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Report to the Chairman, Committee on Veterans Affairs, U.S. Senate

September 1987

NUCLEAR HEALTH AND SAFETY

Radiation Exposures for Some Cloud-Sampling Personnel Need to Be Reexamined

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Resources, Community, and
Economic Development Division

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September 29, 1987

The Honorable Alan Cranston
Chairman, Committee on Veterans' Affairs
United States Senate

Dear Mr. Chairman:

This report is in response to your request that we determine how many personnel were involved in manning or decontaminating aircraft that flew through nuclear clouds during operations Tumbler-Snapper (1952), Redwing (1956), and Dominic I (1962), and how much radiation was received.

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

This work was performed under the direction of Keith O. Fultz, Associate Director. Other major contributors are listed in appendix VII.

Sincerely yours,

J. Dexter Peach

J. Dexter Peach
Assistant Comptroller General

Executive Summary

Purpose

Between 1945 and 1962, according to Department of Defense (DOD) estimates, nearly 200,000 Americans participated in the atmospheric nuclear weapons testing program, with more than half receiving some level of radiation exposure. The Veterans Administration uses DOD exposure estimates in adjudicating former weapons test participants' radiation-related disability claims. However, a report released by a public interest group in late 1985 indicated that certain radiation exposure estimates may have been understated. The report questioned the estimates for personnel involved in manning or decontaminating aircraft that had flown through nuclear clouds during the tests to collect radiological samples.

Because of that report, the chairman of the Senate Committee on Veterans' Affairs asked GAO to determine how many personnel were involved in nuclear cloud-sampling work at three operations—Tumbler-Snapper (1952), Redwing (1956), and Dominic I (1962)—and how much radiation they received.

Background

DOD assigned responsibility to the Defense Nuclear Agency (DNA) in 1977 to estimate both the external and internal radiation doses test participants received. DNA has published an historical report on each of the 20 atmospheric nuclear weapons test operations, summarizing the external radiation (from radiation sources located outside the body) received by participating personnel. Usually, estimates of external radiation are based on film badges worn. Because film badges cannot measure internal radiation (from radioactive sources deposited within the body), DNA is in the process of estimating the amount of radiation test participants received from this mode of exposure. (See ch. 1.)

Results in Brief

Approximately 300 Air Force personnel were involved in nuclear cloud-sampling work at each of the three operations included in GAO's review, and the amount of radiation they received is subject to some question. As best GAO could determine, based principally upon a review of film badge exposure records, external radiation for some personnel who were at operations Redwing and Dominic I is understated and, because of that, needs to be reexamined. Further, ground personnel during operations Tumbler-Snapper and Redwing did not consistently wear protective breathing devices when working around radioactively contaminated cloud-sampling aircraft and the effect of that lack of protection on how much internal radiation they may have received needs to be evaluated. (See ch. 2.)

Principal Findings

Accuracy of Film Badges and Film Badge Exposure Records

Film badges are the official record of personnel exposure to external radiation for those who participated in the atmospheric nuclear weapons testing program. However, problems were identified with some of the film badges used, particularly at operations Tumbler-Snapper and Redwing. For instance, about 10 years after the film badge's use at Tumbler-Snapper, the manufacturer reported that the badge's two film components could not effectively measure radiation between 4 to 9 rem. (See ch. 2.)

In addition, GAO found errors in about 26 percent and 13 percent of the records used to tabulate the readings from all film badges worn by personnel at operations Redwing and Dominic I, respectively. For example, at Operation Redwing, an estimated 2 to 3.5 rem of radiation fell on islands housing cloud-sampling personnel but was not added to about 8 percent of the individuals' cumulative exposure totals. Arithmetical mistakes were also found in about 6 percent of the Redwing individual exposure records—most being understatements of less than 1 rem but one understatement was over 8 rem. Correction of these errors would increase some individuals' doses and also add to the number of individuals who received more than the current 5-rem per year federal limit. Furthermore, one Redwing participant's dose, once his record is corrected, would exceed the 20-rem limit established for that operation. (See ch. 2.)

Readings of Other Radiation Monitoring Devices

While a film badge has its advantages, one disadvantage is that it does not provide an immediate measure of external radiation. To provide aircrews with immediate radiation readings, another radiation monitoring device, the integron, was installed in the aircraft cockpit to help crews operationally monitor and control their exposures during cloud-sampling missions. However, the integron readings were not used in developing aircrew exposure estimates.

For two of the three operations included in this review, GAO found that the integron read higher levels of radiation than anticipated compared with the film badges worn by the crew. On the basis of earlier weapons tests, a ratio between the reading on the integron and film badges used was known to exist. This meant that the integron and the film badges used were consistently measuring a somewhat different amount of radiation, but the difference remained essentially fixed, which resulted in a ratio. In 65 percent and 72 percent of 147 and 189 comparisons at operations Redwing and Dominic I, respectively, however, the reading on the integron exceeded this ratio, suggesting that either the integron read high or the film badges read low and, if the latter occurred, aircrews received a larger amount of external radiation than has been officially recorded. (See ch. 2.)

Possibilities for Internal Radiation Exposure

In addition to possible external radiation, it is generally recognized that personnel participating in the atmospheric nuclear weapons testing program could also have received an internal radiation exposure. Internal exposures can occur through three pathways—inhalation, ingestion, or cuts or open wounds—and cannot be measured by an integron or a film badge.

Generally, GAO found indications that ground crews may have received some internal radiation exposure, particularly during operations Tumbler-Snapper and Redwing. At Dominic I, ground crews wore respirators while removing radiological samples from cloud-sampling aircraft. However, at Tumbler-Snapper and Redwing, this was not consistently done. Further, no personnel at Operation Tumbler-Snapper and only a few personnel at Operation Redwing were monitored for internal radiation exposure, and the limited monitoring that was done may not have been reliable. For example, to test Redwing personnel for plutonium, only one 24-hour urine sample was taken after possible exposure (considered to be the acceptable practice then). However, according to four health physicists GAO contacted, it is now recognized that repeated urine samples should be collected over several days to accurately estimate a plutonium exposure. (See ch. 2.)

DNA began its internal radiation exposure assessment in 1980, but it found problems in the methodology used by its contractor, and it is currently in the process of estimating such exposure for cloud-sampling personnel at all atmospheric nuclear weapons tests. As part of this process, DNA should recognize that—for cloud-sampling ground personnel at operations Tumbler-Snapper and Redwing—protective breathing devices were not consistently worn.

Recommendations

GAO recommends that the Secretary of Defense direct DNA to

- correct the GAO-identified errors in the film badge exposure records of cloud-sampling personnel participating in operations Redwing and Dominic I and, given the frequency of such errors identified, review for similar errors the film badge exposure record of each Air Force individual who participated in any of the other atmospheric nuclear weapons tests; and
- use integron readings in conjunction with film badge readings to better define the radiation dose received by cloud-sampling personnel for all atmospheric nuclear weapons tests, including operations Redwing and Dominic I.

Agency Comments

DOD agreed with most of the draft report's findings and first recommendation. However, DOD did not agree with the draft report's second recommendation and indicated that film badges worn by each cloud sampler is a better indication of the individual's dose than the integron. GAO has reworded its recommendation to indicate that GAO is not advocating using integron readings in lieu of film badge readings, but that integron readings be used in conjunction with film badge readings to better define cloud-sampling aircrew dose. (See app. III for DOD's comments and GAO's detailed evaluation of those comments.) The Veterans Administration stated that if DNA's reexamination results in increased dose estimates, it would want to review the records of any of those individuals who had previously filed compensation claims that were denied on the basis of low dose estimates. (See app. IV.) Comments received from the Office of Technology Assessment and the National Council on Radiation Protection and Measurements are included in appendices V and VI.

Contents

Abbreviations

DNA	Defense Nuclear Agency
DOD	Department of Defense
GAO	General Accounting Office
NCRP	National Council on Radiation Protection and Measurements
RCED	Resources, Community, and Economic Development Division
VA	Veterans Administration

Introduction

From 1945 to 1962, the United States—like other countries developing atomic arsenals—detonated nuclear weapons in the atmosphere. The detonation occurred by various means, such as dropping the weapon by aircraft and exploding it at a prescribed altitude, or placing the weapon on a steel tower 500 feet high and exploding it by remote control. A principal activity at these weapons tests was to confirm the efficiency and nuclear yield[1] of the detonation by cloud sampling—obtaining gaseous and particulate samples of the radioactive mushroom cloud.

In the 1940s, cloud sampling was done by remotely controlled drone aircraft,[2] but beginning in 1951, manned aircraft were assigned this task. This change occurred after a manned aircraft accidentally penetrated a nuclear cloud without the crew's experiencing any outwardly apparent ill effects. Between 1951 and 1962, the Department of Defense (DOD) estimates that approximately 4,000 personnel were in units responsible for manning or decontaminating aircraft that flew through nuclear clouds or that tracked nuclear clouds downwind, but only a portion of the men in the units performed these specific tasks.

In late 1985, a public interest group—Environmental Policy Institute—reported[3] that, at Operation Redwing in 1956, a radiation monitoring device installed inside aircraft that had penetrated the nuclear clouds read more than twice the level of radiation recorded on film badges worn by the aircraft crews.[4] Because of the potential significance of the higher readings reported and the knowledge that film badge results are normally used as the official record of an individual's radiation exposure, the Senate Committee on Veterans' Affairs asked us to review this matter further. Specifically, the committee asked that we evaluate how many personnel were involved in manning or decontaminating aircraft that flew through the nuclear clouds at operations Tumbler-Snapper (1952), Redwing (1956), and Dominic I (1962), and how much radiation was received.

[1]Yield is the total effective energy released in a nuclear detonation. It is usually expressed in terms of the TNT equivalent required to produce the same energy release in an explosion. Nuclear detonation yields are commonly expressed in kilotons or megatons (thousands or millions of tons) of TNT equivalent.

[2]A drone is a pilotless, radio-controlled aircraft.

[3]The Institute reported its findings in Experimental Irradiation of Air Force Personnel During Operation Redwing—1956, issued in November 1985.

[4]A film badge is a small piece of film or films sensitive to ionizing radiation that are encased in a metal or plastic container usually clipped to the wearer's clothing.

Elements of Nuclear Cloud Sampling

To perform nuclear cloud sampling, aircraft were specially modified to collect the samples necessary for analysis. As shown in figure 1.1 (see p. 10), the F-84 fighter aircraft used at weapons test operations from 1952 to 1957 was fitted with two different sampling systems to fulfill its mission. On the wings of the aircraft, a wingtip tank-sampling system was attached to collect particulate samples during transit through the nuclear cloud. A valve at the front of each tank, remotely controlled from the cockpit, allowed the passage of air through the tank. Within the tank, a filter paper attached to a mesh screen collected particulate matter in the air. Protruding from the nose section of the aircraft, a long, hollow, cylindrical probe allowed the collection of gaseous samples in a plastic bag positioned within the nose.

