in Reporting Reconstructed Radiation Exposure Estimates

We noted that, while the Army has used the highest dose in the error ranges related to the uncertainty factors in reporting reconstructed radiation exposure estimates to the VA, the Navy has not. Therefore, as a part of our work, we analyzed the validity of these uncertainty factors, their impact in assigning radiation exposure estimates, and why the Navy did not use them.

The most radiologically significant of the uncertainty factors is contamination aboard target ships after Test Baker—because of the level of contamination on board the target ships, the number of men involved in boarding these ships, and the amount of time these men spent on board. This factor is derived from the average topside gamma radiation readings taken each day after Test Baker. In examining these readings, we noted, for example, that one ship's topside gamma radiation average was listed differently by various units in four separate Crossroads reports. Table 2.3 summarizes those differences.

Table 2.3: Topside Radiation Averages for Ship A

	Topside radiation average (rems per 24 hrs)				Range of difference between reports
Ship A	Report 1	Report 2	Report 3	Report 4	
(Aug. 7)	.86	1.06	1.10	1.20	.34
(Aug. 8)	.71	.97	.70	1.00	.30
(Aug. 9)	.50	.67	.92	.70	.42
(Aug. 10)	.80	.82	.60	.80	.22

The table illustrates a fluctuation in topside averages in each of the four reports. The average decreases in each report for a day or two followed by an increase in the average gamma radiation amount. These fluctuations represent a wide variation in radiation readings, which the DNA contractor identified as one element as supporting contamination aboard target ships after Test Baker as an uncertainty factor.

Moreover, we noted that the Radiological Safety Officer for Operation Crossroads also commented on the uncertainty associated with using target ship radiation readings in estimating personnel exposure dose. In an August 7, 1946, letter to the commander of the joint task force, he said that "the erratic location of high and low intensities on the target ships does not permit an accurate estimate of any one individual's exposure." He elaborated by saying that an individual "may hesitate longer near a high intensity than was expected, thus accumulating more than a tolerance dose."

The results shown in table 2.3 and the opinion expressed by the former Radiological Safety Officer suggest, in our view, that contamination aboard target ships after Test Baker has some validity as an uncertainty factor. Therefore, during our review, we asked the Navy to calculate a probable gamma radiation dose range—using all five uncertainty factors—for the individual with the highest recorded exposure at Operation Crossroads.

According to DNA's historical report, that individual was a radiation safety monitor who received 3.72 rem of gamma radiation. That number reflects, however, only the gamma radiation received by that individual during those times that he wore a radiation film badge. Calculating for that time when no film badge was worn and allowing for a hypothetically low error factor of 12 percent in film badge accuracy, the Navy calculated that this individual's probable gamma radiation dose range was between 3.651 and 5.365 rem. Table 2.4 summarizes the Navy's calculations.

Table 2.4: Navy Calculations of an Individual's Gamma Radiation Dose Range

	Low	Assigned[a]	High
Calculated dose during 12 days no film badge was worn	0.137	0.514	1.389
Recorded doses from 4 film badges worn (with 12-percent error factor)	3.514	3.720	3.926
2 film badges with zero readings	•	0.000	0.050
Total	**3.651**	**4.234**	**5.365**

[a]This individual's assigned dose is a combination of accumulated film badge readings—amounting to 3.72 rem—and reconstructed dose when no film badge was worn—amounting to .514 rem

Two points are worth noting regarding table 2.4. First, the recorded film badge dose is based partly on one film badge with a 2.0 rem gamma radiation reading. According to Navy NTPR program officials, this badge was supposedly issued to the individual on August 17, 1946, and processed on August 19, 1946. However, official Crossroads records indicate that this individual may have departed the Bikini Island lagoon prior to these two dates. Nevertheless, Navy NTPR program officials say this questionable 2.0 rem film badge dose is still being assigned to this individual. Second, the calculated dose, during those 12 days no film badge was worn, is based on the assumption that this individual spent 12 days aboard his support ship and boarded no target ships. This assumption may not represent what occurred.

The number of radiation safety monitors dwindled as Operation Crossroads progressed. For instance, in an August 7, 1946, memorandum to the commander of the joint task force, the radiological safety officer said that monitoring demands had been increasing steadily while the number of monitors was being depleted by individuals being airlifted home. Thus, this particular radiation monitor's services for boarding target ships would have been in high demand. In addition, this monitor may have boarded target ships without a film badge. We found that, on August 5, 1946, a procedure was instituted to ensure that every radiation monitor had a film badge before going on a mission. Presumably, the procedure was necessary because this was not being done.

However, the most significant aspect of the Navy calculation regarding the radiation monitor is that, if it is accepted that the monitor could have received the highest dose in the probability dose range, then this individual could have received an overexposure on the basis of today's gamma radiation safety standards.[19] DNA and Navy NTPR program officials, on the other hand, initially told us that the dose assigned this Crossroads participant represents their most probable estimate of his gamma radiation dosage. These officials maintained that the Navy's dose reconstructions have been further estimated on the high side by the inclusion of seven additional assumptions.[20] For instance, Crossroads documents show that crews reboarding and decontaminating target ships were divided into four teams. Since it could not always be determined which boarding team or individual was aboard a target ship on any given day, the Navy assumed, as an additional high assumption, that all boarding teams were aboard. Therefore, DNA and Navy NTPR program officials said they were reluctant to also disclose the ranges related to the uncertainty factors because they felt this could lead to a veteran being assigned a higher-than-likely radiation exposure estimate and thereby getting disability when he or she was not entitled to it.

Subsequently, DNA has changed its position. Responding to the requirements of Public Law 98-542, DNA has published for review and comment—in the May 9, 1985, Federal Register—minimum standards that will be uniformly applicable to all branches of the military services. These standards govern the preparation of radiation dose estimates in

[19]According to a Navy NTPR program official, this monitor does not have a service-connected disability claim on file at the VA.

[20]The Army has not yet further raised its assumptions but is considering doing so.

response to VA inquiries in connection with a veteran's disability claim.[21] As part of those standards, DNA has proposed that, if recorded film badge data is unavailable or incomplete, a dose reconstruction for the most probable external gamma radiation dose would be provided, with error ranges or limits, if available. The DNA assistant NTPR program manager told us that our work and congressional interest in this area highlighted a need for this change.

Observations

It is DNA's responsibility to see to it that the VA is provided with as complete data as possible on the radiation doses received by participants in the atmospheric nuclear weapons testing program. In our view it is reasonable, therefore, for DNA to require the military services to use error ranges, or limits, in reporting reconstructed radiation dose estimates to the VA if there is some uncertainty associated with personnel doses. On the basis of our review, some uncertainty is associated with the Crossroads radiological environment, which justifies the reporting of reconstructed radiation dose estimates, with error ranges, for that operation. Moreover, some inaccuracies are also associated with film badge readings, which similarly justify also reporting those readings with error ranges. We observed that doing so is not a part of DNA's newly proposed minimum reporting standards.

[21] Public Law 98-542, entitled "Veterans Dioxin and Radiation Exposure Compensation Standards Act," October 24, 1984, requires, in part, the VA to prescribe regulations regarding the determination of service connection of certain disabilities of veterans who were exposed to radiation from nuclear detonations while on active service and the DNA to prescribe guidelines through a public review and comment process, specifying the minimum standards governing the preparation of radiation dose estimates in connection with veterans' claims for compensation and making such standards uniformly applicable to the several branches of the Armed Forces.

Conclusions, Recommendations, and Agency Comments

Conclusions

A review of radiation safety at Operation Crossroads is fraught with difficulties and underlying risks. For instance, after that operation, the federal government did not collect and store all the material prepared on that operation in one location. Consequently, over the last 40 years, material regarding that operation has ended up in various federal record centers and agency libraries or has simply been lost or misplaced.

During our review we retraced many of the steps followed by DNA in its work on Operation Crossroads. We talked with individuals who participated in that operation and visited locations where Crossroads material is stored. Our review represented, however, only a limited evaluation of selected aspects of radiation safety during that operation.

This review identified, nonetheless, one hypothetical case of overexposure for a Crossroads participant. This may not reflect an actual overexposure at Operation Crossroads, and no actual overexposures may have occurred. Due to a number of factors, including the difficulty in locating Crossroads-related material, we could not make that determination during our review. However, we did determine that DNA may need to reevaluate selected aspects of radiation safety during that operation and adjust Crossroads participants' radiation exposure estimates accordingly.

The film badges used at Operation Crossroads measured a limited range of external gamma radiation—from .05 to 2.0 rem of radiation. In retrospect, it seems that it would have been desirable if the film badges used then had had a higher radiation sensitivity range. Nine Crossroads participants wore film badges that had reached the maximum 2.0 rem radiation limit. DNA assigned each of those individuals a 2.0 rem external gamma radiation dose for those badges, but it is indeed possible that those individuals received a much higher dose of radiation. Because none of these nine badges have been located, they cannot be reread, which is possible using state-of-the-art dosimetry equipment, and a more exact gamma radiation dose assigned to them.

The film used at Operation Crossroads was intended to measure down to .05 rem of gamma radiation. According to DNA, at the low end of this range—from .05 to .1 rem—the film was probably accurate within $\pm$ 100 percent. This means that an exposure up to .1 rem of radiation could have resulted in a reading of .05 rem on the film or, given the limited measurement range of the film, could have registered zero. During the months of July and August 1946, 6,790 film badges were assigned zero readings. Given the reported inaccuracy of the film, any of

these badges might have been exposed to as much as .1 rem of radiation. Interestingly, a .1 rem of radiation in a day would have represented an overexposure on the basis of Crossroads radiological safety standards. According to the technical advisor in the environmental sciences department of the Reynolds Electrical and Engineering Company, it may be prudent to assign the minimum detectable amount—.05 rem—to each film badge that read zero. Agreeing with that thought, we believe the need exists for DNA to evaluate possibly assigning some external dose to each film badge with a reported zero reading.

At present DNA's radiation exposure estimates make no allowance for film badge inaccuracy. However, we found the film badges used at Operation Crossroads provided only an approximate estimate of gamma radiation exposure. If the people involved in reading film badges at the operation had conducted the film badge processing activities perfectly, then the recorded film badge readings would have had an overall accuracy of approximately $\pm$ 30 percent. That is DNA's estimated accuracy of the film alone. If, on the other hand, the film badge processing activities had not been conducted exactly correct, then the overall inaccuracy of the recorded film badge readings could be greater, and possibly much greater, than the inaccuracy of just the film.

In this regard, a considerable amount of information has been developed on the ability of laboratories across the United States to properly process and read film badges. For instance, the U.S. National Bureau of Standards tested several laboratories in the mid-1950's and found that, under controlled laboratory conditions, their readings of film badges were often inaccurate by as much as $\pm$ 100 percent. It is unlikely that the film badge readings made under field conditions at Operation Crossroads would have been any more accurate than those in laboratories. Therefore, we believe a need exists for DNA to establish an overall accuracy for Crossroads film badges and factor this accuracy into its personnel exposure estimates.

Because DNA believes comprehensive personnel decontamination procedures existed from the beginning at Operation Crossroads, its radiation exposure estimates do not recognize the possibility that personnel may have retained radioactivity on their bodies and their clothes upon return from work on contaminated target ships. However, considerable evidence exists that personnel decontamination procedures evolved at Operation Crossroads from a very simplistic approach to radiation protection to a more detailed one as experience was gained about the extent and spread of radioactive contamination at that operation. We believe

the absence of comprehensive decontamination procedures, from the beginning of Operation Crossroads, resulted in participants being exposed to radiation that has not been accounted for by DNA.

For instance, prior to July 31, 1946—6 days after Test Baker—no evidence exists that personnel were required to shower or change clothes after boarding contaminated target ships. For a period of time, heavily contaminated clothing also was not discarded and may have been worn again after having been washed. Moreover, even after comprehensive decontamination procedures were instituted, some violations of safety precautions were reported. We believe a need exists for DNA to analyze the extent to which personnel received additional radiation exposure from a lack of comprehensive decontamination procedures, or from such procedures being subsequently violated, and factor the effects of this analysis into the agency's personnel exposure estimates.

An individual can receive an internal alpha and beta radiation exposure by three possible pathways—through inhalation, ingestion, or a cut or open wound. DNA has analyzed only the possibility that Crossroads personnel inhaled radioactive materials and, in that analysis, used a constant alpha-beta-gamma ratio that may have underestimated alpha radiation at Operation Crossroads by a factor of 5 or even 10. We believe a need exists for DNA to reevaluate its analysis of internal radiation exposure and disclose any errors, or uncertainties, associated with that analysis. We also believe a need exists for DNA to evaluate the two other internal radiation exposure pathways—through ingestion or cuts or open wounds. With respect to ingestion of radioactive materials, we believe DNA should assess those scenarios in which internal radiation exposure could have been the greatest. On the basis of available information, some crews remained aboard remanned target ships from August 1946 through the end of the year. These crews ate three meals a day for approximately 4 months aboard a contaminated ship and may have had the highest opportunity for internal radiation exposure.

Crossroads personnel were subject to both external gamma and beta radiation. Although the film badges used at Operation Crossroads provided an approximate estimate of gamma radiation, these same film badges were incapable of accurately recording beta. Despite this, DNA has not performed a dose reconstruction for external beta radiation but, instead, has assigned beta radiation doses to Crossroads participants on the basis of film badge readings because it believed these doses tended to overestimate a person's exposure to beta. Instead, it seems that, in many cases, personnel exposure to beta radiation may have been

underestimated or not estimated at all. We believe a need exists for DNA to reassess the accuracy of the external beta radiation dose information for those Crossroads participants who wore film badges and, given that all Crossroads participants did not wear film badges, perform a dose reconstruction for external beta radiation.

At the time of our review, DNA had not required the military services, in reporting radiation exposure estimates to the VA to disclose the error range related to reconstructed radiation doses. As a result we found that, while the Army has been reporting this error range, the Navy has not. In part because of our interest in this subject, DNA included in its minimum standards for reporting radiation exposure estimates—pursuant to Public Law 98-542 and published for comment in the Federal Register on May 9, 1985—a requirement that all military services would uniformly disclose the error range associated with reconstructed radiation doses, if available. While we believe this requirement is justified, in view of finding uncertainties about the Crossroads radiological environment, we also believe a need exits for the military services to further disclose the error range associated with film badge readings. Because inherent inaccuracies are associated with the film in film badges and with film badge processing, this further disclosure could better aid the VA in adjudicating veterans' service-connected radiation disability claims.

Recommendations

We recommend that the Secretary of Defense direct the Defense Nuclear Agency to adjust, where feasible, the Crossroads participants' exposure estimates by

- assigning, given the limited sensitivity range of the Crossroads film, some external gamma radiation dose to each film badge that was reported to have read zero and developing an error range for each Crossroads film badge reading that recognizes film and film processing inaccuracies;
- estimating the extent to which personnel received additional radiation exposure from a lack or violation of comprehensive decontamination procedures;
- reevaluating and disclosing the possible errors or uncertainties associated with its analysis of internal radiation exposure by inhalation;
- analyzing possible internal radiation exposure from ingestion or through cuts or open wounds; moreover, with respect to ingestion, assessing

those scenarios that offered the greatest opportunity for internal radiation exposure, such as when crews remanned target ships after Operation Crossroads; and

- reassessing the accuracy of the external beta radiation dose information for those Crossroads participants who wore film badges and, given that all Crossroads participants did not wear film badges, performing a dose reconstruction for external beta radiation.