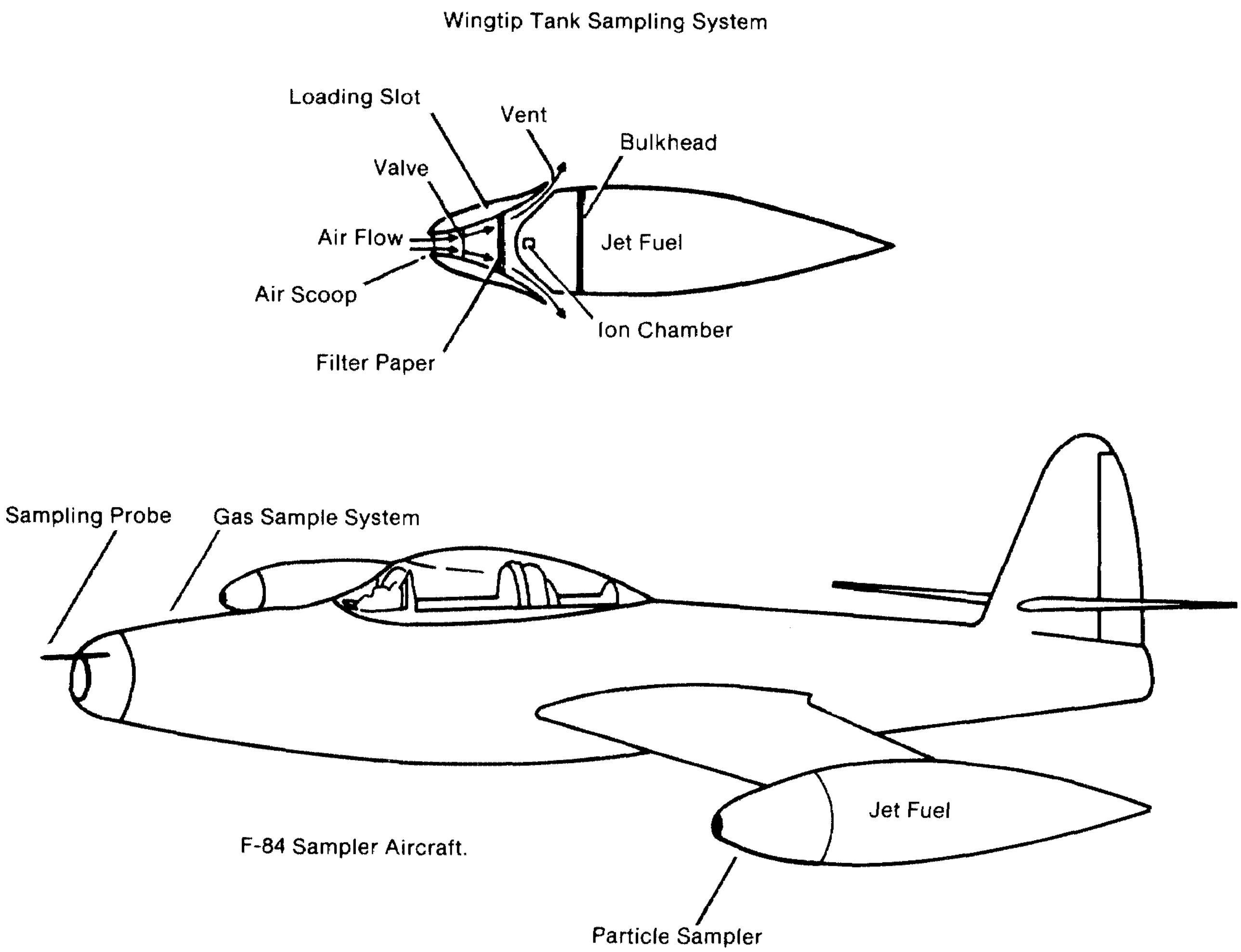
Aircrews also received special instruction on how to perform the cloud-sampling mission. Before each cloud-sampling flight, scientific and military advisors briefed cloud-sampling crews on the upcoming mission, discussing with them the effects of radiation, the expected levels of radiation to be encountered, and the flight patterns to be flown. Expected radiation doses were determined by using such factors as the time of the sampling flight after detonation and the length of time spent in the cloud. In addition, aircrews were instructed on operating and reading radiation monitoring devices installed on the aircraft as well as on using the aircraft's oxygen-breathing system to prevent possible inhalation of radioactively contaminated outside air.[5]

The specific flight paths of the cloud-sampling aircraft and entry points into the nuclear cloud to collect the radiological samples were determined by a control aircraft—positioned within viewing distance of the nuclear cloud—carrying the scientific and the military advisors as crew. The cloud-sampling aircraft made several passes through the cloud, but the aircrew was advised not to exceed a specified radiation dosage limit. To assure that they did not, a monitoring device measuring cumulative radiation exposure on an immediate basis was available for the crew's use. This device was either a pencil dosimeter—a cylinder about the size and shape of a fountain pen—or an instrument called an integron.[6] Once the crew either obtained a successful cloud sample or estimated, on the basis of the radiation monitoring device, that the prescribed dosage limit would be exceeded, the sampling aircraft ended its mission and returned to base.

[5]Outside air is normally brought into an aircraft for pressurization, heating, and ventilation.

[6]An integron was an ion chamber device used on cloud-sampling aircraft to provide an immediate measure of gamma radiation present. See glossary for the definition of an ion chamber.

Figure 1.1: F-84 Sampler Aircraft



Source: DNA's Historical Report on Operation Ivy, DNA 6036F, p.97

Upon returning to base, the cloud-sampling aircraft was taken to a remote airfield area to be secured until it could be tested and declared radiologically safe. The first order of business was removal of the crew to minimize further radiation exposure. For the one-person F-84 fighter aircraft illustrated in figure 1.1, the ground crew used a forklift to remove the pilot to preclude his receiving additional radiation exposure by contacting the exterior of the aircraft. Next, the ground crew—using 8- to 10-foot poles—promptly removed the samples collected and placed them in lead containers for immediate shipment to a designated laboratory for analysis. Finally, the ground crew surveyed the aircraft using radiation measuring instruments to determine the level of radioactive contamination. Depending upon the level of contamination, the aircraft was either immediately decontaminated with a special chemical washing compound and water or allowed to decline in radioactivity before decontamination commenced. When the aircraft was decontaminated, the ground crew moved it onto the parking ramp for routine maintenance. Here, personnel removed, checked, and recalibrated the radiological instruments for the next mission.[7]

History of Manned Nuclear Cloud Sampling

The birth of manned nuclear cloud sampling occurred in 1948 during the nuclear test operation known as Sandstone. At that time, an aircraft on a cloud-tracking mission accidentally penetrated a nuclear cloud without the crew's experiencing any outwardly apparent ill effects. This inadvertent penetration flight caused the military to rethink the future course of nuclear cloud sampling. Prior to that time, drone aircraft were used for cloud sampling because it was believed that such work posed too great a risk for aircraft crews. However, over the next 3 years, the military performed a series of theoretical studies that predicted a minimal radiological risk to personnel involved in such work. On the basis of these studies, the military decided to conduct nuclear cloud sampling using manned aircraft at the next test operation (Ranger), which occurred in January and February of 1951.

During Operation Ranger, two propeller-driven bomber aircraft were used to sample three of the five detonations, while only one such aircraft participated in the other two. According to available information, the crew breathed 100 percent oxygen from the aircraft's oxygen-breathing system prior to cloud entry and throughout the remaining portion of the flight. The radiological safety instructions given the crew were simple ones. The aircraft crew were to continue their cloud-sampling mission until their instruments showed a 200-millirem radiation dosage limit had been achieved,[8] and then the crew was instructed to abort its mission and return to base. As a result of its successful use at

[7]Calibrating, or recalibrating, refers to checking an instrument by testing its ability to accurately measure a known amount of radiation emitted from a particular radiation source.

[8]A rem is a unit of dose of any ionizing radiation that produces the same biological effect as a unit of absorbed dose of ordinary x-rays. One millirem is one one-thousandth of a rem. The present permissible radiation dose for radiation workers in the United States is 5 rem per year.

Operation Ranger, cloud sampling by manned aircraft became a mainstay of future atmospheric nuclear weapons test operations.

Over the next 12 years—from 1951 to 1962—the military conducted cloud-sampling work using many different aircraft and exercising many different precautions to keep aircraft crews' exposures within acceptable radiological safety limits. Commencing with Operation Greenhouse in the spring of 1951, the military recognized that radiological risks could be reduced by using aircraft that more quickly traversed the nuclear cloud and required fewer crew members. Whereas the propeller-driven bomber aircraft employed during Operation Ranger required a crew size of 10, the military concluded that a jet aircraft with 1 or 2 crew members would be better for cloud-sampling work. Thus, such aircraft were phased into future weapons test operations as the demands of the Korean War and of operational readiness allowed.

During Operation Buster-Jangle in the fall of 1951, the military experimented with improving the in-flight environmental conditions within the cabin and cockpit areas on cloud-sampling aircraft. At operations Ranger and Greenhouse, the air ducts used to pressurize[9] the cloud-sampling aircraft were closed prior to cloud entry to keep radioactive particles from entering the cabin area. This depressurized condition, however, caused the windshield to frost over, which limited visual sighting of the cloud. The depressurized condition also allowed a rapid drop in temperature, which made the crew uncomfortable and reduced its efficiency. To resolve these problems, the military experimented with placing a filter on the pressurization system and allowing the sampling aircraft to remain pressurized during its entire mission.

During Operation Ivy in the fall of 1952, the military began using protective barriers to reduce the sampling crews' radiation exposure. At this operation, a loose lead-glass cloth shroud was selected as an appropriate safety feature. (See fig. 1.2.) The shroud fit over the head, draped down the back, and extended over the sides and front to just below the knees of the crew member. Later operations saw the introduction of lead-lined vests and lead-lined seats for further radiological protection.

[9]Pressurization is a process of creating a nearly normal atmospheric environment, as in an aircraft, where normal breathing is possible without the aid of any apparatus. However, even on pressurized cloud-sampling missions, according to one cloud-sampling scientific advisor, aircrews breathed 100 percent oxygen from the aircraft's oxygen-breathing system.

Figure 1.2: Protective Lead-Glass Cloth Shroud Being Placed on Sampler Pilot, Operation Ivy

Source: DNA's Historical Report on Operation Ivy, DNA 6036F, p. 100.

Operation Tumbler-Snapper

Operation Tumbler-Snapper consisted of eight low- to intermediate-yield nuclear detonations, or tests, conducted at the Nevada Proving Ground in the spring of 1952. The operation was divided into two phases, with the Tumbler phase consisting of four tests for studying weapons effects and the Snapper phase consisting of four tests for improving the design of nuclear weapons. DOD estimated 10,600 of its personnel took part in the operation.[10]

Cloud-sampling duties at Operation Tumbler-Snapper were carried out by a test group of approximately 270 Air Force personnel, about 80 of whom flew through nuclear clouds. The Atomic Energy Commission (a predecessor agency of the Department of Energy) and DOD established a limit of 3.0 rem of radiation exposure per 13 weeks for all personnel participating in the operation, except for cloud-sampling aircrews, who were authorized to receive up to 3.9 rem. Operation Tumbler-Snapper consisted of 63 cloud-sampling missions using both propeller and jet aircraft. According to DOD, the cloud-sampling aircrews received an average radiation exposure of 1.13 rem, and the entire test group an average of .55 rem.

Operation Redwing

Operation Redwing consisted of 17 nuclear tests conducted at the Pacific Proving Ground in the spring and summer of 1956.[11] The operation was held primarily to test high-yield thermonuclear devices that could not be tested in Nevada. Numerous technical experiments were carried out in conjunction with each of the 17 tests. DOD estimated that 10,800 of its personnel took part in the operation.[12]

Cloud-sampling duties at Operation Redwing were carried out by a test group of approximately 205 Air Force personnel, about 35 of whom flew through nuclear clouds. The Atomic Energy Commission and DOD established a limit—slightly higher in comparison with Operation Tumbler-Snapper—of 3.9 rem of radiation exposure per 13 weeks for each person participating in Operation Redwing, except for cloud-sampling aircrews, who were authorized to receive up to 20 rem.[13] However, if a cloud-sampling aircrew member accumulated 3.9 rem or more on any

[10]Because of the lack of surviving historical documentation, DOD—as of May 1987—had identified by name only 7,696 Tumbler-Snapper participants; film badge data were available on 5,378 of these. Film badge data indicate that 307 of the 5,378 had a recorded exposure greater than 1 rem.

[11]The Pacific Proving Ground consisted principally of Enewetak and Bikini atolls in the northwestern Marshall Islands in the central Pacific Ocean.

[12]Film badge data indicate, according to DOD, that 5,000 of the estimated 10,800 DOD personnel at Operation Redwing received a recorded exposure greater than 1 rem.

[13]The Atomic Energy Commission and DOD established the 3.9-rem and 20-rem limit on the basis of their judgment of what represented a safe level of radiation exposure and would allow cloud-sampling personnel to accomplish their mission. In 1956, the annual exposure limit, as recommended by the National Council on Radiation Protection and Measurements, was 15 rem per year.

one mission, no second mission would be authorized before a lapse of 13 weeks had occurred. During Redwing, 104 cloud-sampling missions were flown using jet aircraft. According to DOD, the cloud-sampling aircrews received an average radiation exposure of 6.85 rem, and the entire test group received an average of 4.05 rem.

Also at Operation Redwing were about 70 Air Force personnel participating in a project called early cloud penetration, the primary objective of which was to measure the radiation dose and dose rate one would experience in flying through the cloud. A major difference between these and the cloud-sampling personnel was the period of time after the detonation that passage through the cloud occurred. Early cloud penetration aircrews flew into the cloud as soon as 20 minutes after detonation, whereas cloud-sampling aircrews made their flights into the cloud 60 to 120 minutes after the detonation. During Operation Redwing, about 20 early cloud penetration personnel using jet aircraft flew 22 missions, resulting in 27 penetrations through the clouds. According to DOD, the early cloud penetration aircrews received an average radiation exposure of 5.65 rem with all project personnel receiving an average of 1.83 rem.

Operation Dominic I

Operation Dominic I consisted of 36 nuclear tests conducted, for the most part, near Christmas and Johnston Islands in the Pacific Ocean from April to November 1962.[14] Twenty-nine of the tests were conducted for the purpose of weapon development, 5 were for the purpose of studying the effects of nuclear detonations as defensive weapons against ballistic missiles, 1 was a test of the Polaris weapon system, and 1 was a rocket-launched antisubmarine nuclear depth charge. DOD estimated that 20,700 of its personnel took part in the operation.[15]

Cloud-sampling duties at Operation Dominic I were carried out by a test group essentially comprised of about 330 Air Force personnel, about 85 of whom flew through nuclear clouds. At Operation Dominic I, all individuals except cloud-sampling personnel were limited to receiving an exposure of 3.0 rem per 13 consecutive weeks with an annual maximum limit of 12 rem. However, cloud-sampling personnel were authorized to receive a maximum permissible exposure of 20 rem for the operation.

[14]Christmas Island is a United Kingdom possession located 1,200 nautical miles south of Honolulu. Johnston Island is a United States possession located 780 nautical miles west-southwest of Honolulu.

[15]Film badge data indicate, according to DOD, that only 525 of the estimated 20,700 DOD personnel at Operation Dominic I received a recorded exposure greater than 1 rem.

During Dominic I, aircrews flew 244 cloud-sampling missions using jet aircraft. According to DOD, the cloud-sampling aircrews received an average radiation exposure of 5.68 rem with the entire test group receiving an average exposure of .68 rem.

Responsibilities of the Defense Nuclear Agency

Operations Tumbler-Snapper, Redwing, and Dominic I represented only 3 of 20 atmospheric nuclear weapons test operations conducted by the United States between 1945 and 1962. During this period, an estimated 200,000 American military personnel and civilians participated in the atmospheric test operations, and more than half received some level of radiation exposure. Responding to various test participants' claims to the Veterans Administration (VA) for radiation-related disability compensation, DOD, in December 1977, assigned responsibility to the Defense Nuclear Agency (DNA) to begin a program of wide-ranging actions.

DNA, in turn, established a nuclear test personnel review program that has included (1) compiling a roster of the American military personnel and civilians involved in the atmospheric nuclear tests, (2) developing an 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 veterans, the VA, and others by researching and providing as complete data as possible on individual participation and radiation doses.[16]

With its October 1984 release on Operation Crossroads, DNA completed its publication of an historical report on each of the 20 atmospheric nuclear weapons test operations.[17] Each report—including those on operations Tumbler-Snapper, Redwing, and Dominic I—provides an overview of the operation, an identification of the principal organizations and branches of the military service involved, a description of the radiological safety procedures in place, and a summary of personnel exposure to external radiation.

[16]Radiation doses received by active force personnel who did not participate in the atmospheric nuclear weapons testing program are kept under a separate registry.

[17]We evaluated radiation exposure estimates for Operation Crossroads in our report Operation Crossroads: Personnel Radiation Exposure Estimates Should Be Improved (GAO/RCED-86-15, Nov. 8, 1985).

Usually, specific discussion in the historical reports on personnel exposure to external radiation is based upon exposure to external gamma radiation (expressed in units called rem).[18] This exposure may be taken from film badges worn by participants during the various test operations or, in cases where film badges were not worn or were lost, may be the result of a dose reconstruction. The reports list, by participating organizations, the total number of individuals who were badged and the number of radiation exposures by exposure ranges.

In addition, DNA is in the process of estimating possible personnel exposure to internal alpha, beta, and gamma radiation.[19] DNA began its internal exposure assessment in 1980 with a contract effort aimed at identifying those individuals who received significant internal radiation doses. Because of problems with the methodology used by the contractor, DNA redirected its effort in 1984. It plans to publish, by the summer of 1987, a report identifying those individuals who participated in any of the various nuclear weapons test operations within the continental United States and who received an estimated 50-year radiation dose of less than 150 millirem to the bone.[20] Aircrew members who flew on cloud-sampling missions at Operation Tumbler-Snapper have been identified in the report as having received an estimated internal dose below this amount because they were protected by the respiratory breathing devices they wore. Successively, DNA is preparing a similar report identifying individuals with equally low internal radiation doses who participated in any of the various oceanic nuclear weapons test operations. As a culmination of its efforts, DNA is further developing internal radiation doses for those individuals who presumably received a radiation dose of greater than 150 millirem to the bone. According to the DNA assistant nuclear test personnel review program manager, specific internal radiation doses are being calculated first for those units that include an individual or individuals who have submitted a claim to the VA for radiation-related disability compensation.

[18]Gamma radiation is electromagnetic radiation accompanying many nuclear reactions. Gamma rays can travel great distances through air and can penetrate a considerable thickness of material.

[19]Alpha radiation 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 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.

[20]This dose—150 millirem to the bone—is 1 percent of the radiation protection guideline (annual limit) for occupational exposure currently recommended by the National Council on Radiation Protection and Measurements.

Objectives, Scope, and Methodology

In late 1985, a public interest group—Environmental Policy Institute—issued a report based largely on its evaluation of a 1956 military document, Early Cloud Penetrations— Operation Redwing (Preliminary Draft). The public interest group's report indicated that an experiment was conducted at Operation Redwing in which Air Force personnel and aircraft were deliberately and repeatedly flown through highly radioactive mushroom clouds. More importantly, the public interest group's report stated that the Redwing early cloud penetration report admitted that film badges of aircrew members flying through nuclear clouds registered readings lower than actual exposure—in some cases by a factor of 2-1/2. Thus, when the film badges measured radiation levels of 15 rem to the crew, more sensitive and accurate instruments on the aircraft measured 35 to 40 rem.

Because of the higher exposure readings reported and the knowledge that film badge results are normally used as the official record of an individual's radiation exposure, the Senate Committee on Veterans' Affairs asked us to review this matter further. Specifically, the committee asked us to determine the number of personnel manning or decontaminating aircraft that flew through the nuclear clouds at Operation Redwing and how much radiation they received. In addition, the committee asked that we do the same analysis at two other atmospheric nuclear test operations selected at our discretion, subject to its approval. We used three criteria to select the other two test operations: (1) each involves the same approximate number of personnel manning or decontaminating aircraft flying through nuclear clouds as occurred at Operation Redwing (about 300), (2) one represents a Nevada Test Site operation—given that Redwing took place in the Pacific Ocean, and (3) each occurs several years apart from Redwing (to allow an evaluation of any changes in procedures followed). On the basis of these criteria, we selected, and the committee approved, operations Tumbler-Snapper (1952) and Dominic I (1962) for review.

We performed our review between February 1986 and January 1987. As a first step, we attempted to determine whether radiation instruments on aircraft flying through nuclear clouds at Operation Redwing had indeed read radiation doses 2-1/2 times higher than doses recorded on film badges worn by the aircraft crews. To make that determination, we analyzed information contained in two principal documents: Early Cloud Penetrations—Operation Redwing (Preliminary Draft) and Early Cloud Penetrations—Operation Redwing (Final Report). The preliminary draft discussed a radiation monitoring device called a P-meter, which was installed in the nose section of the aircraft and which read radiation doses 2-1/2 times higher than doses recorded on film badges worn by the aircraft crews. The final report stated that the apparent discrepancy between the readings of the P-meter and the film badges led to further evaluation after Operation Redwing.