In addition, where any of the preceding actions has been determined not to be feasible, we recommend that the Secretary of Defense require DNA to document the reasons for each such determination so that the military services can provide this information to the VA and the affected veterans.

We also recommend that the Secretary of Defense direct DNA, in implementing its new standards for reporting radiation exposure estimates to the VA, to not only require the military services to disclose the error range associated with reconstructed exposure estimates but also require them to disclose the error range associated with individual film badge readings.

Agency Comments

We provided draft copies of this report to VA and DOD. VA stated that it does appear that service personnel were exposed to more radiation during Operation Crossroads and the subsequent cleanup than they would have been after safety precautions were better developed and used as in subsequent nuclear tests. Although outside the realm of this report, VA also indicated that our recommended actions for calculating radiation doses for Crossroads participants should also be applied to participants in all atmospheric nuclear tests. These new calculations, VA stated, would almost certainly result in reports of higher levels of radiation exposure and could require a reevaluation of previously denied claims. In this regard, VA remarked, it is imperative that any new calculated dose assessment be reported to the VA if dose information had previously been reported in connection with a claim for a veteran's benefits. VA stated it could not be certain whether changes in radiation dose estimates resulting from our recommendations would require reversal of VA decisions regarding service-connected disabilities allegedly resulting from radiation exposure. For example, even a two- or three-fold increase in an initially small radiation dose estimate would likely be of little significance in the VA's adjudication of a claim dependent upon that estimate. Increases of such a magnitude could have greater importance where a substantial radiation dose was initially estimated. (See app. III.)

DOD, in commenting on our draft report, generally disagreed with the report's findings, conclusions, and recommendations. We found, however, situations where DOD (1) provided incorrect or unsupported statements, (2) misinterpreted certain Crossroads-related documents, or (3) presented information inconsistent with DNA's historical report on Operation Crossroads and other material. For those reasons, we continue to believe that DOD can improve radiation exposure estimates for Crossroads personnel by effectively addressing and implementing our recommendations. The information that follows addresses DOD's position on each of the issues discussed in our report. In addition, DOD's comments and our detailed evaluation of those comments are provided in appendix IV.

Film Badge Error Range

DOD agrees that film badges provided only an approximate estimate of gamma radiation exposure for Crossroads personnel. It contends, however, that the error associated with the film badges is ± 30 percent as opposed to as much as ± 100 percent as discussed on pages 25 and 26.

DOD's estimate that the error is ± 30 percent is based on the educated judgment of its consultant on film badge dosimetry and represents the inaccuracies associated only with the film. It does not include the possible inaccuracy associated with processing the film. Because there are no data on actual Crossroads film badge processing accuracy, we analyzed film badge processing accuracy attained under controlled laboratory conditions. In this regard, we found—in 1953 and in 1963—laboratories were tested on their ability to properly assign radiation estimates to film badges that had been exposed to known amounts of radiation, and these laboratories were frequently in error by ± 100 percent. We believe that it is unlikely that film badge dosimetry results under harsh field conditions at Crossroads were more accurate than the more recent test results obtained under laboratory conditions.

On the other hand, it is DOD's position that the procedures and controls followed at Operation Crossroads were better than those followed by the two laboratories being tested. We disagree. DOD provided no evidence that either the film badge storage, exposure, and processing or the laboratory equipment used had been better at Operation Crossroads than it was in the laboratories being tested. Moreover, we believe DOD has understated the possible uncertainties associated with the Crossroads film badges in three of five possible areas— calibration, environment, and densitometer (a machine used to read the film badges). For instance, DOD states that eight areas of each Crossroads film were read with the

densitometer to ensure accuracy. However, in reviewing, for example, the original film badge ledger for the first 350 film badges processed at Crossroads, the ledger shows that only 15 of the 350 film badges had 8 readings recorded. For the other 335 films, only 2 readings were recorded. It is possible that the Crossroads personnel processing these 350 films did read 8 areas on each film, but no proof of that is contained in the ledger—the only documentation that showed the recorded results.

Minimum Film Badge Detection Level

DOD disagrees that Crossroads film badges were incapable of reading below .05 rem of radiation and offers, as proof, evidence that some Crossroads participants were assigned film badge doses at the .01 to .04 rem level.

However, according to the former chief of the Crossroads dosimetry section, the film badges used at Crossroads permitted dose measurement only as low as .05 rem. In addition, according to a letter written by DOD's film badge dosimetry consultant, to DNA's assistant NTPR program manager, dated January 9, 1985,

"it is questionable whether exposures of 40 MR [.04 rem] or less could be reported with any accuracy during Crossroads. Minimum exposures of 40, 30, or even 10 MR [.04, .03, or even .01 rem] can be reported for film badges exposed under laboratory conditions, but these exposures could not be reported accurately with film badges stored, exposed, and processed under the harsh environmental conditions during Crossroads." [underscoring added]

Personnel Decontamination Procedures

DOD agrees that personnel decontamination procedures evolved at Crossroads but insists that the possibilities for radiation exposure were limited to a few participants prior to the development of personnel decontamination procedures on July 30, 1946, and that, prior to that time, any radiation exposure created by wearing contaminated clothes or not promptly showering has been compensated for by the overestimations made in its dose reconstruction analysis.

However, there is no evidence that the procedures cited by DOD as being developed on July 30, 1946, were applicable to more than one Crossroads support ship. In addition, on the basis of DNA's historical report on Operation Crossroads, more than a few participants possibly received radiation exposure prior to the date of these procedures. For instance, DNA's historical report shows that between July 25 and July 31, 1946,

more than 34,500 Navy and Army personnel aboard more than 100 support ships reentered Bikini lagoon and that approximately 3,400 of these personnel were involved in such tasks as retrieving scientific instruments and test animals from target ships, towing and beaching target ships, resurfacing target submarines, flying aerial reconnaissance, and evaluating damage to military test equipment, and thus in a position to be potentially contaminated.

Moreover, we disagree that DOD's dose reconstruction accounts for uncertainties from deficient personnel decontamination procedures. DOD's dose reconstruction calculated a radiological environment and determined the movement of individuals in that environment. In certain cases, for instance, where a support ship passed by a contaminated target ship, DOD assumed that each person on the support ship was on the deck closest to the target ship. This was done because the exact position of every person was not known. Such an assumption may or may not have overestimated each person's true exposure from the radiological environment depending on his or her actual location. However, it would not account for wearing contaminated clothes or not promptly showering.

Internal Radiation Exposure by Inhalation

DOD used a constant alpha-beta-gamma ratio to calculate internal radiation exposure by inhalation. DOD said we misinterpreted a Crossroads memorandum, written by the head of the technical analysis section of the Joint Crossroads Committee, as suggesting that a constant alpha-beta-gamma ratio could have underestimated alpha radiation by a factor of 5 or even 10. Instead, DOD said the memorandum referred to the problems of estimating plutonium levels from geiger counter readings.

We disagree. In the memo, the head of the technical analysis section pointed out that

"the fission product [gamma and beta radiation] -plutonium [alpha radiation] ratio does not appear to be constant at different locations so that any selected conversion factor might be in error by a factor of 5 or 10. This change in ratio would indicate that selective absorption has been taking place, so that the fission products and plutonium are being concentrated to different extents on some surfaces."

In subsequent discussions with the author of this memorandum and with a radiochemist at DOE's Hanford Operations Office, we confirmed that our interpretation of this memorandum was correct and that the

alpha-beta-gamma ratio at Operation Crossroads would not have remained constant.

Internal Radiation Exposure by Ingestion

DOD offers two reasons why no further evaluation of internal radiation exposure by ingestion is required. The first reason is that the alpha-beta-gamma ratio at Operation Crossroads was constant. The second reason is that DOD has already looked at a worst-case scenario involving an engineering team working on the USS New York and concluded that the team's internal radiation dose received by ingestion was minimal.

As previously discussed, the alpha-beta-gamma ratio was not constant. We also do not believe DOD's analysis of the engineering team working on the USS New York for 16 hours on August 8, 1946, and eating three meals on board was a hypothetically worst-case scenario. DOD, in its analysis of that case, assumed that contamination was evenly spread over the entire surface of the ship. Then, DOD assumed that a member of the engineering team placed one hand on only one spot on the surface of the ship prior to each meal and, from that small area, transferred only one percent of the contaminants to the hand—all of which was ingested. Given the possibility that (1) contact with the ship occurred where there was a higher than average concentration of contamination on the USS New York, (2) a member of the engineering team placed his hand or hands on more than one spot on the contaminated surface of the ship, or (3) more than one percent of the contaminants was transferred to his hand or hands, it is our opinion that the doses for this member of the engineering team may not represent a worst-case scenario.

Internal Radiation Exposure by Open Wounds

DOD does not believe it needs to address internal radiation exposure by open wounds because (1) documentation exists that shows that contamination of open wounds was not a problem at Crossroads and (2) its calculation for an open wound, on a worst-case basis, showed minimal internal radiation exposure.

Conversely, we continue to believe that possible internal radiation exposure by open wounds needs to be addressed. First, no evidence exists that Crossroads personnel were alerted to the steps to be followed in case of an open wound until August 30, 1946, approximately 20 days after termination of decontamination operations at Crossroads. Although DOD states that the seriousness of internal radiation exposure by open wound was otherwise known—by offering one account of an open wound case at Crossroads—we believe it is possible that other

open wound cases, given the number of personnel boarding contaminated target ships, were neither reported nor received appropriate treatment.

Second, we disagree with DOD's view that it has reconstructed a hypothetically worst case open wound. DOD said a 1-centimeter by 0.1 centimeter puncture, which transferred 100 percent of all contaminants into the blood stream, would result in an exposure of only 0.03 rem to the bone marrow, or approximately 0.2 percent of the National Council on Radiation Protection and Measurements guidelines for exposure to internal organs. However, in its reconstruction, DOD assumed (1) the puncture was relatively small—width of 0.1 centimeter (or about the size of the wire in a standard paperclip) and depth of less than 1/2 inch (1 centimeter), (2) the object that caused the puncture wound was contaminated with alpha radiation based on the average amount of beta and gamma radiation existing per square centimeter on the target ship USS New York on September 6, 1946, and (3) the alpha-beta-gamma ratio was constant. Given the possibility that (1) a greater-size wound occurred; (2) the contaminated object that caused the wound had a higher than average amount of contamination on it; (3) the wound occurred earlier than September 6, 1946, which was 27 days after decontamination operations were halted at Crossroads; or (4) the alpha-beta-gamma ratio varied, it is our opinion that DOD's example may not represent a worst-case scenario.

External Beta Radiation

DOD does not dispute our finding that some errors were made in recording external beta radiation doses at Operation Crossroads but contends that external beta radiation is not a long-term medical hazard. Therefore, DOD does not see the need to go back and make corrections, even where admitted errors occurred.

On the other hand, we continue to believe that DOD should evaluate the accuracy of the beta radiation dose information for several reasons.

For instance, contrary to DOD's statement, external beta radiation may produce long-term health effects. According to two experts in the area of medical effects from nuclear radiation—one with the health and safety research division at the Oak Ridge National Laboratory and the other the former head of the Marshall Island Medical Program at the Brookhaven National Laboratory—external beta radiation may cause skin cancer. For that reason, the Oak Ridge National Laboratory expert told us the effects of external beta radiation "should not be dismissed

out of hand. While beta radiation is generally much less significant than gamma radiation, a careful reconstruction would be necessary before it could be concluded that the effects of beta radiation need not be included in the overall dose estimate."

In addition, while DOD may be correct to state that medical records for Crossroads veterans do not indicate any evidence of beta exposure, at least one severe case of beta radiation overexposure reportedly did occur. According to the former head of Marshall Island Medical Program at the Brookhaven National Laboratory who was also a former Crossroads participant, one serviceman received extreme beta radiation burns on his hands by handling the radiological filter from a drone aircraft. Thus, we believe Crossroads medical records may not have documented all radiation-related cases that occurred.

Reporting Film Badge Error Ranges to VA

DOD states that by the end of 1985 it will be completing a report on the accuracy of film badge dosimetry and this report will be sent to all VA regional offices. DOD, believes that, through this mechanism, error ranges for film badge readings will be reported to the VA, and this may satisfy our recommendation.

We disagree. A veteran's total radiation exposure is often the product of a number of individual film badge readings. Unless the individual readings are known and the correct error ranges are assigned to those individual readings, a mistake may result in developing a composite error range for the total radiation exposure. To minimize the possibility of such a mistake, we believe the military services (given their familiarity with the data) should report film badge readings with error ranges to VA rather than have VA develop this information.

Military Response to Recommendations of the Radiological Safety Officer

Table I.1: Radiological Safety Officer's Dated Recommendations and Military Responses

Date	Recommendation	Whether or not implemented
April 27, 1946	All fresh water tanks should be filled prior to the entry of any ship into contaminated water, and no ships should operate their distilling plants unless absolutely necessary.	No
August 3, 1946	The intervening time between August 3 and August 14, 1946, should be spent on working on only those target ships with little radioactive contamination or where the usefulness to the task force is great and the effort and rush is worthwhile;	No
	the remaining target ships, such as the **Independence** and the **Pensacola,** should be declared hopelessly contaminated, towed to shallow water, beached, and time allowed for radioactive decay to take place; and	No
	as much scientific equipment as it is safe to do so should be rescued.	Yes
August 7, 1946	The present operations in the Bikini lagoon should be terminated on or by August 15, 1946, since there is neither equipment nor adequate monitoring personnel available to continue safety operations beyond this date;	Yes
	a small force should be organized and left at Bikini as a stop gap to continue (1) small scale studies of decontamination procedures, (2) recovery of scientific instruments, and (3) prevent the sinking of whatever vessels that can be saved without risk of exposing personnel to dangerous amounts of radioactivity; and	Yes
	if it is contemplated that the task force return to Bikini either for further study of the problem of decontamination or to prepare for a third nuclear test, the proper arrangements should be made and facilities should be made available to handle the problem of decontamination on a large scale.	Not Applicable

August 13, 1946	No further work must be permitted in the contaminated target ships without well organized and adequate safeguards including special equipment for personnel and proper radiological equipment; and	Yes
	the present use of task force personnel should be restricted to the recovery of instruments and limited to surveys consistent with radiological safety.	Yes
January 6, 1947	Only those target ships should be saved that are considered to be a definite experimental or training value to the Navy. The rest should be disposed of by sinking in deep water in the open ocean.	No

[a]This recommendation is not applicable given that the military did not return to Bikini either for further study of the problem of decontamination or to prepare for a third nuclear test.

Table I.1 indicates that four recommendations were not implemented by the military. The first such recommendation urged that support ships not operate their distilling plants—for making fresh water—in contaminated waters. Because this recommendation was not universally implemented throughout the joint task force, the distilling units on an unknown number of support ships became contaminated and subsequently had to be flushed with cold water or a chemical compound. There is no evidence, however, that the fresh water supplies on any of these support ships became contaminated, and a Navy/NTPR official told us, that had that occurred to any appreciable amount, the salt from the salt water would not have been distilled out and the fresh water would have become brackish-tasting and unfit to drink. Thus, if this official's contention is true, the major effect of not implementing this recommendation was increased radiation readings on support ships from contaminated piping and other equipment. We noted that DNA has considered this situation in its dose reconstruction calculations (see p. 45 for a discussion of dose reconstruction).

The second and third unimplemented recommendations urged that the time between August 3, 1946, and August 14, 1946, should be spent working on only those target ships with little radioactive contamination and that the more heavily contaminated target ships should be beached and time allowed for radioactive decay to take place. Actually, between August 3, 1946, and August 10, 1946—when the operation was officially terminated—the joint task force seemingly attempted to decontaminate all target ships without regard to degree of radioactive

contamination. As a result, with safety precautions supposedly equal throughout the joint task force, those crew members that boarded the more heavily contaminated target ships probably received more radiation exposure than if they had boarded the less-contaminated target ships. We noted that DNA has accounted for what ships individuals worked on in reconstructing personnel exposure doses.

Finally, the fourth unimplemented recommendation urged that only those target ships should be saved that were considered to be of definite experimental or training value to the Navy and that the rest should be disposed of by sinking in deep water in the open ocean. After the termination of Operation Crossroads, most of the target ships were either towed to Kwajalein Island, remanned, or towed back to the United States. Eventually, the Navy recognized that most of the ships returning to the United States either were not suitable for continued use or could not be decontaminated to safe-enough levels and were subsequently sunk. Prolonging the disposal of these contaminated target ships could have caused personnel who continued ship decontamination procedures to receive additional radiation exposure. We noted that DNA has considered this effect and reconstructed a radiation exposure for the participating personnel.

Allegation Regarding the Collection of Documents Once Belonging to the Crossroads Radiological Safety Officer

During our review, the office of the ranking minority member of the Senate Committee on Veterans' Affairs also asked us to look into an allegation that important Crossroads material had been removed from the collection of documents once belonging to the late Radiological Safety Officer. These documents are now on file at the University of California at Los Angeles library. We discovered that the Federal Bureau of Investigation had conducted an investigation and concluded that there was no substance to the allegation. As part of our work, we interviewed the Bureau agent who conducted the investigation and obtained copies of his interviews.

In addition, we met with the individual who had made the allegation and learned that the allegation was based, in part, on this individual's expecting, but not being able, to find certain information in the collection of documents in question.[1] In reviewing the collection of documents, we found no evidence to suggest that the information sought had, at any time, been a part of the collection. Moreover, given that this collection of documents represents only the personal files of one key Crossroads participant, we did not expect this collection to be complete in every respect.

[1]The information pertained to certain urinalysis testing that was performed on some Operation Crossroads participants and the discovery of the probable presence of plutonium on August 10, 1946 (see p. 13 for a discussion of this second subject).

Advance Comments From the Veterans Administration

Office of the
Administrator
of Veterans Affairs

Washington DC 20420

Veterans
Administration

AUG 26 1985

Mr. Richard L. Fogel
Director, Human Resources Division
U.S. General Accounting Office
Washington, DC 20548

Dear Mr. Fogel:

Your July 10, 1985 draft report "Improvements Needed in Estimating Personnel Radiation Exposures from the 1946 Nuclear Test—Operation Crossroads" has been reviewed.

The General Accounting Office (GAO) concluded that the Defense Nuclear Agency (DNA) should be directed to adjust, where feasible, the estimates of radiation exposure experienced by participants in Operation Crossroads. If any of the several actions that GAO recommends be taken to adjust the estimates proves infeasible, the DNA should document the reasons for each such determination so the military services can provide this information to the Veterans Administration (VA) and the affected veterans.

GAO also recommends that the Secretary of Defense direct the Defense Nuclear Agency, in implementing its new standards for reporting radiation exposure estimates to the VA, to not only require the military services to disclose the error range associated with reconstructed exposure estimates but also require them to disclose the error range associated with film badge readings.

The VA has no objections to the reporting of dose estimates with error ranges. It has been the VA's policy to presume that a veteran was exposed to the highest level of any radiation dose range reported for that veteran by DNA. This policy is consistent with our current rule on resolving reasonable doubt in favor of claimants.

It does appear that service personnel were exposed to more radiation during the course of Operation Crossroads and the subsequent cleanup than they would have been after safety precautions were better developed and used as in later trials. While GAO recommends revised methods of calculating radiation exposure levels for Crossroads participants, it appears that this new methodology should also be applied to participants in all atmospheric nuclear tests. These new calculations would almost certainly result in reports of higher levels of radiation exposure and could require reevaluation of previously denied claims. In this regard, it is imperative that any dose assessment calculated under the new methodology be reported to the VA if dose information had previously been reported in connection with a claim for veterans' benefits.

2.

Mr. Richard L. Fogel

All previously denied claims for which a new radiation exposure estimate becomes available would have to be reconsidered on the basis of new and material evidence and under the regulations promulgated pursuant to Public Law 98-542. Reconsideration would not require a reopened claim because the new evidence would already be in the Government's possession.

At this time, we cannot be certain whether changes in radiation dose estimates resulting from recommendations in the draft report would require reversal of VA decisions regarding service-connection of disabilities allegedly resulting from radiation exposure. For example, even a two- or three-fold increase in an initially small radiation dose estimate would likely be of little significance in the VA's adjudication of a claim dependent upon that estimate. Increases of such a magnitude could have greater importance where a substantial radiation dose was initially estimated.

Thank you for the opportunity to review the draft report.

Sincerely,

Deputy Administrator For

HARRY N. WALTERS
Administrator

Advance Comments From the Department of Defense

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

RESEARCH AND ENGINEERING

THE UNDER SECRETARY OF DEFENSE

WASHINGTON, DC 20301-3010

23 AUG 1985

Mr. Frank C. Conahan
Director, National Security & International Affairs Division
United States General Accounting Office
411 G Street, NW
Washington, D. C. 20548

Dear Mr. Conahan:

This letter is the Department of Defense (DoD) response to the General Accounting Office (GAO) Draft Report, "Improvements Needed in Estimating Personnel Radiation Exposures from the 1946 Nuclear Test - Operation CROSSROADS" dated July 10, 1985 (GAO Code 301675), OSD Case 6797.

At CROSSROADS, the radiation exposures were low. Of the 42,000 participants in CROSSROADS, approximately 7,500 men were not exposed to any radiation at all. The average exposure to the 42,000 CROSSROADS personnel was about 0.390 rem. To put this in perspective, the current standard for annual occupational exposure is 5.0 rem, the current standard for annual exposure to the general public is 0.5 rem and the exposure we all receive each year from natural background radiation is 0.1 rem at sea level and 0.2 rem at higher altitudes such as Denver, Colorado.

See comment 1.

Adoption of all of the GAO recommendations would increase the DNA estimates, according to preliminary calculations, by only 10% of the average dose. Such increases would still result in extremely low radiation exposures. Nevertheless, DoD generally non-concurs with the draft report, disagreeing with most of the findings and recommendations.

See comment 2.

The CROSSROADS radiological safety program was performed in a scientifically responsible manner by the recognized experts of the time. Further, the DoD has estimated exposures in a responsible manner, intentionally overestimating individual exposures in cases where there are uncertainties.

See comment 3.

Two of the primary GAO recommendations were addressed by DoD prior to the initiation of the GAO review. First, in 1983 DoD began research on the accuracy of the film badges, dosimeters and radiac devices used at all of the atmospheric nuclear tests. The results will be published in a report scheduled for release in late 1985.

Frank C. Conahan

Second, since 1979, all DoD published dose reconstructions have provided uncertainty analysis around the most probable dose. These dose reconstructions are currently being reviewed by the National Academy of Sciences for accuracy. The eleven publications are applicable to approximately 100,000 men. All are available for public purchase, and complimentary copies have been provided to the Veterans Administration to aid in the adjudication of compensation claims.

Detailed comments are set forth in the enclosure. Thank you for the opportunity to comment on the draft report.

Sincerely,

DONALD A. HICKS

Enclosure
as stated

GAO DRAFT REPORT - DATED JULY 10, 1985
(GAO CODE 301675) - OSD CASE 6797

"IMPROVEMENTS NEEDED IN ESTIMATING PERSONNEL RADIATION EXPOSURES FROM THE 1946 NUCLEAR TEST--OPERATION CROSSROADS"

DEPARTMENT OF DEFENSE COMMENTS

FINDINGS

FINDING A: CROSSROADS Film Badges Provided Only An Approximate Estimate of Gamma Radiation Exposure. The GAO reported that the 1946 atmospheric nuclear weapons test, known as Operation CROSSROADS, consisted of two nuclear bomb detonations within the Bikini Island lagoon in the Pacific Ocean. After each detonation, a joint task force of Army and Navy personnel and scientists entered the lagoon and examined the damage to, and radiation intensities on, target ships. Film badges were worn by CROSSROADS participants to detect radiation. GAO noted that film badges are widely used because they are small, light, provide a permanent record of exposure amount and have no complicated circuits. GAO further noted, however, that according to available technical literature, there are also drawbacks to the film badges--citing inaccuracies in the ability, or sensitivity, of the film to measure radiation and in the processing of the film itself--unless processing conditions are carefully controlled. The GAO found, however, that in its radiation exposure estimates, the Defense Nuclear Agency (DNA) has not recognized inaccuracies attributable to film badges or its processing for the film badges worn at Operation CROSSROADS. GAO reported that DNA has assigned film badges an overall accuracy of approximately ±30 percent, which does not consider the film badge processing accuracy. The GAO also found that the film used at Operation CROSSROADS was intended to measure gamma radiation between 0.05 to 2.0 rem of radiation, and at the low end of the range was probably accurate within ±100 percent. In addition, GAO reported that during the months of July and August 1946, 6,790 film badges were assigned 0 readings. Given the reported inaccuracy of the film, GAO concluded that any of these badges might have been exposed to as much as .1 rem of radiation--an overexposure based on CROSSROADS radiological safety standards. GAO reported that nine CROSSROADS participants wore film badges that had reached the maximum of 2.0 rem, and DNA assigned each of those nine individuals a 2.0 rem external gamma radiation dose, even though it is possible they received a much higher dose of radiation. The GAO concluded that the film badges used at Operation CROSSROADS provided only an

ENCLOSURE

Now on p. 3, pp.21-26, and pp. 52-53.

approximate estimate of gamma radiation exposure. Noting CROSSROADS dosimetry was conducted almost 40 years ago under harsh field conditions, GAO further concluded that it is unlikely those results were more accurate than the more recent test results obtained under controlled conditions (pp. iii-iv, pp. 16-36, 55-57, GAO Draft Report).

See comment 4.

DoD Position: DoD non-concurs. While some of the facts cited by GAO concerning CROSSROADS film badges are accurate, they are not complete and do not support the conclusions drawn by GAO. All film badges have the potential for inaccuracies. There are five possible sources of error--emulsion, calibration, environment, processing and densitometer reading. GAO specifically cited dosimetry studies in the mid-1950's and applied the largest uncertainty associated with these studies to CROSSROADS. After comparing all the possible sources of uncertainties in the mid-1950's film badge tests with the CROSSROADS film badge procedures, it is the DoD position that the CROSSROADS film badge procedures were far superior. (A detailed discussion and comparison is shown below). Moreover, DoD does not agree with the GAO conclusion that all zero rem recorded doses could have been 0.1 rem, since a reevaluation of the original film badge readings shows that the zero rem exposures were truly zero. There is documented evidence that CROSSROADS film badges read and recorded as low as 0.01 rem, not the 0.05 rem figure quoted by GAO.

See comment 5.

Since December, 1983, DNA has been preparing a report and an associated fact sheet addressing error ranges of film badges used in atmospheric nuclear testing. When published later this year the report and fact sheet will be available to the general public and will be used in responding to Veteran's Administration (VA) inquiries. Scheduled for release in late 1985, the current draft of the report shows that CROSSROADS film badges had an uncertainty band of ±30 percent in the exposure range of concern (above 0.1 rem), with most of the uncertainties causing overestimations of the true dose. The draft indicates that in extremely low doses (e.g, 0.02 rem), the percentage uncertainty could be as high as ±100 percent. However the effect of the uncertainty is not significant since the dose is so low. For example, a CROSSROADS film badge reading of 0.020 rem could be subject to an uncertainty of 0.020 rem or 100 percent. But a film badge reading of 1.000 rem which is subject to an uncertainty 0.020 rem results in an uncertainty of only 2 percent.

See comment 6.

See comment 7.

Film Badge Uncertainties.

As indicated above, film badge uncertainties may be broken down into five categories--film emulsion, calibration, environment, processing, and densitometer readings. These are described below:

See comment 8.

o The emulsion on each film may vary from prescribed standards, and this may cause uncertainties. This source of uncertainty can be minimized by exposing some film in each batch to a radiation source of a known amount, developing the film, matching the developed film with the known source, and determining the variation. This was done at CROSSROADS.

See comment 9.

o Calibration uncertainties can occur when the processor is uncertain what kind of energy spectrum the film was exposed to (as was the case in the GAO example). If, however, the processor knows what energy spectrum to expect, he can properly calibrate his film and equipment. This was done at CROSSROADS.

See comment 10.

o The environmental effects of heat, light and humidity can damage the film and cause uncertainties. This is why film is stored in refrigerators when not in use. When the film is worn however, it may be exposed to environmental effects. Normally, the film is wrapped in plastic or similar protection to reduce effects of the light, heat, and humidity. These precautions were taken at CROSSROADS.

See comment 11.

o The various processing steps, particularly the temperature of the processing fluids, can also lead to uncertainties. Effective controls can be set up to reduce these uncertainties to almost zero. Effective controls were set up at CROSSROADS.

See comment 12.

o Finally, after the film has been developed, the net density on the film is compared to known densities by using a device called a densitometer. Some variance of the net density may occur within each film, therefore uncertainties may occur if only one section of the film is compared to the known densities on the densitometer. Eight areas of each film were compared at CROSSROADS.

GAO cites the laboratory dosimetry tests conducted in the mid-1950's and points out that in some cases uncertainty reached 100 percent. In reviewing the GAO referenced tests, the majority of these uncertainties occurred in the areas of film emulsion and calibration. No unexposed films were provided to conduct emulsion tests. Nor, apparently, was any information provided on the energy spectrum for calibration. The films were exposed under controlled conditions; thus no environmental damage occurred. The processing and densitometer uncertainties are unknown. Thus, it is not surprising that some of the laboratories, working without any calibration or film emulsion information produced uncertainties of up to $\pm$100 percent.

At CROSSROADS, on the other hand, highly detailed procedures were set up to reduce film badge uncertainties. A report by the Chief of the Photodosimetry Section (an expert in his field)

See comment 13.

documents each step in the process. The report states that film emulsion was checked frequently within each batch. Test films were exposed for varying lengths of time to a known source, a small amount of radium, which was set up to eliminate radiation scattering back to the film. According to the report, the film emulsion checks reduced this type of uncertainty to less than ±20 percent.