According to the final report, two checks of the P-meter were ultimately made. The Air Force tested the P-meter in aircraft at Kirtland Air Force Base, New Mexico, and found that the nose section of the aircraft experienced extremely cold temperatures in flight and that extremely cold temperatures apparently caused the P-meter to read more than two times too high. In addition, the National Bureau of Standards tested the P-meter and found that extremely cold temperatures would cause this device to malfunction by a similar amount. As a result of both checks, the final Redwing early cloud penetration report discounted the radiation readings made by the P-meter. During our work, we contacted a radiation expert at the National Bureau of Standards to confirm the findings of the final report. This expert advised us that the Bureau had tested the P-meter for the Air Force in the mid-1950s and had determined that extremely cold temperatures would cause the P-meter to read more than two times too high.

To better analyze events and circumstances surrounding personnel manning or decontaminating aircraft that flew through nuclear clouds, we sought information from numerous sources. We researched material pertinent to the three operations selected for our review at such locations as the Defense Nuclear Agency; U.S. Department of Energy; National Archives; Federal Records Center; Reynolds Electrical and Engineering Company's Coordination and Information Center;[21] Air Force Weapons Laboratory in Albuquerque, New Mexico; Air Force Nuclear Test Personnel Review Team Office at Brooks Air Force Base in San Antonio, Texas; and the Smithsonian Institution's Air and Space Museum. In addition, we contacted outside sources such as the National Association of Radiation Survivors, National Association of Atomic Veterans, Federation of American Scientists, and Radiation Research Project. These efforts showed that many aircrews were involved in many different tasks during the atmospheric nuclear weapons testing program. Aircrews were involved in such activities as dropping the nuclear weapon, testing the effects of the weapon by positioning their aircraft within

[21]The Reynolds Electrical and Engineering Company is a private contractor that provides dosimetry service to the U.S. Department of Energy at the Nevada Test Site. This company operates, for the Department of Energy, the Coordination and Information Center, which has been designated as the ultimate repository for all unclassified information regarding the atmospheric nuclear weapons testing program.

proximity of the weapon's blast, and tracking the nuclear cloud downwind by contacting the periphery of the cloud. Our review did not cover those aircrew activities; instead, our work was limited to those aircrews with the specific mission of flying through the nuclear clouds at operations Tumbler-Snapper, Redwing, and Dominic I, plus the related ground crew personnel involved in decontamination work.

To evaluate the accuracy of the radiation film badges used, we reviewed the historical reports prepared by DNA on operations Tumbler-Snapper, Redwing, and Dominic I, and DNA's supporting documentation. We also interviewed experts in film badge dosimetry, including officials with the National Bureau of Standards, U.S. Nuclear Regulatory Commission, and Reynolds Electrical and Engineering Company. In addition, we interviewed several film dosimetry experts who participated in two of the three operations we reviewed. Further, we researched and analyzed available information on film badge accuracy from such sources as the U.S. Department of Energy, the Reynolds Electrical and Engineering Company's Coordination and Information Center, and the Los Alamos National Laboratory.

To assess whether film badge exposure records of personnel manning or decontaminating aircraft that flew through nuclear clouds at operations Tumbler-Snapper, Redwing, and Dominic I accurately reflected their exposure to radiation, we analyzed these records for possible inaccuracies. For instance, in the case where a film badge was reportedly lost during the operation, we attempted to determine whether an appropriate dose—based on exposures received by others doing similar work—had been added to the pertinent individual's film badge exposure record. To the extent that an individual was known to be present for a specific period of time during the operation, we attempted to determine whether the film badge doses recorded in the individual's exposure record covered this entire period of time. Finally, we reviewed individual film badge exposure records for arithmetical mistakes.

To evaluate the amount of external gamma radiation received by personnel manning or decontaminating aircraft that flew through nuclear clouds, we sought all available information on all gamma radiation monitoring devices used to monitor personnel exposure during the subject operations. We observed that, particularly in the aircraft, other devices—beyond the P-meter previously discussed—were positioned in the cabin or cockpit area to monitor the crews' exposure to gamma radiation. The readings from these devices were recorded on data sheets or in ledgers, which were available on all atmospheric nuclear weapons testing operations. During our review, we obtained copies of such documents for the three subject operations and compared the readings from these devices against the readings recorded on the film badges worn by the aircraft crews.

To analyze the relative accuracies of these other devices used to monitor gamma radiation, we researched available information on these devices at the Los Alamos National Laboratory, the Reynolds Electrical and Engineering Company's Coordination and Information Center, and the U.S. Department of Energy. In addition, we interviewed an official who helped design one of the devices—the integron—and two individuals who calibrated the integron and the other devices prior to each Redwing nuclear test.

To evaluate the amount of internal radiation received by personnel manning or decontaminating aircraft that flew through nuclear clouds, we sought information on whether personnel were protected from or monitored for internal radiation exposure. In this regard, we noted that some personnel participating in early cloud penetration flights during Operation Redwing were subjected to urinalysis and whole body counter testing before and after the operation.[22] As part of our review, we obtained the results of such testing and interviewed the official responsible for the design and operation of the whole body counter during these tests. We also asked four nationally known health physicists from the Brookhaven National Laboratory, Monsanto Research Corporation, Inhalation Toxicology Research Institute, and Battelle Pacific Northwest Laboratories to estimate previous internal radiation exposure for these Redwing cloud penetration personnel on the basis of traces of plutonium found in their urine after the operation.

Finally, to develop a greater appreciation of the precautions taken to protect personnel manning or decontaminating aircraft that flew through nuclear clouds, we interviewed many of the individuals who participated in such work. Specifically, we interviewed several scientific advisors who directed cloud-sampling aircraft on these missions and the officer who directed and participated in the early cloud penetration flights at Operation Redwing. We also interviewed many of the aircrew members who flew through the nuclear clouds and the ground crew members who performed the aircraft decontamination.

[22]In 1956, the whole body counter was a large, long cylindrical device in which a human subject was placed to measure radiation emanations from the subject's body. Since 1956, the design and configuration of the whole body counter has changed.

During our review, we did not analyze the health effects of exposure to low-level ionizing radiation or the duties of the VA in adjudicating veterans' radiation-related disability claims. We did note, however, that of the cloud-sampling personnel included in our review, one Tumbler-Snapper and seven Redwing individuals have submitted claims, none of which has been granted. We made our review in accordance with generally accepted government auditing standards.

Evaluation of Radiation Doses Received by Nuclear Cloud-Sampling Personnel

A majority of the estimated 200,000 American military personnel and civilians who participated in the atmospheric nuclear weapons testing program received an average aggregate external gamma radiation exposure of about 0.5 rem, according to DNA data. In comparison, personnel who manned or decontaminated aircraft that flew through nuclear clouds received, at one test operation, a recorded average external gamma radiation exposure dose of more than 4.0 rem.

During our review, we evaluated the accuracy of the recorded radiation doses cloud-sampling personnel received at three nuclear test operations—Tumbler-Snapper (1952), Redwing (1956), and Dominic I (1962). For the latter two operations, we found information indicating that the recorded exposure to external gamma radiation for some personnel is understated. The amount of that understatement varied from individual to individual but could result in a doubling of a particular individual's recorded exposure (see app. II).

This understatement is based on determining that, for external radiation

- certain problems were or are known to exist with the film badges used to officially record exposure, particularly during operations Tumbler-Snapper and Redwing;
- certain individuals' cumulative film badge exposure records contained errors, such as exposure totals in some Redwing cases—not reflecting radiation received from fallout; and
- monitoring devices installed in the cockpit of the cloud- sampling aircraft at operations Redwing and Dominic I read higher levels of radiation than anticipated compared with the film badges worn by the aircraft crews.

We also found that possibilities existed—particularly during operations Tumbler-Snapper and Redwing—for some level of internal radiation exposure. Specifically,

- ground personnel participating in operations Tumbler-Snapper and Redwing, in comparison with Operation Dominic I, were not fully protected against possible internal radiation exposure; and
- no personnel at Operation Tumbler-Snapper and only a few personnel at Operation Redwing were monitored for internal radiation exposure.

External Gamma Radiation Exposure Assigned to Personnel Needs to Be Reexamined

Film badges are the official record of personnel exposure to gamma radiation for those who participated in the atmospheric nuclear weapons testing program. However, for personnel who manned aircraft flying through nuclear clouds, crew exposures were also measured by other radiation monitoring devices located in the cockpit or elsewhere. For example, in cloud-sampling aircraft, radiation monitoring devices were routinely positioned either on the instrument panel in front of the pilot or behind the pilot's seat. Our comparison of the readings on these devices and on the film badges, along with other information we developed, suggests that external gamma radiation exposure assigned to some personnel at operations Redwing and Dominic I is understated. For that reason, using the readings from these other devices in conjunction with film badge readings to establish personnel exposure would seem advisable and could lead to more accurate aircrew doses.

Certain Problems Were or Are Known to Exist With Film Badges Used to Record Radiation Exposures

Beginning with the first successful testing of a nuclear weapon at Alamogordo, New Mexico, in 1945, film badges were used to measure gamma radiation exposure for personnel participating in the atmospheric nuclear weapons testing program. There are several reasons for this. According to a DOD radiological safety manual prepared in 1947, film badges are small and light, provide a permanent record of exposure amount, and have no complicated circuits to become unadjusted. However, film badges also have some drawbacks. Problems can exist in the ability or sensitivity of the film to measure radiation as well as in the processing of the film—unless processing conditions are carefully controlled. These problems manifest themselves in varying degrees as inherent inaccuracies associated with all film badges. Because of these inaccuracies, we identified, in an earlier GAO report,[1] that film badge dosimetry has been in error by ±100 percent or more in assigning gamma radiation doses. (This amount of error agrees with the findings of the 1985 National Academy of Sciences study, Review of the Methods Used to Assign Radiation Doses to Service Personnel at Nuclear Weapons Tests, inasmuch as one of the principal film badge experts serving on that study also reviewed and concurred in the findings on film badge accuracy in our earlier report.)

Available information suggests, however, that several additional problems were or are known to exist with the film badges used, particularly during operations Tumbler-Snapper and Redwing. For instance, in some

[1] Operation Crossroads: Personnel Radiation Exposure Estimates Should Be Improved (GAO/RCED-86-15; Nov. 8, 1985).

cases, additional problems are identified in the historical reports DNA has prepared on these operations or in a 1985 report DNA issued on film badges used in the atmospheric nuclear tests. In other cases, additional problems are identified in documents that were prepared during or soon after these two operations. Collectively, these additional problems raise questions about the accuracy of the gamma radiation exposure doses that were measured.