As noted above, the CROSSROADS film was calibrated using radium. All net optical density under the lead filters of the film badge was assumed to be caused by gamma radiation. This calibration accurately accounted for the high energy photons which constituted the great majority of the exposure from fission products at CROSSROADS. The low energy photons were an insignificant part of the energy spectrum so it was not necessary to calibrate for them. When film calibrated to a high energy spectrum is exposed to low energy radiation there is an over response, which leads to an overestimate of the true dose. Thus, any calibration uncertainties at CROSSROADS related to energy spectrums resulted in the overestimation of the low energy portion of the gamma exposure.

See comment 6.

Film actually exposed to the heat and humidity at CROSSROADS would almost certainly overestimate the true exposure. Environmental damage to film in a hot and humid situation virtually always increases the film's net optical density just as if there were a radiation exposure. It is theoretically possible that the reverse could happen, in situations when very high humidity is present for extended periods without condensation forming on the film. However, this is extremely unlikely. The harsh field conditions noted in the GAO report could only apply while the film was worn because film processing and storage was accomplished under environmentally controlled conditions. The effect of these harsh conditions (i.e., the heat and humidity while the film was worn) would be an overestimation of the dose, not an underestimation.

See comment 6.

The processing of CROSSROADS film is well documented in the Chief of Photodosimetry Section's report. He details how the film was immersed in developer and a timing clock was started at the same moment. After exactly four minutes, the film was withdrawn from the solution and immediately rinsed in distilled water. The developer solution was kept at 68° Farenheit with less than one degree variance. There were no harsh conditions with respect to film processing. In fact, the laboratory was intentionally located on an air conditioned ship with suitable shielding from radiation so as to avoid any damage to the film. Movies of this process document that the laboratory and equipment were state-of-the-art. The personnel employed in the photodosimetry section were experts in their field. The film processing was very good by today's standards. Therefore, uncertainties in processing at CROSSROADS were minimal.

See comment 14

See comment 12.

At CROSSROADS, the personnel working with the densitometer checked eight sections of each film. The readings were compared before determining the final dose in order to ensure accuracy. Any unusual readings were rechecked. This process severely limited any densitometer uncertainties.

In summary, the CROSSROADS photodosimetry section avoided many of the uncertainties which occurred in the blind dosimetry tests conducted in the mid-1950's. Therefore, it is not valid to associate the worst result of the laboratory tests in the mid-1950's with CROSSROADS activities. A comparison of these uncertainties is listed below:

TYPE AND MAGNITUDE OF FILM BADGE ERRORS

(+ indicates the effect will cause the film badge reading to be higher than the actual dose)

FILM EMULSION	CALIBRATION	ENVIRONMENTAL DAMAGE	PROCESSING	DENSITOMETER READINGS
1950's Laboratory Tests				
± Large	± Large	none	unknown	unknown
CROSSROADS				
± 20%	+ minimal	+ limited	± minimal	± minimal

See comments 8 to 13.

Film Badges With Zero Rem Readings.

According to GAO, the film badges at CROSSROADS could not record exposures below 0.05 rem, and the 6,790 film badges with zero rem readings could be as high as 0.100 rem. In fact, 0.05 rem was not the minimum level of detection on CROSSROADS film. Rather, it was the minimum level in which a high degree of accuracy could be associated with the film. At CROSSROADS, many films were recorded in the 0.01 to 0.04 rem range. A random check of 300 recorded CROSSROADS film badge exposures showed 41 of them had exposures in the 0.01 to 0.04 rem range. A breakdown of these 41 exposures is as follows:

DOSE	0.01Rem	0.02Rem	0.03Rem	0.04Rem
NUMBER	6	12	9	14

See comment 5

It is true that in these extremely low ranges the recorded exposures are only approximations of the true dose. However, it is also clear that a specific effort was made to distinguish between low exposures and zero exposures. In addition, a review of the CROSSROADS densitometer readings shows that the recorded zero rem readings were, in fact, zero readings. Therefore, it would be wrong to elevate all zero exposures to 0.05 or 0.1 rem. Moreover, such a policy would be contrary to the practice of the health physics profession. All zero rem recorded doses are always reported as zero.

2.0 Rem Readings

Nine of the 10,431 CROSSROADS film badges showed readings of greater than 2.0 rem, the maximum recorded dose at CROSSROADS. DoD investigated each of these exposures and found that six of them are suspect and the personnel probably received significantly less than the 2.0 rem exposure for various reasons. For example, one film badge was issued at random to a stewards mate with no record of entering a radioactive environment. It is possible that his film badge was damaged by the heat and humidity from one of the ovens or dishwashers he worked near, resulting in an overestimate of the true dose. Despite the fact that six of the nine 2.0 rem film badges were questionable, DoD reported all nine readings as 2.0 rem exposures. If any of these men file a Veteran Administration claim, DoD will perform a dose reconstruction, using information supplied by the veteran, to provide the best possible assessment of the true exposure.

FINDING B: Personnel Decontamination Procedures Seemed To Evolve At Operation CROSSROADS. The GAO reported that a joint task force attempted to establish personnel decontamination procedures that would minimize both the spread of radioactivity and the potential personnel exposure to it. The GAO found that because DNA believed that these decontamination procedures adequately protected CROSSROADS personnel from the beginning, its radiation estimates do not recognize the possibility that individuals retained radioactivity on their bodies or their clothes upon their return from work on target ships. The GAO further found that procedures seemed to evolve at Operation CROSSROADS from a very simplistic approach to radiation protection, to comprehensive personnel decontamination procedures that were not instituted until more than two weeks after the second nuclear test. For instance, prior to July 31, 1946--6 days after the second test--there is no evidence that personnel were required to take a shower or change clothes after boarding contaminated target ships. The GAO also found that even after comprehensive decontamination procedures were instituted, some violations of safety precautions were reported. (The GAO noted that at Kwajalein Island, the senior radiation safety monitor alleged a general breakdown in radiation safety precautions.) The GAO concluded that the absence of comprehensive decontamination procedures from the beginning of Operation CROSSROADS, or by such procedures being violated, has resulted in participants being exposed to radiation that has not been accounted for by DNA and recorded on the film badges they sometimes wore (p. v, pp. 25-34, 57-58, GAO Draft Report).

Now on pp. 3-4, pp. 26-34, and pp. 53-54.

DoD Position: DoD partially concurs. While some of the facts presented by GAO are accurate, it is the DoD position that their potential impact is significantly overstated.

The GAO report states that decontamination procedures were not in effect until July 31, 1946, and implies that as a result, the entire task force was contaminated. In reality, few participants (less than 1 percent) had the potential to be contaminated prior to July 31, 1946. This is because no local fallout resulted from the ABLE detonation on July 1, 1946. Following Test BAKER on July 25, 1946, no one conducted any decontamination work on the target ships until after the July 31, 1946 regulations were in effect. Even after this date fewer than 22 percent of the 42,000 man task force had any involvement in decontamination work.

See comment 15.

Test ABLE was an airburst which produced no fallout over the lagoon, target array, or support fleet. The only residual contamination was the result of the initial neutron activation. Since the low-level shipboard radiation was integral to the target ship materiel and did not involve deposition of loose fission products on surfaces, there was no possibility of contamination or internal exposure to the personnel. Thus personnel decontamination was not required for Test ABLE.

See comment 16.

See comment 17.

Following Test BAKER, the base surge from the underwater detonation spread contamination over 72 of the 92 target vessels and the nearby lagoon water. Because of this, prior to July 31, 1946, only small boarding teams and some technical personnel were allowed to board some of the 72 contaminated target vessels for short periods of time. (Boarding was permitted on eight of the 20 target vessels which were not in the base surge.)

See comment 18.

The degree of contamination was not unexpected, but the difficulty of removing the contamination from the ships was unanticipated. The initial boarding teams consisted of 86 men divided into small units, specially equipped and trained in the hazards of reboarding the target vessels. About 12 percent of this group consisted of radiation monitors, whose job was to ensure that personnel did not receive an exposure in excess of 0.1 R per day. The teams reboarded* some of the target vessels to recover test objects and instruments. There is photographic evidence to prove that they wore disposable clothing (gloves, booties, etc.) to prevent self contamination and the tracking of contamination back to their support ships.

See comment 19.

Although the GAO report implies otherwise, personnel decontamination was by no means a new procedure in 1946. For example, the Chief of the Radiological Safety Section at CROSSROADS established personnel decontamination procedures in the early days of the Manhattan Project at Oak Ridge. Technical personnel from Oak Ridge and other Manhattan Project laboratories were well experienced in personnel decontamination. Moreover, the members of the radiation safety team were highly qualified scientists and physicians who were trained in protecting personnel from radiation hazards.

See comment 20.

Personnel Decontamination Procedures.

The first specific guidelines for personnel decontamination were issued on July 30, 1946 (rather than the July 31, 1946 memorandum cited by GAO) to all personnel in Task Group 1.1, the Technical Group at CROSSROADS. These were the only CROSSROADS personnel (beside the initial boarding teams of 86 men) who went aboard the contaminated vessels or handled recovered instruments prior to July 31. The memorandum contained guidelines for each boarding team and for personnel working on recovered instruments. These instructions were in addition to the standing Operation Orders on the avoidance of

*Reboarding refers to a short stay aboard a target vessel. The length of stay depended on the level of residual radiation. The time aboard was predetermined by a radiological monitor so as to keep exposures below 0.1 rem per day. The target vessel crews were berthed aboard support ships while the levels of radiation on the target ships were too high. If the intensity of the radiation dropped to safe levels, the vessels could be remanned for regular duty.

See comment 21.

radiological exposure. The July 30, 1946, memorandum required any man who had any possible radiation exposure to turn in his shoes and clothing every day. Showers were also required for anyone handling contaminated objects.

On July 31, 1946, a memorandum was distributed regarding decontamination procedures. This memorandum, referred to in the GAO report, was sent to all target ship crews--the men who actually conducted the decontamination--defining precautions to prevent possible exposure to radiation when reboarding the target ships, and personnel decontamination procedures when they returned to the support ship at the end of their shift. The procedures required the personnel, (1) to be fully clothed at all times, (2) to store K-rations and water in spaces free of contamination, (3) to remove and launder all clothing upon returning to the support ship, and (4) to shower upon return to ship.

See comment 22.

It must be underscored that only a small portion of the task force was involved in decontamination, and that this work did not begin until after the July 31, 1946 guidelines were issued. Nor were all the target vessels boarded for decontamination. A review of Navy records shows that only 37 of the 72 target vessels caught in the base surge were reboarded for even potential decontamination.

See comment 23.

According to the notes of the Chief of Radiological Safety Section, large scale decontamination efforts took place aboard the target vessels only from August 6-10, 1946, with no more than 2,000 men involved on any one day. These men operated from only a few ships.

See comment 17.

Eight of the 20 target vessels which were not enveloped by the base surge, and thus did not require decontamination, were reboarded prior to July 31, 1946. Of the 72 target vessels caught in the base surge, only 37 were reboarded by their crews for decontamination, and none prior to August 1, 1946. The schedule for the 37 target ships initially boarded by their crews for either short term inspection or decontamination is:

DATE	AUG 1	AUG 2	AUG 3	AUG 4
Ships	4	3	1	2
DATE	AUG 5	AUG 6	AUG 7	AUG 8
Ships	2	0	5	1
DATE	AUG 9	AUG 10	AUG 11	AUG 12
Ships	5	4	0	2
DATE	AUG 13	AUG 18	AUG 21	SEP 4
Ships	5	1	1	1

Each day, upon returning from the target vessels to the support ships, the decontamination crews were required to change and launder their clothes and shower. Documents dated August 3, 1946 show that these procedures produced a severe drain on the ships' fresh water supply. As early as August 3, 1946, the Medical-Legal Board indicated the need for decontamination way-stations. The Board also recognized that special laundry procedures were necessary for clothing too badly contaminated to be salvaged. It was stated that there should be a provision for keeping the regular clothing in a clean portion of the station ship and segregating the contaminated clothing in another area. These concerns were identified prior to the beginning of any large scale target vessel boarding, and would have precluded any significant cross contamination of spaces and personnel returning from the target vessels to the support ships. There is photographic evidence that the recommendations of the Medical-Legal Board were implemented. The standards for clearance were promulgated by CTG 1.2 and are listed below:

See comment 24.

a. Clothes showing 0.01 to 0.1 R/day (gamma) were ordered laundered.

b. Clothes above 0.1 R/day were automatically thrown away, unless a special laundry with remeasurement was available.

c. Shoes showing 0.5 R to 1.0 R/day (beta plus gamma) were ordered scrubbed.

See comment 25.

d. Shoes showing over 2.0 R/day (beta plus gamma) were automatically thrown away, except where special monitoring after scrubbing was available.

According to the Chairman of the Medical-Legal Board (who served as the senior advisor to the Chief of the Radiation Safety Section), no person was found perceptibly contaminated on his body. Occassionally, hands showed beta activity and were ordered scrubbed with soap and water.

See comment 26.

A special survey of support ships (where the target crews were berthed) conducted prior to August 6, 1946, found that "except for a few isolated cases, no physical hazard could be expected from this contamination." Air samples showed no alpha, beta, or gamma radiation. There was no evidence of inhalation or ingestion of radionuclides. The mess halls and galleys were free of contamination. However, based on the standards in effect, some of the personnel and their clothes were contaminated (by probably less than 0.01 rem per day), and permanent monitors were established aboard each ship to set up a system of monitoring and decontamination. The only source of general contamination was from personnel with residual contamination after washing their clothes

See comment 27.

and showering. This level of radiation was slight but was sufficient to be registered on geiger counters. To reduce the spread of the low-level contamination, a system was set up on August 6, 1946, the date when large scale decontamination commenced.

See comment 28.

In summary, the potential contamination cited by GAO is minimal. The dose from residual contamination, after showering and laundering, is very slight, at most 0.01 rem per day; limited to target vessel boarding teams and technical personnel (about 21 percent of all CROSSROADS personnel), and could have occurred only during a few days in early August 1946. As pointed out to GAO, all CROSSROADS dose reconstructions and assignments were intentionally overestimated by approximately 50 percent by DoD. This was done to account for various uncertainties such as the one cited by GAO. The result is that the DoD exposure estimates more than compensate for such uncertainties.

See comment 2.

Safety Violations.

The safety violations cited in the GAO report occurred over 200 miles from Bikini at Kwajalein Atoll, seven months after CROSSROADS. It involved about 200 personnel who were engaged in target ship security detail activities. The senior radiological monitor for the 200 men at Kwajalein was a recently trained Navy Ensign, who did not participate in CROSSROADS. The hundreds of CROSSROADS scientists and radiological monitors, who had ensured personnel safety in 1946, had since departed from the Marshall Islands. An inquiry conducted in May 1947 by scientists who had served at CROSSROADS as the Safety Officer, the Chief of the Radiological Safety Section, and a Senior Monitor concluded that the violations cited by GAO occurred only after March 1947. Thus, these violations in the spring of 1947, should not be associated with activities that occurred in the summer of 1946.

See comment 29.

FINDING C: Internal Alpha And Beta Radiation Exposure Has Not Been Fully Investigated. The GAO reported that film badges used at Operation CROSSROADS were incapable of measuring for internal alpha and beta radiation; therefore, DNA performed a dose assessment for these radiation exposures. The GAO found that in its report entitled, "Internal Dose Assessment--Operation CROSSROADS," DNA only analyzed the possibility that CROSSROADS personnel inhaled radioactive materiels, and used a constant alpha-beta-gamma ratio. GAO reported that subsequent information indicated that the alpha-beta-gamma ratio was not constant, and may have underestimated alpha radiation by a factor of 5 or even 10. The GAO further found that, although there was evidence to suggest eating of food was permitted aboard target ships for a period of time, DNA did not consider the possibility of ingestion of radioactive materiels. GAO reported that DNA officials admitted ingestion could have occurred, and at GAO's request the DNA contractor that prepared the internal dose assessment report calculated that for one day (using a constant alpha-beta-gamma ratio), a crew member would have received less than 2 percent of the annual recommended internal dose limits. The GAO observed that if a crew member had received 2 percent of the annual dose limit in a day, based on a constant alpha-beta-gamma ration--which could be in error by a factor of 10--this crew member could have received 20 percent of his annual dose limit in a day. The GAO also found that possible internal radiation exposure by cuts or open wounds was not discussed in the dose assessment report and it was not until about five weeks after the second test that personnel were advised that no one with open wounds not securely covered and protected by bandages, would be permitted to perform work on target ships. The GAO concluded that the initial absence of such a procedure could have increased the risk of an individual's intake of radioactive materiels. The GAO further concluded that without an analysis of all three exposure pathways, which recognizes possible errors or uncertainties associated with that analysis, any estimate of internal radiation exposure for Operation CROSSROADS may be understated (PP. 34-42, 58, GAO Draft Report).

Now on p. 4, pp. 35-41, and p. 54.

DoD Position: DoD non-concurs. The GAO findings are based on incorrect assumptions. Specifically:

1. GAO misinterpreted a document concerning the alpha-beta-gamma ratio for USS ROCKBRIDGE.

2. The scenarios suggested by GAO for possible ingestion dose prove to be less than the DoD worst case reconstruction (which resulted in an exposure of 0.0014 rem to the bone).

3. Open wounds capable of causing of internal exposure received prompt medical treatment. At CROSSROADS smaller wounds could not cause a biologically significant exposure.

See comment 30.

Alpha-beta-gamma ratio.

GAO misinterpreted a document and suggested that the alpha-beta-gamma ratio could be in error by a factor of five to ten. In fact, the document cited by GAO (concerning USS ROCKBRIDGE) does not address the alpha-beta-gamma ratio. Rather, it deals with the difficulty in estimating the plutonuim levels (plutonuim is primarily an alpha emitter) based on geiger counter readings. The X-263 geiger counter, cited in the document, was incapable of measuring alpha radiation. It was, however, capable of measuring beta and gamma (fission product) radiation. The author of the document was attempting to use the beta and gamma readings as a rough indication of the alpha/plutonium levels. The author had consulted a radiochemical analysis of the contamination on the USS ROCKBRIDGE. This provided the author with an exact count of the plutonium and fission product levels as of October 15, 1946. Therefore, measuring the fission product levels with the X-263 and knowing the fission product to plutonium ratio from the radiochemical analysis allowed, in principle, quick estimation of plutonium levels. In short, the author was discussing the errors in quickly estimating plutonium levels based on gamma and beta readings at late times, without using the time consuming radiochemical analysis.

The author's memorandum makes it clear he could not use this technique because the gamma and beta levels on the ship had decayed to such extremely low levels that the X-263 could not accurately record them. According to the author, "It would appear that the use of the X-263 readings to measure the plutonium contamination by means of a predetermined conversion factor is becoming increasingly difficult and open to question." Relying on the the low gamma readings could produce an error of five to ten from the plutonium levels derived from radiochemical analysis. This gamma reading error factor was misinterpreted by GAO to mean that the alpha-beta-gamma ratio could have varied by a factor of five to ten. In short, the ROCKBRIDGE report cites an error factor of five to ten when trying to estimate plutonium levels using extremely low gamma and beta geiger counter readings. It was not, as GAO suggested, an error factor of five to ten in the alpha-beta-gamma ratio.

The alpha-beta-gamma ratio derived in the DoD model was based on radiochemical analysis, not geiger counter survey readings. The analysis was performed by a Los Alamos scientist prior to September 6, 1946. The scientist used samples taken from CROSSROADS target and support ships. The results showed that the alpha-beta-gamma ratio was quite uniform throughout the various ships. This data is in complete agreement with the radiochemical analysis of the ROCKBRIDGE, performed on October 15, 1946.

In summary, the ROCKBRIDGE report cited by GAO referred to the feasibility of estimating plutonium levels from geiger counter readings; and not with the variance in the alpha-beta-gamma ratio as GAO suggested. The problems encountered in the ROCKBRIDGE report do not affect the DoD model used for the inhalation studies, since DoD did not use any geiger counter readings in the model. Rather, DoD relied on radiochemical analysis data to develop its model. A comparison of the radiochemical data used by DoD for its model with the radiochemical data in the report cited by GAO verifies the correctness of the ratio used by DoD when radiological decay is properly accounted for.

INGESTION

The internal dose for ingestion was calculated in December 1984. For the reasons stated before, DoD used the correct alpha-beta-gamma ratio. The worst case reconstruction is for an engineering team aboard the USS NEW YORK on August 8, 1946. This team was selected because they were the group aboard a major target vessel for the longest period of time while it was still relatively highly contaminated. On the date in the reconstruction (August 8, 1946), four separate boarding teams came aboard for two hours each. All boarding team personnel (execpt the engineering section) ate breakfast and dinner aboard the support ship on which they were berthed. One of the teams could possibly have had lunch aboard the ship.

The engineering team in the dose reconstruction was aboard the NEW YORK for 16 hours on August 8, 1946. They were working below decks in an area of low-level radiation, as compared to the boarding teams which probably worked topside in the areas of the highest radiation. The engineering crews operated below decks for 16 hours and still avoided exceeding the 0.1 rem external limit. However, because of their stay time they had one of the few opportunities to eat three meals aboard a contaminated target vessel.

The food they consumed was not contaminated. The K-Rations and water were sealed and stored in an area free of contamination. Therefore the only possible way ingestion could have occured would be from transferring contaminants from the sailor's hands to his mouth. To maximize this dose, we assumed that during his meal the sailor ate topside (which wasn't standard operating procedure), placed his hand on a highly contaminated spot, transferred 1 percent of the contaminants to his hand (the contamination could not be removed easily), and then proceeded to lick all the contaminants from his hand. Using this scenario for three meals, it was determined that the 50 year dose total was approximately 0.0014 rem to the bone, or less than 0.01 percent of the NCRP Guidelines. The dose to all internal organs is approximately 2 percent of the NCRP guidelines.

Any other situation would produce a lower dose since the other ships in question had less contamination, or the sailors were not on board long enough to eat a meal. Also, it would be improper to simply extrapolate this worst case over a series of boardings since the NEW YORK was boarded only on a few days and the rate of decay would decrease the dose. Further, it is unlikely that the sailor licked his hand clean after every meal.

GAO speculated that a remanned target ship, which had a maximum readings of 0.65 rem per day on August 15, 1946 might have produced a higher ingestion dose. The ship alluded to was the USS PARCHE, a submarine which was not remanned until August 22, 1946 (the ship was reboarded on August 15 for 5-6 hours, which meant that a man standing on the most contaminated spot for 6 hours would receive a dose to mid-line tissue of 0.114 rem, not 0.65 rem as suggested by GAO). Extensive decontamination efforts were conducted on PARCHE prior to remanning. Employing GAO's scenario, DoD assumed that a sailor remanned the PARCHE on August 22, 1946 for his 75 day cruise back to port. During that cruise, DoD assummed that the sailor ate three meals a day at the most contaminated spot in the boat, wiped his hand on the spot, and then licked his hand clean. The effect of eating this way for 75 days produced a dose that was only two-thirds as much as the DoD worst case discussed above.

See comment 31.

In sum, the alpha-beta-gamma ratio suggested by GAO for use in the ingestion model is not applicable, and none of the scenarios suggested by GAO have exceeded the DoD worst case dose estimate for ingestion.

Open Wounds

Doses have not been calculated for open wounds for two reasons. First, documentation exists which shows that contamination of open wounds was not a problem at CROSSROADS. Second, calculations for open wounds have to be provided on a case-by-case basis. DNA has, however, performed a worst case reconstruction which will be discussed later.

In his book, No Place To Hide, Dr. David Bradley discusses the first case of possible open wound contamination at CROSSROADS. On August 24, 1946, thirty days after the last test, a sailor working on a target ship was cut on the hand by a cable which was contaminated. Following the standard practice of the Manhattan Project, high amputation (removal of the arm at the shoulder) was the prescribed course of action for suspected plutonium contamination. Bradley, a medical doctor and radiation monitor, examined and monitored the wound closely and determined that it was free of contaminants. Thus, amputation was avoided.

A second account (although not directly related to CROSSROADS) demonstrates the concern shown in the mid-1940s. The account was found in a document in the collection of the CROSSROADS Chief of Radiological Safety. A man had wounded himself in a laboratory with plutonium contaminated glassware. The wound was cleaned and analyzed. Even if no medical treatment had taken place, the calculated 50 year committed dose from this wound would have been 0.00013 rem to the bone marrow, a truly insignificant dose. With the degree of concern shown for these wounds, it is doubtful that a similar incident could have occurred at CROSSROADS and gone undocumented.

Smaller surface scratches and cuts would not become contaminated because bleeding cleans the wound and the scabbing process removes most of the contaminants. Larger cuts would require attention because of the radiological concerns cited above and because the Marshall Island environment causes such wounds to become infected unless treated promptly.

In the past, DNA has not calculated the internal dose from open wounds since the reconstructions are normally provided for units of men, such as a ship's crew. It would be unrealistic to assume every member of the crew was lacerated by a contaminated object. No Veterans Administration case for CROSSROADS has yet occurred where there was an indication of wound contamination. Should such a case occur a reconstruction for the specific circumstances will be performed. A dose reconstruction for a worst case puncture wound is provided here. It assumes a 1 cm by 0.1 cm puncture wound which transferred 100 percent of all contaminants into the blood stream (in essence, an injection of all the contaminants). This results in an exposure of 0.03 rem to the bone marrow, approximately 0.2 percent of the NCRP Guidelines for exposure to internal organs.

See comment 32.

FINDING D: Estimating External Beta Radiation Exposure At Operation CROSSROADS. In its historical report for Operation CROSSROADS, DNA indicated that recorded beta readings obtained for that operation are of questionable accuracy. GAO found, however, that DNA has not performed a dose reconstruction for external beta radiation but, instead, has simply assigned the recorded beta readings, without change, to those personel wearing film badges, because DNA officials believed that each film badge was fitted with a lead cross that served as a filter. The rationale is that while the lead cross would effectively block beta radiation, it would allow gamma radiation to blacken the film under the cross. On the other hand, the film area outside the lead would be blackened only by beta radiation. Based on information available today, GAO found this rationale was incorrect for the type of film badges used--i.e., gamma radiation would have blackened the film area outside the lead cross as much as the film area under the cross. GAO reported that because of this, DNA believes that any reading of the area outside the lead cross would reflect blackening from both gamma and beta radiation and overestimate the recorded beta dosage. GAO noted, however, that the first 350 test film badges processed during July 1946, indicated that 250 of them were recorded as if the blackening caused by both gamma and beta radiation was less than the blackening caused by gamma radiation alone. GAO, therefore, concluded that beta radiation, for these 250 film badges, may have been underestimated as opposed to the reverse. The GAO further concluded that the presence of beta radiation cannot be ignored because it can affect those organs and glands close to the outer layers of skin and augment damage caused by gamma radiation. The GAO finally concluded that in may cases, personnel exposure to beta radiation may have been underestimated or not estimated at all. (pp. 42-46, 58-59, GAO Draft Report).

Now on p. 3, pp. 41-44, and p. 54-55.

DoD Position: DoD Nonconcurs with all of the GAO conclusions.

At CROSSROADS, film badges contained a single piece of film encased in a lead cross. The lead cross filtered out the beta radiation. The area not under the lead (known as the corners) recorded both beta and gamma radiation. Thus the corners recording both beta and gamma radiation should be darker than under the lead cross which records only gamma radiation. GAO examined 350 CROSSROADS film readings and found that 250 had readings where the area under the lead cross was darker (the reverse of what might be expected). Based on these 350 film badge readings, GAO suggested that the beta radiation was underestimated due to fading. However, film fading occurs only when the badge is worn for several weeks or months. All of the 350 film readings examined by GAO were worn for only one day. Fading could not have occurred in such a short time.

Of the 350 film readings GAO examined, only 6 had any radiation exposure at all. The remaining 344 films had recorded readings of zero rem beta and gamma. The slight darkening on the 250 film readings examined by GAO was obviously not due to radiation. Rather, the darkening under the lead cross was probably caused by heat damage. The lead cross in the film badge can become hot in the tropical environment, and this heat could have "burned" the film slightly, causing it to darken more than the corners. The darkening under the lead cross noted by GAO was very slight and was less than the darkening associated with a radiation exposure of 0.010 rem. Thus, GAO's conclusion that film badges underestimated beta radiation cannot be substantiated by the 350 film readings they examined.

Very few CROSSROADS personnel had any potential for beta radiation exposure. Of the 42,000 participants at Operations CROSSROADS, only the approximately 9,000 persons who worked with the target fleet had any opportunity to receive a beta dose. Decontamination procedures were more than adequate in preventing any significant beta contamination aboard the support fleet.

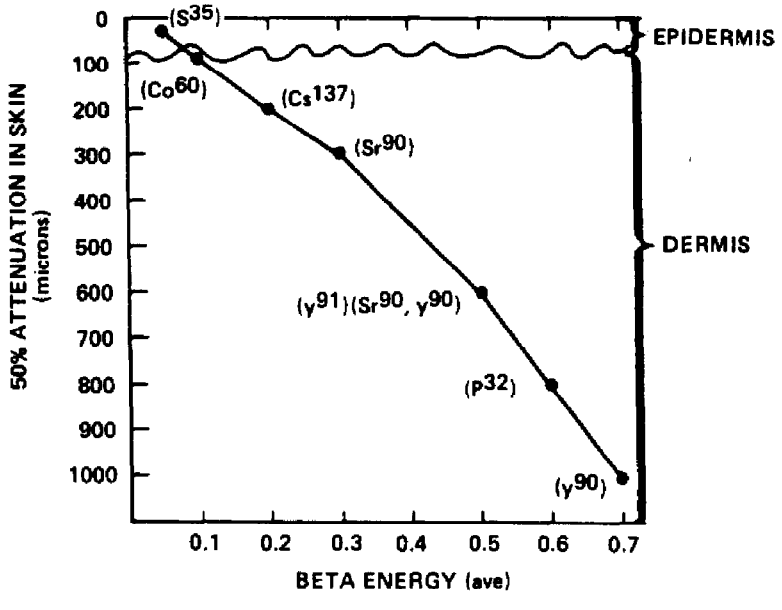
GAO indicates that beta radiation from CROSSROADS could penetrate up to 1.2 cm (one half inch) in body tissue. However, the great majority of beta radiation from fallout cannot penetrate the skin. As seen in the accompanying graph, none of the most significant fission product betas can penetrate the skin, which is about 0.1 cm or 0.04 inch. This lack of penetrating power of the beta radiation means that the gonads and other critical organs are completely protected by clothing and skin. The only way that a beta dose to the eye could occur would be by direct contact of contamination to the eye. This case is very unlikely because of the irritating nature of the contamination from the heavy salt content and the effect of the normal tearing process which flushes material out of contact with the eye.