Film Badges Used at Tumbler-Snapper

DNA's historical report on Operation Tumbler-Snapper does not provide a great deal of information about the film badges worn by cloud-sampling personnel during that operation. The report indicates that a type 558 film packet was used and that this film packet was given to each air and ground crew member at a briefing held the day before each nuclear test. The report also indicates that, after the second of the eight Tumbler-Snapper tests, there were indications that some of the film badges were giving erroneous readings. Therefore, it became the standard procedure for personnel to wear two film badges, taped side-by-side, with the average of the two readings recorded as the person's official dose.[2]

DNA's 1985 report on film badges used at the various atmospheric nuclear tests, including Tumbler-Snapper, also indicates that there were problems with the 558 film packet used. According to the report, there were two film components in the packet—a component designed to measure low amounts of radiation and a component designed to measure higher amounts of radiation. The data presented in the report indicate that a gap of between 6 and 20 rem apparently existed in the amount of radiation the two film components could effectively read. Similarly, according to a 1961 publication by the manufacturer of the film badge, the two film components could not effectively read radiation between 4 to 9 rem. However, according to a film badge expert at the Reynolds Electrical and Engineering Company and a major contributor to this 1985 DNA report, the two film components could effectively measure radiation up to 10 rem; but between the 10- to 15-rem range, the two film components had an inaccuracy of about plus 60 to minus 30 percent. In other words, this film badge expert estimated that if the film packet were exposed to 12 rem of radiation, the film components could interpret that exposure as being anywhere between 8.4 and 19.2 rem. According to information contained in DNA's 1985 film badge report, the

[2]Neither the report nor supporting documents described what was meant by, or the basis for, indications that film badges were giving erroneous readings. Further, we could not determine if averaging the readings from two film badges corrected this problem.

558 film packet was used at only one other test operation—Ivy (in the fall of 1952)—before it was discontinued.

Film Badges Used at Redwing

Over the next 5 years—from 1953 to 1957—a type 559 film packet was used. Each 559 film packet—like the film packet worn at Tumbler-Snapper—also contained two film components.

According to DNA's report on Operation Redwing, the 559 film packet was issued on both a permanent and a mission basis. A permanent badge was given to all operation personnel, beginning on April 15, 1956, with exchanges scheduled for every 6 weeks, to measure their inadvertent exposure to radiation. A mission badge was given to those personnel specifically authorized to enter known radioactive areas (radioactivity over 0.010 rem per hour). The DNA Redwing historical report also indicates that, as the operation progressed, it was found that the first set of permanent badges worn longer than 4 weeks became badly watermarked, showed severe light leaks, and were generally quite difficult to read. As a result, the exchange period for all task groups at the operation was shortened to no more than 4 weeks.

As with the Tumbler-Snapper film badge packet, information also suggests there was a certain inaccuracy associated with the two film components in the Redwing film badge. Specifically, the radiological safety reports prepared on two of the three test operations immediately preceding and one operation immediately following Redwing each commented on an inaccuracy problem associated with this particular type of film badge. For instance, the radiological safety report on Operation Castle (1954) indicated that the two film components in the Redwing-type film badge were reasonably accurate up to 3 rem, but were unable to accurately evaluate exposures in the region of 10 rem. According to a major contributor to DNA's 1985 film badge report, in the region of 10 to 15 rem, the two film components in the Redwing-type film badge were able to distinguish radiation to an accuracy of plus 40 to a minus 20 percent. In other words, this expert said if the film packet were exposed to 10 rem of radiation, the film components could interpret that as being anywhere between 8 and 14 rem.

Film Badges Used at Dominic I

In 1962, at Dominic I, a type 556 film badge packet was used that also contained two film components. While no additional inaccuracy problems are known to exist with the Dominic I badge, as existed with the badges used at operations Tumbler-Snapper and Redwing, the Dominic I badge was prone to environmental damage.

For instance, in a December 27, 1962, letter, the head of the Dominic I radiological safety section indicated that the Dominic I film badge did not stand up to the temperature and humidity. This caused the film badge, according to this officer, to register a radiation dose where none actually occurred. He also said that in cases where the dose could have been significantly high, such as with cloud-sampling pilots, the badges were changed with such frequency that no trouble was experienced.

Later, in 1980, a private dosimetry company reexamined approximately 1,350 Dominic I film badges at the request of the Navy because of anomalously high film badge readings on some ships remote from the Dominic I nuclear test sites. This company found that film damage was a major contributor to the elevated doses on these ships. The relevance of this information, however, to the film badges worn by cloud-sampling personnel is unclear. In comparison, cloud-sampling personnel were members of the Air Force who were island-based. Also, cloud-sampling personnel wore their film badges for a shorter duration and, thus, their film badges were susceptible to less environmental damage.

Individual Cumulative Film Badge Exposure Records Contained Errors

While it is important that a film badge accurately measure an individual's radiation exposure on a particular occasion, it is equally important to correctly tabulate the results of readings from film badges worn on all occasions. These tabulated results form the permanent record of cumulative film badge exposure. In turn, these permanent records—during the atmospheric nuclear weapons testing program—served to identify those persons approaching or exceeding the maximum permissible exposure for their respective operation. A determination could then be made as to those persons' continued participation in the operation.

At each of the three atmospheric weapons test operations we reviewed, it was standard practice to record individual cumulative exposure on file cards. For Operation Tumbler-Snapper, those file cards have been lost or destroyed during the intervening years and, thus, were unavailable for review.[3] For Operation Redwing, about 26 percent of those file cards contained errors. The most significant errors identified were (1)

[3]Radiation exposure doses have been assigned to Tumbler-Snapper personnel on the basis of a summary list of exposures prepared soon after that operation.

gaps on the file cards indicating missing film badge readings or occasions when a film badge was not worn and (2) situations where gamma radiation received from fallout during the Redwing tests was not added to cumulative exposure totals. For Operation Dominic I, about 13 percent of the file cards contained errors, primarily because no reading was assigned when a film badge was lost or not turned in.

During our review, we provided DNA and the Air Force with a list of those errors we identified. According to the Air Force nuclear test personnel review project manager, the Air Force has not, in the past, checked for accuracy a veteran's film badge exposure record, but instead has relied upon the Reynolds Electrical and Engineering Company—present repository for all military film badge exposure records—to provide the Air Force with an accurate exposure total for its personnel.[4] At the time of our review, the Reynolds Electrical and Engineering Company had not analyzed the Air Force film badge exposure records in its possession for accuracy but has since begun doing so at DNA's direction.

Individual Cumulative Exposure Records for Redwing

At Operation Redwing, the film badge exposure record listed the individual's name, organization, and each permanent or mission badge worn. For each permanent and mission badge, the exposure record listed the date it was returned, its number, density (a measure of blackening of the film as an indication of radiation exposure), and radiation reading expressed in millirem. By listing the date the film badge was returned, a check could be made to see whether the individual had in his possession a film badge covering the entire period of the operation. The exposure record also listed cumulative exposure by adding the readings of the individual permanent and mission badges worn.[5]

Our evaluation of approximately 280 individual Redwing exposure records showed that 74, or about 26 percent, contained errors.[6] A small

[4]Conversely, according to the DNA assistant nuclear test personnel review program manager, the Navy and the Army have made a check of the film badge exposure records for some of their respective personnel, particularly when an individual submits a Veterans Administration radiation-related disability claim.

[5]Individuals were instructed to wear both permanent and mission badges during a mission. Thus, combining the badge readings could result in a redundant recording of radiation dose. In practice, however, some individuals did not wear their permanent badges on a mission, in which cases the readings from their permanent and mission badges were combined.

[6]Eight of the film badge exposure records contained more than one type of error. Thus, a listing of the number of records with errors, by error type, does not agree with this total (74).

number—17, or about 6 percent—involved arithmetical mistakes. All the arithmetical mistakes, except one, resulted in an understatement of radiation dose, usually on the order of a few hundred millirem, with only four mistakes greater than 1 rem. These four were an overstatement of 1.1 rem and understatements of 1.4, 3.9, and 8.6 rem. An even smaller number—7, or about 2 percent—were occasions where a film badge was reportedly lost and no radiation dose credited to the particular individual's exposure record. According to DNA officials, it was and is now the military's policy to credit a particular individual's exposure record, when that person had lost his film badge, with the highest radiation dosage received by any member of that individual's party. As stated, however, for about 2 percent of the exposure records, this was not done. In a greater number of records (58 or about 21 percent), we identified two other types of errors.

Gap in Redwing Cumulative Exposure Records

At Operation Redwing, after the issuance of the first set of permanent badges worn on April 15, 1956, with exchanges scheduled every 6 weeks, it became established policy that permanent badges were to be worn for no longer than 1 month. This policy was put into effect, as previously mentioned, because it was found that the first set of permanent badges worn longer than 4 weeks became badly watermarked, showed severe light leaks, and were generally quite difficult to read. Therefore, over the entire period of Operation Redwing, permanent badges should have been worn and turned in on roughly a monthly frequency—around June 1, July 1, and August 1, 1956. In about 13 percent of the exposure records, however, a gap in or deviation from this frequency exists.

For example, figure 2.1—an actual exposure record for a person involved in removing cloud samples from aircraft—shows that only one permanent film badge was worn and turned in on June 6, 1956. His cumulative exposure total is based on the reading from that 1 permanent badge plus readings from 10 mission badges worn subsequently. There are two possibilities why no other permanent film badges were recorded in this exposure record: either (1) other permanent badges worn after June 6, 1956, were unexplainably not added to the exposure record[7] or (2) no other permanent badges were issued.

[7] One Operation Redwing report stated that film badge readings for some participants had not been added to their exposure records.

Figure 2.1: Example of a Gap in a Redwing Cumulative Exposure Record

DATE		FILM BADGE						DOSIMETER		REMARKS
		PERMANENT			MISSION			MR		
1956	NO.	DEN	MR	CUM	DEN	MR	CUM	DAY	CUM	
6 JUN	68081				0	0	0			
6 JUN	00057	0.27	485	485						
13JUN	70281				0.20	380	380			
14JUN	71122				0.05	110	490			
16JUN	71248				0.04	90	580			
22JUN	76411				0.02	50	630			
26JUN	76482				0.11	225	855			
4 JUL	76762				0.39	640	1,495			
9 JUL	77335				0.10	210	1,705			
11JUL	77736				0.09	190	1,895			
21JUL	77840				0.22	410	2,305			
22JUL	46954				0.60	900	3,205			3,690 (3,205 + 485)

4926th TESTRON 3,690
T.G. 7.4

INDIVIDUAL RADIATION EXPOSURE RECORD

Source: Reynolds Electrical and Engineering Company.