Finally, there is no evidence to indicate any health effects from an external beta exposure at CROSSROADS. This is because:

1. All external beta radiation exposures at CROSSROADS were low level doses.

2. Studies on people who were exposed to high level beta radiation from fallout have shown that even this group has no long term medical problems attributable to external beta exposures.

3. Current research has shown no long term health effects which can be attributed to external beta radiation exposures.



ATTENUATION IN SKIN OF BETA EMITTING ISOTOPES

External beta radiation from fallout affects only the skin. An external exposure to high levels of beta radiation can cause superficial lesions on the skin along with erythema, commonly known as "beta burns".

Commencing in 1979, DoD began reviewing the medical records of CROSSROADS Navy participants, in order to gather all the relevant medical and personnel information on the veterans. Some of the items the searchers were looking for included medical evidence of radiation exposures, such as "beta burns" and unusual blood counts. After reviewing 35,000 CROSSROADS medical records (98 percent of the Navy participants) there was no evidence of any "beta burns" or any other ailments attributable to radiation exposure. This indicates that CROSSROADS personnel were not exposed to high levels of beta. In the entire 17 year history of atmospheric nuclear testing, there are only 65 known cases of "beta burns" among the 203,000 DoD personnel involved in the tests; these occurred in 1954.

In 1954, several hundred Marshall Islanders were exposed to high levels of radiation from fallout. This fallout was many orders of magnitude greater than found at CROSSROADS. Most of this group did not decontaminate themselves for over 24 hours, and some did not remove the contaminants for several days. Many in this group developed skin lesions and erythema from beta radiation. The skin burns healed quickly, leaving scars on the skin with the worst burns.

The exposed Marshallese have been regularly checked by doctors for any problems. As recently as 1980, the follow-up showed no long term effects from the external beta exposure. Therefore, since CROSSROADS personnel were exposed to only a small fraction of the external beta radiation to which the Marshallese were exposed to it follows that no latent medical problems would result from exposure to beta radiation received at CROSSROADS. It is also worth noting that the available scientific literature does not indicate there are any somatic or genetic effects from a single external exposure to low level beta radiation.

In summary, the evidence demonstrates the following facts.

1. Over 98 percent of the film readings examined by GAO showed radiation exposures of zero rem beta and gamma.

2. Film fading could not have taken place on the CROSSROADS films examined by GAO.

3. Films could have suffered heat damage to the area under the filter, giving a slighty increased darkening under the cross rather than the corners. This is apparently what happened on the 350 films examined by GAO.

4. Only about 9,000 persons had any opportunity to receive a beta exposure.

5. The great majority of fallout beta radiation cannot penetrate more than about 0.1 cm. This makes the beta dose of significance only for the skin.

6. Studies of populations heavily contaminated by fallout have not revealed any long term symptoms from their acute beta exposures.

7. Medical records for CROSSROADS veterans do not indicate any evidence of beta exposure, or any other symptoms attributable to radiation. This indicates that all external beta exposures were low level, which in any case would not cause any long term medical effects.

See comment 33.

FINDING E: The Military Services Have Not Been Required To Disclose Error Ranges Associated With Reconstructed Radiation Exposure Estimates. In the case of service connected claims submitted to VA for potential disability from participation in the atmospheric nuclear weapons testing program, the veteran is asked to identify the particular weapons test, unit, activities and known radiation involved. The VA, in turn, provides this information to the appropriate Military Service and asks (1) for verification and (2) the Service to supply a radiation exposure estimate. The GAO reported that this estimate usually represents the external gamma and beta radiation recorded on the film badges worn and a reconstructed external gamma radiation dose for those times no film badge was worn. The GAO noted that the DNA contractor, responsible for the dose reconstruction report on external gamma radiation, included several uncertainty factors in its model calculations which tended to recognize that certain CROSSROADS radiological data was not precise and should be discussed in terms of an error range, with confidence limits. GAO found that while the Army has used the error range related to the uncertainty factors in reporting reconstructed radiation exposure estimates to the VA, the Navy has not. In addition, GAO found that neither Military Service's radiation exposure estimates reported to the VA recognized the inaccuracies associated with film badge readings. The GAO concluded that with approximately 500 claims presently on file at the VA relating to Operation CROSSROADS, it is important that the reported film badge readings and the reconstructed doses for that operation be factual and as complete as possible. The GAO further concluded that in view of the uncertainties about the CROSSROADS radiological environment, it is reasonable for DNA to require the Military Services to use error ranges, or limits, in reporting reconstructed radiation dose estimates to the VA. (pp. 46-54, 59, GAO Draft Report)

Now on pp. 45-50, and p. 56.

DoD Position: DoD partially concurs. When DoD prepares a major dose reconstruction, such as the one for the Naval personnel at CROSSROADS, it publishes this document and makes it available to the general public. A copy of the basic CROSSROADS dose reconstruction, which included uncertainty bands, was sent to every Veterans Administration Regional Office (VARO) library. A transmittal letter to the VARO Director was sent along with the basic CROSSROADS dose reconstruction. The uncertainty bands and assumptions used in the report have not however, been specifically cited in the 500 DoD responses to VA inquiries on CROSSROADS radiation exposures. Also there was no mention of film badge accuracy in the individual responses. Prior to the GAO investigation, DoD began researching a report on the accuracy of the film badges, dosimeters and radiac devices used at all the atmospheric nuclear tests. This report, scheduled for publication in late 1985, will be distributed to all VARO's. As noted by GAO, DoD published in the Federal Register of May 9, 1985 its proposed guidelines for responding to VA inquiries on radiation claims. DoD indicated it will provide, whenever possible, the uncertainty bands around the most probable dose for the veteran. See DoD response to Recommendation 7.

See comment 34.

Now on p. 67

FINDING F: Allegation Regarding the Collection of Documents once Belonging to the CROSSROADS Radiological Safety Officer Unfounded. The GAO reported that the Federal Bureau of Investigation had conducted an investigation and concluded that there was no substance to the allegation that important CROSSROADS materiel had been removed from the collection of documents once belonging to the late Radiological Safety Officer at CROSSROADS. The GAO further reported that it met with the individual who had made the allegation and learned that the allegation was based, in part, on this individual's expecting, but not being able to find, certain information in the collection of documents in question. The GAO found no evidence to suggest that the information sought had, at anytime, been a part of the collection. The GAO concluded that, given this collection of documents represents only the personal files of one key CROSSROADS participant, it did not expect it to be complete in every respect. (p. 66, GAO Draft Report)

DoD Position: DoD Concurs. The allegation was without foundation.

Now on p. 4, and pp. 55-56.

RECOMMENDATIONS

RECOMMENDATIONS 1: The GAO recommended that the Secretary of Defense direct the Defense Nuclear Agency to adjust, where feasible, the CROSSROADS participants' exposure estimates by assigning some external gamma radiation dose to each film badge reported as reading zero, and developing an error range for each CROSSROADS film badge reading that recognizes film and film processing inaccuracies. (p. 59-60, GAO Draft Report)

DoD Position: DoD partially concurs. DoD will publish, in late 1985, a report addressing the accuracy of the film badges, dosimeters, and radiac devices used during all of the atmospheric nuclear tests. It will be distributed to all Veterans Administration (VA) Regional Offices, and will be available for purchase from the National Technical Information Service. In addition, DoD will develop a summary sheet on film badge accuracy for inclusion in all DoD responses to VA inquiries on this issue. Therefore, it will be unnecessary for the Secretary of Defense to direct such action.

DoD does not, however, intend to assign some external exposure estimate to each CROSSROADS film recorded as zero. As explained in the DoD response to Finding A, such an action would not be logical, since CROSSROADS films were developed and read to as low as 0.010 rem. Moreover, an examination of the densitometer readings for CROSSROADS films shows that all recorded exposures of zero rem were properly recorded as zero rem. In addition, to elevate all zero rem doses to a minimum level would without doubt, lead to an unsupportable overestimation of CROSSROADS doses.

Now on p. 4, and pp. 55-56.

RECOMMENDATIONS 2: The GAO recommended that the Secretary of Defense direct the Defense Nuclear Agency to adjust, where feasible, the CROSSROADS participants' exposure estimates by estimating the extent to which personnel received additional radiation exposure from lack of, or violation of comprehensive decontamination procedures. (p. 60, GAO Draft Report)

DoD Position: DoD non-concurs. As stated in the DoD response to Finding B, there was very little potential radiation exposure that could have been caused by a lack of comprehensive decontamination procedures. DoD has already intentionally overestimated its CROSSROADS dose reconstructions and assignments by approximately 50 percent. This was done specifically to account for uncertainties such as those cited by GAO.

Now on p. 4, and pp. 55-56.

RECOMMENDATIONS 3: The GAO recommended that the Secretary of Defense direct the Defense Nuclear Agency to adjust, where feasible, the CROSSROADS participants' exposure estimates by reevaluating and disclosing the possible errors or uncertainties associated with its analysis of internal radiation exposure by inhalation. (p. 60, GAO Draft Report)

DoD Position: DoD non-concurs. As explained in the DoD response to Finding C, GAO misinterpreted a key point in a memorandum on the USS ROCKBRIDGE. DoD used radiochemical data to develop its model for inhalation of radionuclides. The inhalation model is considered accurate. The DoD report on CROSSROADS inhalation exposure is scheduled for publication later this year. It will be distributed widely, including all Veterans Administration Regional Offices, and will be available for purchase from the National Technical Information Service. Since this report is a worst case calculation, the uncertainties need not be separately reported.

Now on p. 4, and pp. 55-56.

RECOMMENDATIONS 4: The GAO recommended that the Secretary of Defense direct the Defense Nuclear Agency to adjust, where feasible, the CROSSROADS participants' exposure estimates by analyzing possible internal radiation exposure from ingestion or through cuts or open wounds, and assessing those scenarios that offer the greatest opportunity for internal radiation exposure (such as when crews remanned target ships after Operation CROSSROADS). (p. 60, GAO Draft Report)

DoD Position: DoD partially concurs. As discussed in the DoD response to Findings C, DoD has already assessed the worst case for ingestion. This worst case has been calculated and shown to cause a 50 year committed bone dose of 0.0014 rem, approximately 0.01 percent of the National Council of Radiation Protection and Measurements (NCRP) guidelines for exposure to the bone. This worst case dose will be incorporated into the overall internal dose (inhalation and ingestion) that is reported to the Veterans Administration.

It is incorrect to assume that any significant number of people at CROSSROADS were working around contaminated objects with open wounds or were wounded while working with contaminated objects. As stated in the DoD response to Finding C, the opportunity for contamination through open wounds is very limited. There is also documentation to show that no such contamination occurred at CROSSROADS. Only a severe puncture wound has the potential to cause contaminaton in the environment which existed at CROSSROADS. Such a wound would be documented in the veteran's medical record. Nevertheless, if a Veterans Administration claim is submitted which suggests that a wound was contaminated at CROSSROADS, DoD will perform (if feasible) a dose reconstruction based on the information supplied by the veteran and available documentation such as his medical record. Therefore, it will be unnecessary for the Secretary of Defense to direct such actions.

Now on p. 4 and pp. 55-56.

RECOMMENDATIONS 5: The GAO recommended that the Secretary of Defense direct the Defense Nuclear Agency to adjust, where feasible, the CROSSROADS participants' exposure estimates by reassessing the accuracy of the external beta radiation dose information for those CROSSROADS participants who wore film badges and, given that all CROSSROADS participants did not wear film badges, performing a dose reconstruction for external beta radiation. (p. 60, GAO Draft Report)

DoD Position: DoD non-concurs. There are no demonstrated somatic or genetic effects from a single exposure to external low level beta radiation. An acute beta exposure at CROSSROADS would have required medical attention, which would have been entered into the individual's medical record. DoD reviewed 35,000 CROSSROADS medical records and found no reference to symptoms attributable to acute beta radiation effects. If on the other hand, a veteran filing a claim with the Veterans Administration alleges his ailment is attributable to high levels of beta radiation at CROSSROADS, the veteran's medical record will be checked to verify this exposure. If the medical record revealed evidence of treatment for beta radiation exposure, DoD would provide a beta dose reconstruction specifically for that veteran.

Now on p. 4, and pp. 55-56.

RECOMMENDATIONS 6: Where any of the preceding actions has been determined not to be feasible, the GAO recommended that the Secretary of Defense require the Defense Nuclear Agency to document the reasons for each such determination so that the Military Services can provide this information to the Veterans Administration and the affected veterans. (p. 60, GAO Draft Report)

DoD Position: DoD considers these comments, which we understand will be published as part of the final GAO report, to be responsive. A copy of the GAO report, with the DoD response will, in turn, be available to the Veterans Administration. Any affected veterans will also be able to obtain a copy of the report from the GAO.

Now on pp. 55-56.

RECOMMENDATIONS 7. The GAO recommended that the Secretary of Defense direct the Defense Nuclear Agency in implementing its new standards for reporting radiation exposure estimates to the Veterans Administration, to not only require the Military services to disclose the error range associated with reconstructed exposure estimates, but also require them to disclose the error ranges associated with film badge readings. (P. 60, GAO Draft Report)

DoD Position: DoD concurs. As stated previously, DoD has been preparing a report which is scheduled for publication in late 1985. The report addresses the overall accuracy of the film badges, dosimeters, and radiac devices used at all atmospheric nuclear tests. This report will be distributed to all Veterans Administration (VA) Regional Offices, and will be available for purchase at the National Technical Information Service. In addition, in its individual responses to the VA, the DoD will include a summary sheet which will address film badge accuracy and invite the reader to consult the above mentioned report for more detailed information. Therefore, it will be unnecessary for the Secretary of Defense to direct such actions.

The following are GAO's comments on the Under Secretary of Defense For Research and Engineering's letter dated August 23, 1985.

GAO Comments

1. The Department of Defense (DOD) provides no evidence to support its position that adoption of all the GAO recommendations would increase dose estimates by only 10 percent of the average dose. In fact, if information provided by DOD in its comments were used, the percentage increase should be much higher than 10 percent.

For instance, DOD does not dispute our position that film badges provided only an estimate of gamma radiation exposure. What is in dispute is the percentage of error associated with the film badges. DOD believes the percentage error associated with the film is about $\pm$ 30 percent.