In either case, the net effect would be an understatement of this individual's exposure total to the extent that, after June 6, 1956, the 10 mission badges did not record all radiation received. Regarding that possibility, this individual told us he was a member of a section responsible for (1) removing the cloud samples from the aircraft and ferrying them from Enewetak Island to Parry Island and (2) retrieving, calibrating, and reinstalling the radiological monitoring devices on the aircraft. Our analysis of other personnel in the individual's work party who wore a similar number of mission badges, plus permanent badges, showed they had an average radiation exposure of 5.6 rem, or approximately 2 rem higher. Thus, there is a strong indication that the mission badges worn by the individual did not record all radiation received and, as a result, his radiation exposure total is understated.

Fallout Not Added to Redwing Cumulative Exposure Totals

At Operation Redwing, the only significant fallout on Enewetak and Parry Islands—on which cloud-sampling personnel were stationed—occurred after the Tewa nuclear test on July 21, 1956.[8] Fallout began at approximately 3:00 p.m. on July 21 and ended at approximately 8:00 a.m. on July 22, 1956. The Operation Redwing radiological safety report showed the average dosage received by any individual on Enewetak or Parry Islands as a result of the fallout varied from 2 to 3.5 rem, depending on the length of stay of the individual and the type of work in which he was engaged. In about 8 percent of the exposure records, however, a radiation dose resulting from this fallout was not added to the individual's cumulative exposure totals.

Figure 2.2, presents an actual exposure record for a cloud-sampling pilot. It shows his permanent and mission film badges worn with his cumulative radiation exposure totaling 6.587 rem. This total was based on mission badges worn because the total for those badges worn exceeded the permanent badge total.[9] The last entry in the mission badge column for July 21, 1956, represents the dose the pilot received in sampling the Tewa nuclear cloud that morning, as determined by evaluating his pilot data sheet. Any dose of between 2 to 3.5 rem received from the Tewa fallout later that day or the following day has not been added to the 6.587 rem mission badge total.

[8]Enewetak and Parry Islands are two of the several islands comprising the Enewetak Atoll.

[9]Individuals were instructed to wear both permanent and mission badges during a mission. Thus, combining the badge readings could result in a redundant recording of radiation dose. In practice, however, some individuals did not wear their permanent badges on a mission, in which cases the readings from their permanent and mission badges were combined.

Figure 2.2: Example of Radiation From the Tewa Fallout Not Being Added to the Cumulative Exposure Total

DATE	FILM BADGE							DOSIMETER		REMARKS
		PERMANENT			MISSION			MR		
1956	NO.	DEN	MR	CUM	DEN	MR	CUM	DAY	CUM	
7 MAY	60201				0	0[a]	0			
7 MAY	60295				0	0[a]	0			
28MAY	66212				.07	150[a]	150			
"	66213				.07	150[a]	150			
6 JUN	00086	0.07	150	150						
14JUN	71071				.21	395[a]	537			
"	71072				.20	380[a]				
26JUN	76469				.28	500[a]	1042			
26JUN	76470				.29	510[a]				
20JUN	19404	.29	510	660						
9 JUL	76617				1.79	3175[a]	4202			
9 JUL	76618				1.78	3145[a]				
21JUL	77919				1.45	2340[a]	6587			6587
21JUL	77920				1.49	2430[a]				
22JUL	20562	2.19	4095[b]	4755						
23JUL	46903	.46	725[b]	5480						

4926th TESTRON 6587
T.G. 7.4

INDIVIDUAL RADIATION EXPOSURE RECORD

Source: Reynolds Electrical and Engineering Company.

[a]Two film badges were worn per mission with the average of the two added to the cumulative total.

[b]The Tewa fallout commenced at 3:00 p.m. on July 21 and did not end until approximately 8:00 a.m. on July 22. Thus, the missing dose that was not added to the 6.587 rem assigned radiation total is the 725 MREM permanent badge for the period of July 22 to July 23, and a portion on the permanent badge with the 4095 MREM reading returned on July 22.

The pilot whose exposure record appears in figure 2.2 told us that he, indeed, remembered the Tewa fallout upon his return to Enewetak Island and instructions being given to stay indoors for a couple of hours, but no longer. He also said there was no restriction placed on swimming in the adjacent Enewetak lagoon.

Our review of the report on the task group comprising cloud-sampling personnel showed, however, that such a restriction was put into place—as a result of high radiation intensity levels being reported in the Enewetak lagoon—but not until some time on July 22, 1956, which was near the end of or after the fallout period. Any radiation dose received by an individual while swimming in the Enewetak lagoon prior to this restriction would also probably not be reflected in the individual's exposure record because of the unlikelihood, while swimming, that any film badge would have been worn.

Individual Cumulative Exposure Records for Dominic I

At Dominic I, the badging system used for cloud-sampling personnel was nearly identical to that used at Redwing. Aircrew members wore two or more mission badges on each sampling flight. These badges were usually processed on the same day. The exposure for each badge was posted on their exposure record, and a cumulative total was maintained. While not on a sampling flight, these men—according to DNA's historical report on Dominic I—wore a permanent badge for 1 to 2 weeks' or for 1 to 2 months' duration. The DNA report also indicates that ground crew personnel, though not issued mission badges, were issued new permanent badges every 7 to 10 days.

Our evaluation of approximately 295 individual Dominic I exposure records showed that 37, or about 13 percent, contained errors.[10] A small number—15, or about 5 percent—were the result of arithmetical mistakes. For those, seven mistakes were understatements and eight mistakes were overstatements of radiation dose, with only one of the mistakes greater than 1 rem—an overstatement of 9.04 rem. In a larger number of records—26, or about 9 percent—film badges were lost or not turned in by individuals and, thus, any dose on those badges was not added to the individuals' exposure totals.

Figure 2.3 presents an actual exposure record that shows this individual's exposure total was 2.363 rem, based on 10 permanent film badges worn. The record also shows that an eleventh permanent film badge was issued on October 10, 1962, but no recording was made of a process date or exposure dosage for this badge. Any dosage that existed on this badge was not added to this individual's exposure total.

[10] Four of the film badge exposure records contained both arithmetical mistakes and lost or missing badges. Thus, a listing of the number of records with errors, by error type, does not agree with this total (37).

Figure 2.3: Example of a Film Badge Dose Not Added to an Individual's Cumulative Exposure Total

Film Badge No.	Issue Date	Process Date	Dosage (mr)	Accumulated Dosage (mr)
28973	16 May 62	24 May 62	79	79
27628	10 May 62	17 May 62	95	174
18854	17 Apr 62	12 May 62	0	174
170433	23 May 62	6 Jun 62	524	698
53051	5 Jun 62	11 Jun 62	557	1255
53295	12 Jun 62	20 Jun 62	860	2115
56092	19 Jun 62	20 Jun 62	0	2115
14147	24 Apr 62	11 May 62	100	2215
63818	30Sept 62	11 Oct 62	108	2323
62497	10 Oct 62			
12702	24 Oct 62	2 Dec 62	40	2363

Serial No.: ________ Soc. Sec. No.: ________ Date of Birth:

Source: Reynolds Electrical and Engineering Company.

The individual whose exposure record appears in figure 2.3 told us that he was continually involved in removing radiological samples from cloud-sampling aircraft and was not absent for any period of time during October from the Dominic I operation. Therefore, it seems probable that, given the nature of this individual's work, a dosage may have existed on the October 10, 1962, badge that was not posted to his exposure record.

Monitoring Devices Read Higher Levels of Radiation Than Anticipated Compared With the Film Badges Worn by the Aircrew

While a film badge has its advantages, one disadvantage is that it does not provide an immediate measure of gamma radiation. It must first be sent to a lab and processed, like photographic film, before a radiation exposure can be read. Therefore, at each weapons testing operation in which cloud-sampling flights were made, another radiation monitoring device was used by aircrews to operationally monitor and control their exposure. This device told the aircrews when they were approaching their prescribed dosage limit and, thus, needed to abort their mission and return to base.

For two of the three operations included in this review, we found that the monitoring device used to operationally control gamma radiation exposure, the integron, read higher levels of radiation than anticipated compared with the film badges worn by the crew. As a result of readings kept during earlier weapons tests, a ratio was known to exist between the radiation reading on the integron and the film badges used. This meant that the integron and the film badges used were consistently measuring a somewhat different amount of radiation, but the difference remained essentially fixed, resulting in a known ratio. In 65 percent and 72 percent of 147 and 189 comparisons at operations Redwing and Dominic I, respectively, however, the radiation reading on the integron exceeded this ratio, suggesting that either the integron read high or the film badges read low. If the latter occurred, aircrews received a larger amount of gamma radiation than has been officially recorded.[11]

When we presented these data to DNA for its review, the agency discounted the data's importance. DNA said that (1) the film badge has been considered the best indicator of personnel exposure to gamma radiation for more than 40 years and (2) the difference in readings by the integron and the film badges, on average, was not statistically significant. We disagree. While the film badge has been extremely useful over the years in measuring gamma radiation, it is not regarded as an infallible instrument. Indeed, information presented earlier in our report shows, we believe, that problems can and did occur with the use of film badges. Therefore, it seems prudent to take advantage of those situations where readings from other radiation monitoring devices are available to verify film badge readings. In addition, integron readings that are, in some cases, at least 1-1/2 times higher than readings by film badges are significant. Further, however, the integron was also not an infallible instrument and, for that reason, it would be unwise to advocate, without reexamination, its use—over the film badge—as the official record of personnel exposure to radiation.[12]

Integron Used at Operation Tumbler-Snapper

The integron was an ion chamber device with box-like dimensions. At Operation Tumbler-Snapper, according to a ledger kept by a scientific advisor during the operation, the integron was mounted on the cockpit floor near the crew's feet. A meter showing the results of cumulative gamma radiation exposure measured by the integron was placed on the instrument panel for ease in reading by the aircraft crew. According to a

[11] The numbers—147 and 189—represent comparisons of integron and film badge readings. On a two-person cloud-sampling aircraft, two integron-to-film badge comparisons were possible.

[12] One cloud-sampling scientific advisor informed us that at the various atmospheric nuclear weapons testing operations he participated in the integron was maintained by Air Force personnel who may or may not have kept it in good working order.

report on the integron prepared by one of its developers, the integron's accuracy was similar to that of the film badges used.

Our review of data comparing 30 readings at Tumbler-Snapper showed that, in about two-thirds of the comparisons, the integron and the film badges agreed with each other within plus or minus 25 percent. Because it apparently gave readings in general agreement with the film badge used, the integron was ultimately used at all remaining atmospheric nuclear weapons tests. After Tumbler-Snapper, the integron was relocated in the cockpit from a floor to a chest-level position and proof-tested for susceptibility to shock and atmospheric stress.

Integron Used at Operation Redwing

At Operation Redwing, the integron was positioned in the cockpit to provide a better indication of aircrew dose. Specifically, for the single seat F-84 fighter aircraft, the integron was mounted in the instrument panel in front of the pilot and, for the double seat B-57 fighter-bomber aircraft, the integron was mounted in the instrument panel behind the pilot and in front of the radiological observer.

In addition to the integron operationally controlling aircrew exposure, by the time Operation Redwing commenced, it was known that the integron could be used to provide a check on the film badges worn by the aircraft crew. According to an April 16, 1956, memo by a Los Alamos cloud-sampling scientific advisor, a ratio of 1.25 existed—based on past weapons test experience—in the reading on the integron and the reading on film badges worn under the crews' lead vests.[13] If such a ratio were not found, the scientific advisor suggested that perhaps the film badges had become contaminated through improper handling after the mission. Therefore, this scientific advisor advocated a check of this integron-to-film badge ratio after each Redwing nuclear test.

While we found no evidence that such a check was made, our review of Redwing data comparing 147 readings showed the reading recorded on

[13]An integron reading of 5 rem compared with a film badge reading of 4 rem would represent, for example, a ratio of 1.25. Our analysis of cloud-sampling data for Operation Teapot in 1955 supported this scientific advisor's statement about a 1.25 ratio. Apparently, the ratio was due, in part, to the film badges being shielded from radiation by the lead vests. Available information indicates that the lead vests worn at Operation Redwing were comparable to ones worn at previous weapons tests. The lead vest, according to the early cloud penetration report on Operation Teapot, covered 15 percent of the body, reduced radiation exposure to that covered portion of the body by 15 percent and, thus, reduced the gamma radiation dose to the whole body by about 2.25 percent (15 percent times 15 percent).

the integron exceeded this 1.25 integron-to-film badge ratio in 96 comparisons, or approximately 65 percent of the time.[14] For Redwing cloud-sampling personnel, the readings on the integron, if accurate, suggest that these individuals received a somewhat larger gamma radiation exposure than that recorded by the film badges worn. For instance, readings from film badges worn during Redwing cloud-sampling missions show that only six individuals received a recorded gamma radiation exposure greater than 10 rem. However, according to integron readings during these same missions, 22 personnel received an exposure greater than 10 rem.[15]

In addition to these comparisons of film badge and integron readings, there is the question of whether film badges worn underneath a lead vest can accurately approximate a person's radiation exposure. As stated in a 1978 report by the National Council on Radiation Protection and Measurements,[16] if a lead-lined apron is worn and only one film badge is used, then the film badge should be worn underneath the apron to estimate the radiation exposure to the person's whole body. The report also noted, however, that the exposure of the face and neck will exceed the exposure recorded under the apron. Therefore, the report stated that the recorded dose should be increased to express thyroid and/or eye lens doses.[17]

According to the DNA assistant nuclear test personnel review program manager, DNA has not used the dose recorded on film badges worn under a lead vest to assign increased doses to the thyroid and the eye lens for cloud-sampling personnel. However, no cloud-sampling individual has submitted a VA claim for radiation-related disability because of an exposure to that portion of the body.

As best we could determine, the lead vest worn at Operation Redwing was not as large as an apron and covered an area only approximately 3

[14]At 6 of the 17 Redwing nuclear tests, the integron—compared with the film badges worn—read, on the average, at least 1-1/2 times higher.

[15]According to the scientific advisor who authored the April 16, 1956 memo, the integron—where positioned—provided an accurate indicator of the exposure to the unshielded portions of the crew's body. Thus, the use of integron readings to establish exposure provides a conservative estimate of radiation dose.

[16]The National Council on Radiation Protection and Measurements is a private non-profit organization chartered by the Congress that publishes reports on all aspects of radiation protection.

[17]The present permissible radiation dose for radiation workers in the United States to the whole body, head, trunk, lens of the eye, and gonads is 5 rem per year.

square feet. Thus, the head and neck were exposed to radiation as perhaps was the area below the waist.[18] Of the seven Redwing cloud-sampling personnel who have submitted VA claims for radiation-related disability, one person's claim was for cancer of the bladder, an organ which lies below the waist.

Integron Used at Dominic I

At Operation Dominic I, the integron was mounted in a cockpit location similar to the position it had for the Redwing nuclear tests. According to a cloud-sampling scientific advisor, the aircraft crews did not wear lead vests—as at Redwing—but instead wore a partial-pressure suit and regular flight clothing with their film badges located between the two.

Our review of data comparing 189 readings showed that the reading recorded on the integron exceeded the 1.25 integron-to-film badge ratio in 136 comparisons, or approximately 72 percent of the time.[19] In making these comparisons, we recognized that the 1.25 integron-to-film badge ratio may not be entirely applicable during Dominic I nuclear tests. Because aircrews did not wear lead vests during their missions, the readings on the integron and on film badges should have been in closer agreement than the 1.25 ratio, which was based on film badges being worn underneath a lead vest.

Therefore, we asked several cloud-sampling scientific advisors why the integron may have read measurably higher amounts of gamma radiation at both operations Redwing and Dominic I. The advisors explained that perhaps the integron (1) had malfunctioned, (2) was not properly calibrated with a radiation source, (3) overresponded to low-energy radiation,[20] or (4) had become contaminated from airborne radioactive particles that entered the cockpit during the flights. Upon further examination, none of those explanations seem to adequately account for the integron's higher readings.

For instance, we found the following:

[18]According to the 1963 History of Air Force Atomic Cloud Sampling, the seats of the cloud-sampling aircraft were also lined with lead, beginning with Operation Castle (1954), to further protect the crew from the radiation present.

[19]At 11 of the 29 Dominic I nuclear tests, the integron—compared to the film badges worn—read, on the average, at least 1-1/2 times higher.

[20]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.

- In addition to those film badges worn by the aircraft crew, two other film badges were also situated in each aircraft cockpit at Dominic I. Both film badges, in 86 comparisons with the integron, read—on the average—a 4 percent and 19 percent higher level of radiation, indicating that the integron probably did not malfunction.
- It seems likely that the integron was properly calibrated, given that both it and the crews' film badges were checked for accuracy using cobalt 60 as a radiation source.
- A 1956 scientific paper prepared on the integron by one of its developers indicated that the integron was specifically designed to protect it from overresponding to the presence of low-energy radiation.
- Airborne radioactive particles entering the cockpit would have contaminated the integron as well as the aircraft crew. According to one of the developers of the integron, the integron was designed to measure only high-energy gamma radiation, which would likewise have irradiated the crew.

If the integron readings are accurate, then Dominic I cloud-sampling personnel received, in comparison with film badges worn, a somewhat larger gamma radiation exposure. For instance, readings from film badges worn during Dominic I cloud-sampling missions show that 14 individuals received a recorded gamma radiation exposure greater than 10 rem. However, according to integron readings during these same missions, 16 personnel received an exposure greater than 10 rem.

Personnel Exposure to Internal Radiation Needs to Be Evaluated

Apart from external gamma radiation, personnel participating in the atmospheric nuclear weapons testing program were also subject to possible internal alpha, beta, and gamma radiation exposure. Such exposure can occur through three pathways—inhalation, ingestion, or cuts or open wounds—and cannot be measured by a film badge worn. Instead, other diagnostic techniques have been used during the atmospheric nuclear weapons testing program to detect personnel exposure to internal radiation. In some cases, for instance, urinalysis testing has been used to determine the presence of plutonium or other radioactive elements within the body.

We found that possibilities existed—more during operations Tumbler-Snapper and Redwing than during Dominic I—for internal radiation exposure. Figures 2.4, 2.5, and 2.6 show the evolution of protective clothing used by ground crew personnel from the earlier operations—Tumbler-Snapper and Redwing—to Dominic I. At Dominic I, ground crews wore respirators while removing radiological samples from cloud-sampling aircraft (fig. 2.6). At Tumbler-Snapper and Redwing, though, this was not consistently done (figs. 2.4 and 2.5). Despite this lack of consistent use of respirators by ground crew personnel, only a few personnel at Operation Redwing were arbitrarily monitored for possible internal radiation exposure. The results of that monitoring concluded that those personnel monitored generally received insignificant exposure doses. We found, however, that conclusion somewhat tenuous given the monitoring methods used. DNA, aware of the possibilities for internal radiation exposure, is currently in the process of more specifically estimating such exposure for cloud-sampling personnel at all atmospheric nuclear weapons tests.

Internal Radiation Exposure Possibilities at Operations Tumbler-Snapper and Redwing

At operations Tumbler-Snapper and Redwing, it appears that necessary precautions to prevent internal radiation exposure were generally followed by personnel who manned cloud-sampling aircraft. According to the 1963 History on Air Force Atomic Cloud Sampling and cloud-sampling pilots with whom we spoke, the crews breathed 100 percent oxygen from the aircraft's oxygen-breathing system throughout the mission.

On the other hand, it does not appear that similar protection was generally afforded ground crew personnel who decontaminated cloud-sampling aircraft. Available information indicates that ground crews wore film badges, fatigue suits and caps, and cotton gloves in the performance of their work. However, respiratory protection devices apparently were not worn.

In Figures 2.4 and 2.5, ground crew personnel at Tumbler-Snapper and Redwing are shown monitoring the radiation intensity of a cloud sample taken from an aircraft and washing a cloud-sampling aircraft. In neither figure is there evidence of respiratory breathing devices being used. While DNA's historical report on Operation Tumbler-Snapper stated that respiratory breathing devices were used and the DNA assistant nuclear test personnel review program manager advised us that figure 2.4 may depict a rehearsal and not represent an actual work-monitoring situation, the officer in charge in this figure told us that this was an actual work-monitoring situation and that no respirators were worn.

;ontrast of Radiological Safety ʼrotection Used at Operations ʼumbler-Snapper, Redwing, and)ominic I

Figure 2.4: Ground Crew Personnel at Tumbler-Snapper Monitoring the Radiation Intensity of Cloud Sample (1952)

Source: Operation Tumbler-Snapper, DNA 6019F, p. 153.

Figure 2.5: Ground Crew Personnel at Redwing Washing a Cloud-Sampling Aircraft (1956)

Source: DNA

Figure 2.6: Ground Crew Personnel at Dominic I Placing a Radioactive Filter in a Lead Container (1962)

Source: Operation Dominic I, DNA 6040F, p. 102.

Despite the appearance from these pictures of a possibility of internal radiation exposure, only certain Redwing individuals were monitored for such exposure. As disclosed in the early cloud penetration report mentioned in chapter 1, the pilots and a few of the ground crew personnel participating in that project were monitored before and after the operation by whole body counter and urinalysis testing. The test results concluded that none of those tested had a significant amount of radioactive material within their bodies. However, we found that conclusion may not be reliable given the monitoring methods used.