DOD also agrees that personnel decontamination procedures evolved at Operation Crossroads. DOD provided us a supporting analysis, however, to show that the radiation exposure from wearing contaminated clothing would not have been significant. That analysis indicated a possible daily exposure dose that is 18 percent of DOD's total calculated average dose for Crossroads personnel.

2. DOD states that its dose estimation (reconstruction) efforts have intentionally overestimated individual doses in cases of uncertainties. (We disclose that in our report.) In DOD's dose reconstruction, a radiological environment was calculated, and the movement of individuals in that environment was determined. In cases where DOD could not establish the precise location for an individual, DOD assumed that individual was in a place to maximize his dose—where he may or may not have been, anyway. (Example: A support ship passes a contaminated target ship. DOD placed each person on the deck of the support ship at that point closest to the target ship.) DOD's assumptions and resulting exposure estimates do compensate for uncertainties regarding movement (or location) of individuals. Such assumptions however, do not compensate for errors associated with (1) calculating the radiological environment, (2) using inaccurate film badges, or (3) wearing contaminated clothing or not promptly showering.

3. We disagree that DOD addressed two of our recommendations prior to the initiation of the GAO review. First, while DOD has been developing a report of the accuracy of film badges, DOD officials told us they are not planning to report the error ranges associated with individual film

badge readings to the Veterans Administration. Therefore, we are recommending that they do so. In addition, since 1979 DOD has published reports of dose reconstruction showing uncertainty analyses (i.e. error ranges) around the most probable dose and has provided copies of the information to the Veterans Administration on a complimentary basis. However, when the Veterans Administration has requested an exposure estimate for a Navy veteran at Operation Crossroads, the Navy has provided only a most probable dose with no error range. (The Army has, however, provided the highest dose in the error range.) In its minimum reporting standards—published for review and comment in the Federal Register on May 9, 1985—DOD now intends to require all military services to report a most probable reconstructed dose with error range. The DNA assistant NTPR program manager told us that our work and congressional interest in this area highlighted a need for this change.

4. Contrary to DOD's statement, we did not apply the largest uncertainties resulting from the two laboratory tests cited in our report to an analysis of Crossroads dosimetry. One test showed several errors between 200 percent and 2,000 percent, and the other test showed that several errors were made in excess of 300 percent. Instead of specifically identifying the largest possible uncertainties, we reported them as part of the error range category of 100 percent or more. Thus, we did not apply the largest uncertainties, as stated by DOD.

5. DOD states that a reevaluation of original film badge readings shows that the zero rem exposures recorded at Crossroads were truly zero. DOD's view is based on zero entries recorded in the film badge ledgers because the films are no longer available. However, in the 1953 laboratory test we reviewed, radiation exposure as high as .1 rem of radiation existed on some of the films that were recorded as having zero exposure. DOD did not provide us any evidence that the same would not have been true for Crossroads. In addition, according to a letter written by DOD's expert consultant on film badge dosimetry to DNA's assistant NTPR program manager dated January 9, 1985,

"it is questionable whether exposures of 40 MR [.04 rem] or less could be reported with any accuracy during Crossroads. Minimum exposures of 40, 30, or even 10 MR [.04, .03, or even .01 rem] can be reported for film badges exposed under laboratory conditions, but these exposures could not be reported accurately with film badges stored, exposed, and processed under the harsh environmental conditions during Crossroads."

Moreover, a report written by the former Chief of the Dosimetry Section at Crossroads stated that the Crossroads film permitted dose measurement only as low as .05 rem.

6. DOD's statement that most of the uncertainties associated with the Crossroads film badges would cause overestimations is not supported by the facts. For instance, DOD contends that film at Crossroads exposed to low-energy of radiation were probably overstated. While we agree that the Crossroads film badges may have overestimated the exposure to low-energy radiation, each of the two laboratory tests that we reviewed indicated that exposure to mixed high- and low-energy radiation levels, as existed at Operation Crossroads, are the most difficult to accurately determine and are generally understated. Specifically, one test showed that 22 of 28 exposures to mixed radiation levels were understated and the other test showed that about 97 of 128 exposures to mixed radiation were understated, and about 40 of the 97 were understated by more than 100 percent.

DOD also contends that environmental damage would overestimate an exposure. Approximately 10,400 film badges were issued during July and August 1946 at Operation Crossroads (Bikini Atoll), but these badges have been lost or destroyed and cannot be rechecked for environmental damage. However, approximately 8,000 film badges were also issued between August 31, and December 31, 1946, at Kwajalein Island—where the Navy offloaded ammunition from contaminated target ships—and these badges are on file at the Reynolds Electrical and Engineering Company in Las Vegas, Nevada. In a sample examination of 137 film badges worn at Kwajalein, the Reynolds Electrical and Engineering Company found that 125 had suffered environmental damage and that 36 of the 125 had been assigned a zero exposure. Thus, for about 29 percent (36 of 125) of the environmentally damaged films, there was no overestimation of exposure dose.

Moreover, DOD states that film badges subjected to high humidity without condensation will result in underestimated doses (see p. 75 of DOD's comments). However, DOD concludes that that did not occur and, therefore, any error associated with environmental damage to the film badges worn would have resulted in overestimating the exposure doses.

Neither we nor DOD knows if the film badges worn at Crossroads were subject to condensation. However, according to a report by the former chief of the Crossroads dosimetry section, the film was packed in several layers of specially prepared paper that was especially resistant to

condensation. Therefore, we believe underestimated exposure doses may have occurred.

7. According to DOD estimates, the Crossroads film, at the 1.0 rem range, was accurate to within only ±25 percent, not the 2 percent DOD cited. (See p. 24.)

8. DOD provided no support to show that film emulsion testing was done at Crossroads but was not done in the two laboratory test studies conducted (see table on p. 76 of DOD's comments). On the basis of available information, the film actually used in the tests was requested from and returned to each respective laboratory tested. According to a dosimetry expert at the U.S. National Bureau of Standards, which conducted the 1953 study, the laboratories in that study had unexposed film to conduct emulsion testing.

9. DOD is incorrect in stating that the energy spectrum was known at Crossroads and thus calibration could be carried out effectively during that operation. In a memorandum dated January 9, 1985, DOD's expert consultant on film badge dosimetry stated that "necessary energy spectrum information [for Crossroads] is not available." In addition, a dosimetry expert at the U.S. National Bureau of Standards told us that the energy spectrum at Crossroads was not known and even now can only be estimated.

10. We agree with DOD that precautions were taken at Crossroads to prevent environmental damage to film. Whether these precautions were successful, however, is unclear. As stated in comment 6, in a sample examination of 137 films worn at Kwajalein, the Reynolds Electrical and Engineering Company found that 125 had suffered environmental damage. Because the type of film badge and facility used to process most of the film badges at Kwajalein Island were the same as that used at Bikini Atoll, it is likely that a representative number of film badges worn at Bikini Atoll may also have experienced environmental damage.

11. DOD states that effective steps for film processing were established at Crossroads. We agree that the proper developing process to be followed was established. However, neither we nor DOD knows whether that process was strictly followed for every batch of Crossroads film processed. We did find evidence that the dosimetry section was losing staff and those remaining often had to work long hours. Specifically, in an August 7, 1946, memorandum to the commander of the joint task force, the radiological safety officer stated that the dosimetry section

consisted of one enlisted man who was capable of processing 100 film badges a day. Moreover, in a 1947 report, the former chief of the dosimetry section acknowledged that the working period in the Crossroads dosimetry section extended "often long after midnight." The combination of a depleted staff working long hours would not have been conducive, in our view, to the strict adherence with established controls.

Conversely, DOD states that the processing controls followed during the two laboratory tests cited in our report are unknown (see table on p. 76 of DOD's comments). While admittedly true— compared with the situation existing at Operation Crossroads— there is no evidence that the laboratories involved in the tests were understaffed or under any constraints to work long hours to complete the tests. Further, since the laboratories in the 1953 test knew they were being tested, it seems likely they would have tried their best to establish and follow effective film processing controls.

12. DOD states that eight areas of each Crossroads film was read under a densitometer and this alleviated densitometer uncertainties. While we agree that Crossroads procedures required dosimetry personnel to compare eight areas of each Crossroads film with a densitometer to ensure accuracy, it is unclear whether that was actually done. For instance, in reviewing the original film badge ledger for the first 350 film badges processed at Crossroads, the ledger shows that 8 areas were read and recorded in the ledger for only 15 of the 350 films. (For the other 335 films, only 2 readings were recorded.) It is possible that the Crossroads personnel reading these 335 other films did compare 8 areas on each film. However, there is no proof of that and the ledger suggests otherwise.

13. The report referenced by DOD consists of excerpts from a lecture given by the former chief of the Crossroads dosimetry section on the subject of photographic dosimetry. This lecture, given approximately 1 year after Operation Crossroads, was a generic discussion of film badge dosimetry with some discussion of what transpired at Crossroads. The lecture does not state that film emulsion checks reduced uncertainties to less than $\pm$ 20 percent at Crossroads. The statement DOD is quoting actually says if film emulsion checks are done, the uncertainty "should be better than plus or minus 20 percent." Also, the lecture does not state that the Crossroads film emulsion was checked frequently within each batch. The lecture actually states "frequent calibrations of the same emulsion will give valuable data on the reliability of the photographic method of dosimetry."

14. DOD states that uncertainties in film processing conditions at Crossroads were minimal because (1) no harsh environmental conditions existed, (2) the laboratory and equipment were state-of-the-art, and (3) the personnel employed in the photodosimetry section were experts in their field.

However, as noted in comment 5, DOD's film badge dosimetry consultant stated that low doses of radiation could not be accurately reported at Crossroads because the film badges used were "stored, exposed, and processed under the harsh environmental conditions during Crossroads." (underscoring added) In addition, DOD states that the Crossroads laboratory equipment was state-of-the-art but indicates (see table on p. 76 of DOD's comments) that processing conditions used during the two laboratory tests were unknown. Given the span of years—from 1946 to the dates of the two laboratory tests—and the evolution that occurred in film badge dosimetry with the development of automated film badge processing techniques, it seems that the laboratory equipment used during the two laboratory tests was as good, if not better than, that used at Crossroads. Further, the dosimetry section did not employ experts in their field throughout the operation. Rather, according to a memorandum by the Radiological Safety Officer, as of August 7, 1946, the dosimetry section consisted of a single enlisted man who had received an indeterminate amount of training.

15. DOD's statements that (1) less than one percent (or 420) of Crossroads participants had the potential to be contaminated prior to July 31, 1946, (2) no one conducted any decontamination work on the target ships until after July 31, 1946, and (3) fewer than 22 percent of the 42,000-man task force had any involvement in decontamination work after July 31, 1946, are inconsistent with DNA's historical report on Operation Crossroads. For example, the historical report showed that

- Between July 25 and July 31, 1946, more than 34,500 Navy and Army personnel aboard more than 100 support ships reentered Bikini lagoon and that approximately 3,400 of these personnel were involved in such tasks as retrieving scientific instruments and test animals from target ships, towing and beaching target ships, resurfacing target submarines, flying aerial reconnaissance, and evaluating damage to military test equipment, and thus in a position to be potentially contaminated.
- Five target ships were remanned in a few days after Test Baker, four on July 29 and one on July 30. Each ships needed some decontamination work and, even then, radiation levels on these ships were not reduced below a tolerance level until August 5.

- "The exact number of men involved in the decontamination work cannot now be determined." However, 17,123 personnel (or 41 percent of the joint task force) were assigned to units that had frequent contact with contaminated target ships.

16. DOD's statement that personnel decontamination was not required for Test Able is inconsistent with information presented in DNA's historical report on the operation. The report shows that, prior to Test Able, the joint task force operation plan predicted that objects in the area immediately under the bomb will become radioactively hazardous to personnel, particulate matter in the air may become radioactive and present an airborne hazard, and the water in Bikini lagoon may become radioactive and present a waterborne hazard. Thus, as a precaution, the establishment and implementation of personnel decontamination procedures, beginning with Test Able, would have been prudent.

17. DOD's statement that there were 92 target ships in the Test Baker target array is inconsistent with DNA's historical report on Operation Crossroads. In that report, a sketch is provided of target ship locations; a description is included of the day-to-day target ship activities; and a table is presented of the radiation readings aboard target ships. The report individually identifies only 78 target ships for Test Baker. For that reason, our report (see p. 9) states there were approximately 80 ships in the Test Baker target array.

In addition, DOD's statement that the base surge spread contamination over 72 target ships is inconsistent with DNA's Crossroads historical report. According to that report, only 58 target ships were immersed by the base surge.

Further, the information provided by DOD in its comments is inconsistent on the number of ships reboarded prior to July 31. On p. 79 of its comments, DOD states that some of the 72 target ships contaminated by the base surge were boarded prior to July 31. On the other hand, in the table on page 80 of its comments, DOD indicates that none of these ships were reboarded by this date. On the basis of DNA's historical report on Operation Crossroads and one of the official reports prepared after the operation, a total of 33 target ships were boarded prior to July 31, including 22 ships contaminated by the base surge.

18. DOD's statement that the degree of contamination after Test Baker was not unexpected is inconsistent with information presented in DNA's historical report on the operation. According to that report, "since the

nature and extent of contamination of the targets [target ships] was completely unexpected, no plans had been prepared for organized decontamination measures."

In addition, contrary to DOD's statement that initial boarding teams (including radiation monitors) wore protective clothing, we were not provided photographic evidence that radiation monitors or any other personnel consistently wore protective clothing (gloves, boots, etc.) in the performance of their work. For instance, on page 106 of DNA's historical report, a radiation monitor is shown on July 28 on the USS Hughes, which was being prepared for towing. The radiation monitor, who was standing beside a welder, was wearing a T-shirt, no protective rubber gloves, no protective rubber boots, no protective breathing device and was smoking a cigarette.

19. Our report neither states nor implies that personnel decontamination was a new procedure in 1946. We stated that, at Operation Crossroads, personnel decontamination procedures seemed to evolve from a very simplistic approach to radiation protection to comprehensive procedures that were not instituted until more than 2 weeks after Test Baker. DOD officials, in providing us their agency's comments on our draft report on August 23, 1985, agreed that personnel decontamination procedures evolved during the operation.

20. DOD's statement that members of the radiation safety team were highly qualified scientists and physicians trained in radiation protection is inconsistent with information presented in DNA's historical report on Operation Crossroads. According to that report, which quoted one of the members of the Radiological Safety Section, ". . . most are older men, some are well-known scientists. Some have worked with radiation in the Manhattan District, but the majority come with little more than a scientific background." (underscoring added) DNA's historical report also showed that members of the Radiological Safety Section received a 12-day intensive course in radiation monitoring, including such subjects as the atomic structure, the fission process, and the radioactivity from a nuclear blast with only a 50-minute discussion of protection against radioactive hazards.

21. The July 30, 1946, guidelines do not indicate applicability to all personnel in Task Group 1.1. Rather, the guidelines, in question, are actually suggestions in a memorandum to the captain of the USS Kenneth Whiting from a radiation monitor. The monitor stated, in the memorandum, that he was making these suggestions "to ensure radiological

safety among personnel of this ship." (underscoring added) According to DNA's historical report on Operation Crossroads, Task Group 1.1 consisted of the USS Kenneth Whiting and nine other vessels. In addition, contrary to DOD's statement, it is unclear—from the wording of the July 30, 1946, guidelines—whether showers were required for anyone handling contaminated objects. According to the guidelines all men working on "hot" instruments were urged to take a good shower and change clothes at the end of the day.

Further, DOD's statement that members of Task Group 1.1 and the initial boarding teams were the only personnel boarding contaminated target ships prior to July 31, 1946, is inconsistent with DNA's Crossroads historical report. According to that report, ships and personnel of Task Group 1.2 were also heavily involved in inspecting target ships, recovering scientific equipment, and repairing/towing target ships prior to July 31.

22. DOD's statement that only 37 of the 72 target ships caught in the base surge were reboarded by their crews for either short-term inspection or decontamination is inconsistent with DNA's Crossroads historical report and one of the official Crossroads reports prepared after that operation. According to those 2 reports, 49 of 58 target ships caught in the base surge were reboarded after Test Baker.

23. While the statement attributed to the Radiological Safety Officer accurately reflects the contents of his notes, large-scale decontamination may have occurred before August 6, 1946. For instance, as stated in comment 15, on July 29 and 30, 1946, crews remanned five target ships, and each ship required some decontamination work. The total crew size of the 5 ships was 695 men. In addition, according to DNA's Crossroads historical report, crews on as many as 11 other target ships began decontamination operations on their ships from August 1 to August 5, 1946. Apparently, however, how many crew members boarded their ships for decontamination work is not completely known. As stated in comment 15, DNA in its historical report indicated that "the exact number of men involved in the decontamination effort cannot now be determined," but 17,123 personnel (or 41 percent of the joint task force), were assigned to units that had frequent contact with contaminated target ships.

24. DOD's statement that as early as August 3, 1946, the Medical-Legal Board indicated the need for a decontamination way-station is correct. However, there is no evidence that a way-station was established until

August 13, 1946. The Medical-Legal Board, which was an advisory group to the Crossroads Radiological Safety Officer, recommended on August 3, 1946, the establishment of such a station. In turn, the Crossroads Radiological Safety Officer made a similar recommendation in a memorandum dated August 7, 1946, to the commander of the joint task force. It was not until August 13, 1946, however, that the commander of the joint task force established the USS Geneva as a central change station for processing working parties proceeding to or from work on target ships. This is after the period of large-scale decontamination efforts that DOD said took place from August 6 to 10, 1946.

In addition, DOD's statement that photographic evidence exists that the recommendations of the Medical-Legal Board were implemented is inconsistent with available information. As stated, on August 3, 1946, the Medical-Legal Board recommended the creation of a decontamination way-station (or change ship) with tie-up facilities for small boats to be used by personnel proceeding to and from the support and the target ships. However, the evidence provided us by DOD officials is a photograph of a changing room on the USS Wharton, which was a support ship assigned to the joint task force instrumentation unit.

25. The decontamination clearance standards for clothes and shoes cited by DOD were, in fact, recommended by the Medical-Legal Board in a meeting on August 12-13, 1946. The joint task force commander, however, had announced the termination of decontamination operations at Crossroads on August 10, 1946.

26. DOD's statement that occasionally hands showed beta activity but no person was found perceptibly contaminated on his body is inconsistent with documents prepared during Operation Crossroads. For instance, the Radiological Safety Officer, in an August 7, 1946, memorandum to the commander of the joint task force, recommended termination of Operation Crossroads in Bikini lagoon, in part, because the "contamination of hands and faces with beta emitters of intensities greater than tolerance (0.5 rem/day) is exceedingly common. It is not infrequent to find personnel with amounts on the bare hands bordering on erythema [reddening of the skin] dose levels (if not removed within 24 hours)."

27. DOD's statements regarding events and circumstances on August 6, 1946, is inconsistent with the document provided us by DOD as support. According to that document—entitled "Final Report of the Alpha Beta Gamma Survey Section" dated August 6, 1946—and DNA's historical

report on Operation Crossroads, nine ships were surveyed but none, contrary to DOD's statement, were used to berth target crews. In addition, while DOD is correct that the document states that "except for a few isolated cases, no physical hazard could be expected to result," the document also states that (1) contamination was found frequently on the clothing and bodies of persons on the ships visited and (2) a number of sleeping quarters were evacuated because they were above tolerance (0.1 rem/day). Further, while contamination was found on all nine ships visited, provisions were made on only three of the ships—as opposed to all, as stated by DOD—to leave permanent monitors aboard and to set up systems of personnel monitoring and decontamination.

28. DOD states that (1) contamination remaining after showering and laundering was slight, (2) contamination was limited to about 21 percent of all Crossroads personnel, and (3) contamination could have occurred only in early August 1946. However, DOD provided no documentation to support the first point. In addition, its other two points are contrary to DNA's historical report on Operation Crossroads, which states that the exact number of men involved in the decontamination effort cannot now be determined but 41 percent of all Crossroads personnel were assigned to units conducting work in contaminated areas and before August 1, 1946, about 3,400 were assigned to units in frequent contact with contaminated target ships.

29. DOD's position that activities at Kwajalein Island should not be associated with Operation Crossroads is inconsistent with the discussion of events and activities in DNA's historical report on Operation Crossroads. In that report DNA discusses in detail that certain target ships were taken to Kwajalein Island for ammunition disposal and were subsequently sailed or towed back to the United States for decontamination experiments or disposal. Our report evaluated Crossroads' radiological safety in accordance with the discussion presented in the aforementioned report.

30. We continue to believe that the alpha-beta-gamma ratio may have varied at Operation Crossroads. In a memorandum dated November 21, 1946, the head of the technical analysis section of the Joint Crossroads Committee (an organization established upon dissolution of the Crossroads joint task force to prepare and publish the official reports on that operation) offered two reasons why an X-263 geiger counter—capable of measuring gamma and beta radiation—should not be used to estimate

alpha radiation from plutonium contamination based on a predetermined conversion factor. One reason offered is that there are inaccuracies associated with use of the X-263 geiger counter itself. The other reason offered is that

"the fission product [gamma and beta radiation] -plutonium [alpha radiation] ratio does not appear to be constant at different locations so that any selected conversion factor might be in error by a factor of 5 or 10. This change in ratio would indicate that selective absorption has been taking place, so that the fission products and plutonium are being concentrated to different extents on some surfaces."

In subsequent discussions with the author of this memorandum and with a radiochemist at DOE's Hanford Operations office, we confirmed that our interpretation of this memorandum was correct and that the alpha-beta-gamma ratio at Operation Crossroads would not have remained constant.

31. We continue to believe that radiation exposure by ingestion of radioactive materials may need further analysis. There are several reasons for this. First, as explained in comment 30, the alpha-beta-gamma ratio could be in error by a factor of 5 or 10. Moreover, as stated on page 38 of our report, DNA's contractor responsible for preparing DNA's internal dose assessment report admitted that the alpha-beta-gamma ratio may not have been constant. Second, it is unclear whether DOD evaluated a hypothetically worst-case scenario, as stated, for the engineering team boarding the USS New York for 16 hours on August 8, 1946, and eating three meals on board. In its analysis DOD assumed that contamination was evenly spread over the entire surface of the ship. Then DOD assumed that a member of the engineering team placed one hand on only one spot on the surface of the ship prior to each meal and, from that small area, transferred only 1 percent of the contaminants to the hand—all of which were ingested. Given the possibility that (1) contact with the ship occurred where there was a higher than average concentration of contamination on the USS New York, (2) a member of the engineering team placed his hand or hands on more than one spot on the contaminated surface of the ship, or (3) more than 1 percent of the contaminants was transferred to his hand or hands, it is our position that the doses for this member of the engineering team may not represent a worst-case scenario. Third, it is our opinion that DOD has not fully estimated the possible internal radiation dose for the crew reboarding and later remanning the USS Parche. DOD began its calculations on August

22, 1946. However, on August 15, 1946, the Parche crew received permission to eat meals aboard the ship, and from that day to August 22, 1946, the crew spent an average of 8 hours out of each day decontaminating the ship. As many as 2 meals per day could have been eaten during this time.

32. We continue to believe that possible internal radiation exposure by open wounds needs to be addressed. First, there is no evidence that Crossroads personnel were alerted to the steps to be followed in case of an open wound until August 30, 1946, approximately 20 days after termination of decontamination operations. Although DOD implies that the seriousness of internal radiation exposure by open wound was otherwise known—by offering one account of an open wound case at Crossroads—we believe it is possible that other open wound cases, given the number of personnel boarding contaminated target ships, were neither reported nor received appropriate treatment.

Second, we disagree with DOD's view that it has reconstructed a hypothetically worst-case open wound. DOD said a 1-centimeter by 0.1-centimeter puncture, which transferred 100 percent of all contaminants into the blood stream, would result in an exposure of only 0.03 rem to the bone marrow, or approximately 0.2 percent of the National Council on Radiation Protection and Measurements guidelines for exposure to internal organs. However, in its reconstruction, DOD assumed (1) the puncture was relatively small—width of 0.1 centimeter (or about the size of the wire in a standard paperclip) with depth of less than one-half inch (1 centimeter), (2) the object that caused the puncture wound was contaminated with alpha radiation based on the average amount of beta and gamma radiation existing per square centimeter on the target ship USS New York on September 6, 1946, and (3) the alpha-beta-gamma ratio was constant. Given the possibility that (1) a greater-size wound occurred; (2) the contaminated object that caused the wound had a higher than average amount of contamination on it; (3) the wound occurred earlier than September 6, 1946, which was 27 days after decontamination operations were halted at Crossroads; or (4) the alpha-beta-gamma ratio varied, it is our position that DOD's example may not represent a worst-case scenario.

33. We continue to believe that DOD should evaluate the accuracy of the external beta radiation dose information for Crossroads participants. Several reasons can be cited for this.

First, as stated in our report, if the beta radiation has sufficient (high) energy, it could penetrate to a depth of one-half inch and affect the skin and those body organs and glands close to the outer layer of skin, such as the eyes and gonads. DOD, in its comments, does not dispute this possibility for high-energy beta radiation but instead contends that a great majority of beta radiation from fallout cannot penetrate the skin. This position does not address the central issue: What was the energy spectrum for beta radiation at Operation Crossroads and did it include any high-energy beta radiation? According to DNA's historical report on Operation Crossroads, the answer to this issue is not known, and DOD did not provide any documentation to refute that view. However, according to a dosimetry expert at the U.S. National Bureau of Standards, a nuclear detonation—such as those at Operation Crossroads—could produce high-energy beta radiation that could penetrate the skin more than 1/2 inch.

Second, contrary to DOD's statement, it is unclear that Crossroads participants' external beta radiation doses were low. As discussed in our report, few external beta radiation exposures were assigned to personnel after July 31, 1946 (see p. 42). The main reason for this is that beta radiation was generally not recorded in the film badge ledgers. DOD officials, in providing us their agency's comments, agreed that an oversight had occurred and attributed it to clerical error.

Third, exposure to external beta radiation was apparently quite common at Operation Crossroads. In a August 7, 1946, memorandum to the commander of the joint task force, the radiological safety officer stated

"contamination of hands and faces with beta emitters of intensities greater than tolerance (0.5 rem/day) is exceedingly common. It is not infrequent to find personnel with amounts on the bare hand bordering on erythema [reddening of the skin] dose levels (if not removed within 24 hours)."

Fourth, contrary to DOD's statement, external beta radiation may produce long-term health effects. According to two experts in the area of medical effects from nuclear radiation—one with the health and safety research division at the Oak Ridge National Laboratory and the other the former head of the Marshall Island Medical Program at the Brookhaven National Laboratory—external beta radiation may cause skin cancer. For that reason the Oak Ridge National Laboratory expert told us the effects of external beta radiation "should not be dismissed out of hand. While beta radiation is generally much less significant than gamma radiation, a careful reconstruction would be necessary before it

could be concluded that the effects of beta radiation need not be included in the overall dose estimate."

Fifth, while DOD may be correct in stating that medical records for Crossroads veterans do not indicate any evidence of beta exposure, at least one severe case of beta radiation overexposure reportedly did occur. According to the former head of the Marshall Island Medical Program at the Brookhaven National Laboratory who was also a former Crossroads participant, one serviceman received extreme beta radiation burns on his hands by handling the radiological filter from a drone aircraft. Thus, we believe Crossroads medical records may not have documented all radiation-related cases that occurred.

34. We continue to believe that military services should disclose the error ranges associated with individual film badge readings in reporting radiation exposure estimates to VA. Conversely, DOD contends that it can accomplish the same objective by simply distributing its forthcoming report on film badge accuracy to all VA Regional Offices and allowing them to make the necessary computations. We disagree. A veteran's total radiation exposure is often a product of a number of individual film badge readings. Unless the individual readings are known and the correct error ranges are assigned to those individual readings, a mistake may result in developing a composite error range for the total radiation exposure. To minimize the possibility of such a mistake, we believe the military services (given their familiarity with the data) should report film badge readings with error ranges to the VA rather than have the VA develop this information.

Glossary

Alpha Particle	a charged particle emitted spontaneously from the nuclei of some radioactive elements and identical with a helium nucleus. Alpha radiation is difficult to detect and its effect is lasting for years. It has a range of only a few inches in the air and is incapable of penetrating clothing or even the outer layer of unbroken skin. However, alpha radiation is a primary hazard when absorbed internally.
Beta Particle	a charged particle of very small mass emitted spontaneously from the nuclei of certain radioactive elements. Beta radiation may travel several feet in the air before being absorbed. In more dense material, such as body tissue, beta radiation may travel up to half an inch. Clothing normally provides adequate protection from beta radiation. Therefore, beta radiation is a hazard only when beta-emitting materials are either in direct contact with the skin or absorbed internally.
Dosimeter	an instrument for measuring and registering the total accumulated dose of (or exposure to) ionizing radiation.
Dosimetry	the measurement and recording of radiation doses and dose rates.
Film Badge	a small piece of film encased in a metal or plastic container and used to measure radiation.
Gamma Ray	electromagnetic radiation originating in the nuclei of certain radioactive elements and accompanying many nuclear reactions. Gamma rays can travel great distances through the air and can penetrate a considerable thickness of material.
Ionization	a process by which radiation, when it encounters living tissue and other matter, transfers some of its energy to the target atoms, tearing off some or all of their electrons and leaving the atoms with a positive electrical charge.
Joint Crossroads Committee	a committee established, upon dissolution of the Crossroads joint task force, to prepare and publish the official reports on that operation.

National Council on Radiation Protection and Measurements	a private, nonprofit organization chartered by Congress that publishes reports on all aspects of radiation protection.
Plutonium	one of the radioactive components of the bombs used at Operation Crossroads and an emitter of alpha radiation.
Rem	a unit that expresses biological effects. Exposure to one roentgen of gamma radiation is approximately equivalent to one rem.
Roentgen	a unit that expresses the amount of ionization that gamma radiation produces in air.

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