According to the person responsible for the design and operation of the whole body counter used in testing certain Redwing personnel, the device was not reliable for sensing those radioactive elements, such as iodine, strontium, or plutonium, which either localize in particular parts of the body or are not strong emitters of radiation. For instance, iodine collects in the thyroid. Unless the whole body counter used in 1956 was placed directly over the thyroid, which, according to this person, it was not, the whole body counter would not have detected any iodine.

According to four health physicists whom we contacted, the urinalysis testing that was done to determine the presence of plutonium within the body also contained some uncertainties.[21] For instance, for the Redwing personnel tested in 1956, only a single 24-hour urine sample was collected after their possible exposure during Redwing. Although a single collection was acceptable in 1956, each health physicist told us that it is now recognized that repeated urine samples should be collected over several successive days to accurately estimate the intake of plutonium. Illustrating the importance of that point, one health physicist said it would not be inconceivable for an individual's excretion of plutonium to vary by a factor of 10 from day to day.

In addition, each health physicist stated that an assumption must be made regarding whether the plutonium intake was in a soluble or insoluble form requiring weeks or years to excrete from the body. Depending upon what form is assumed, the estimated internal radiation exposure dose that was received by the Redwing personnel in question could vary considerably.

[21] The four health physicists are from the Brookhaven National Laboratory, Monsanto Research Corporation, Inhalation Toxicology Research Institute, and Battelle Pacific Northwest Laboratories.

Rather than rely upon an estimated dose, each health physicist suggested, instead, that a more prudent course may be to obtain current urinary or other bioassay results for these Redwing personnel to establish their internal radiation exposure.[22] The Veterans' Dioxin and Radiation Exposure Compensation Standards Act, (P.L. 98-542) dated October 24, 1984, requested the Secretary of Health and Human Services to prepare a report to the Congress on the reliability and accuracy of urinary or other bioassay testing techniques in determining previous radiation exposure. However, that report will not be available until the fall of 1987.

It is worth noting that at Operation Redwing, early cloud penetration personnel, who were the only ones tested after the operation, may not have received the highest internal radiation exposure doses during the operation. In comparison with those personnel, Redwing cloud-sampling personnel received a higher average recorded external radiation exposure—4.05 rem compared with 1.83. To the extent that a relationship existed at Operation Redwing between the degree of internal and external radiation exposure, then cloud-sampling personnel could have received an internal radiation exposure dose that was measurably higher.

Internal Radiation Exposure Possibilities at Operation Dominic I

At Operation Dominic I, it appears that necessary precautions to preclude internal radiation exposure were generally followed by personnel who manned cloud-sampling aircraft. According to cloud-sampling pilots with whom we spoke, aircrews were instructed to and did breathe 100 percent oxygen from the aircraft's oxygen-breathing system throughout the cloud-sampling mission.

Similarly, though in striking contrast to either operations Tumbler-Snapper or Redwing, it appears that necessary precautions to prevent internal radiation exposure were also generally followed by ground crew personnel. Figure 2.6 shows ground crew personnel at Dominic I placing a radioactive filter in a lead container for shipment to a designated laboratory for analysis. In the figure, ground crew personnel are wearing cloth head coverings and complete coveralls—with tight closures around the wrists, ankles, and neck--and respirators. In photographs provided to us by DNA, use of such clothing and devices was generally

[22] Such urinary or other bioassay results cannot distinguish between an internal radiation exposure received 30 years ago or more recently.

indicative of the protection offered ground crew personnel during the Dominic I operation.

Even though figure 2.6 indicates that adequate respiratory breathing devices were apparently used, no individuals or groups of individuals Dominic I were monitored for internal radiation exposure. According t the Air Force nuclear test personnel review team chief, no specific crit ria were ever developed by the military during the atmospheric nuclea weapons testing program on who was or who was not to receive such monitoring. Any specific decision to monitor an individual or group of individuals at a particular weapons test, according to the Air Force team chief, would have been made by the commander-in-charge or the responsible health and safety personnel in attendance on the basis of that person's judgment as to who might have received an internal radiation exposure.

Of those personnel participating in Operation Dominic I, likely candidates for internal radiation exposure monitoring, if specific criteria had existed, might have been members of the Air Force test group conducting nuclear cloud-sampling work. Twenty persons, according to DNA's historical report on Dominic I, received a recorded external radiation exposure of 10 rem or higher. All but one of these persons were members of this group.

Conclusions and Recommendations

Conclusions

Reviewing any specific aspect of the atmospheric nuclear weapons testing program is not without uncertainties and underlying risks. All pertinent program information was not permanently stored in one central location, and over the intervening years, key pieces of information have been lost, destroyed, or misplaced.

In reviewing nuclear cloud-sampling activities at three nuclear test operations—Tumbler-Snapper (1952), Redwing (1956), and Dominic I (1962)—we found some information relevant to these operations that had not been used in developing DNA's historical reports. Specifically, we were able to locate the data sheets used to record the radiation readings measured by various monitoring devices installed in the cockpit of cloud-sampling aircraft. We compared these readings with those recorded on the film badges worn by cloud-sampling personnel.

That comparison, along with other information we developed, suggests that recorded exposure to external gamma radiation for some personnel is understated and, because of that, should be reexamined. The amount of that understatement varied from individual to individual but could result in a doubling of a particular individual's recorded dose to levels in excess of the annual federal exposure limit. However, the exact number of cases in which this could occur can only be determined by further analysis.

Film badges were the official record of external gamma radiation exposure for those who participated in the atmospheric nuclear weapons testing program. However, certain inaccuracy problems, beyond the inherent inaccuracies associated with all film badges, were or are known to exist with the film badges used at operations Tumbler-Snapper and Redwing. For instance, at those two operations, it is acknowledged that problems existed in the badges' ability to effectively measure external gamma radiation over particular radiation ranges. According to a film badge expert used by DNA in preparing a 1985 report on film badges used during the atmospheric nuclear tests, the Tumbler-Snapper film badge—between 10 to 15 rem—had an inaccuracy of plus 60 to minus 30 percent. According to this same expert, the Redwing film badge—between 10 to 15 rem—had an inaccuracy of plus 40 to minus 20 percent. Because of such inaccuracies, uncertainties exist in the amount of external gamma radiation that was measured.

In addition to the need to accurately measure radiation exposure, there is the equal need to maintain an accurate, cumulative record of each film badge worn. However, for operations Redwing and Dominic I, an unusually large number of the film badge exposure records contained errors.

In some instances, arithmetical mistakes were made. In other instances, a film badge was lost or not turned in, and no radiation dose was credited to the particular individual's exposure record. In other instances, as at Operation Redwing, external gamma radiation that was received during fallout from one of the nuclear tests was not added to some of the individuals' cumulative exposure totals maintained on their exposure records.

The net effect of these and other errors identified during our review generally was an understatement of external gamma radiation exposure dose. In our view, these errors should be corrected. Moreover, given the frequency of such errors identified, a review should be made for similar errors in the film badge exposure record of each Air Force individual who participated in the atmospheric nuclear weapons testing program.

For personnel who flew aircraft through nuclear clouds, exposure to external gamma radiation was not only monitored by film badges worn on or inside clothing, but also by other devices positioned within the aircraft cockpit itself. One device in particular, the integron, was used at each of the three operations included in our review to operationally control aircrew exposure. The integron was capable of providing both an immediate measure of external gamma radiation and a check against the radiation readings on the film badges worn by the crew.

Of the three operations included in our review, at Tumbler-Snapper the integron and the film badges worn provided comparable readings. Because of that and other experiences with the use of the integron, prior to Operation Redwing in 1956, a ratio of 1.25 between the readings measured by the integron compared with film badges worn under a lead vest was known to exist. Our review of both Redwing and Dominic I readings showed, however, that, in a large percentage of the comparisons, the integron's readings exceeded the 1.25 ratio. Several different explanations were offered as to why the integron may have read measurably higher, including the possibility that the integron either had malfunctioned or was not properly calibrated with a radiation source. Upon examination, however, none of these explanations seemed to adequately account for these higher readings.

If indeed accurate, these integron readings suggest that the film badges read low and that cloud-sampling personnel received a larger amount of gamma radiation exposure than has been officially recorded. Therefore, a reexamination of integron readings should be made. This reexamination does not, however, advocate the use of integron readings in lieu of those readings made by the film badge. On the other hand, it does envision that using integron readings in conjunction with film badge readings can better define aircrew dose.

As part of this reexamination, an analysis should also be made of a person's total gamma radiation exposure based on film badges worn underneath a lead vest. According to available information, the lead vest covered only the area from the shoulders down to the waist. While this would protect the organs principally at risk—most of the active bone marrow, the lungs, gastrointestinal tract, and liver—it would not protect the thyroid, eye lens, and area below the waist. Doses to those parts of the body could lie somewhere between the readings that were recorded on the integron and the film badges shielded by the lead vest.

In addition to external gamma radiation, cloud-sampling personnel were also subject to possible internal alpha, beta, and gamma radiation exposure. That is why, particularly at Operation Dominic I, air and ground crew personnel were fully protected from such exposure. For instance, where airborne radioactive particles were possibly present, ground crews wore respirators. At operations Tumbler-Snapper and Redwing, however, similar respiratory protection devices were not consistently worn. The lack of consistency in wearing such devices during the various test operations should be recognized by DNA in its internal radiation exposure evaluation. This evaluation should also probably include estimating the internal radiation exposure received by Redwing cloud-sampling personnel who were exposed to fallout from one of the test shots and possibly inhaled radioactive materials, or who swam in the Enewetak lagoon and possibly swallowed radioactive materials. DNA, generally aware of the possibilities for internal radiation exposure, is currently in the process of estimating such exposure for cloud-sampling personnel participating in all atmospheric nuclear weapons tests.

To the extent that the Secretary of Health and Human Services reports back to the Congress that urinary or other bioassay testing can reliably and accurately determine previous radiation exposure, then possible testing of Tumbler-Snapper and Redwing ground crew personnel may be more prudent than simply estimating the internal radiation exposure doses they received. According to four health physicists whom we contacted, estimated internal radiation exposure doses can vary considerably depending upon the assumptions made.

Recommendations

We recommend that the Secretary of Defense direct DNA to

- correct the GAO-identified errors in the film badge exposure records of cloud-sampling personnel participating in operations Redwing and Dominic I and, given the frequency of such errors identified, review for similar errors the film badge exposure record of each Air Force individual who participated in any of the other atmospheric nuclear weapons tests; and
- use integron readings in conjunction with film badge readings to better define the radiation dose received by cloud-sampling personnel for all atmospheric nuclear weapons tests, including operations Redwing and Dominic I.

Agency Comments

We provided draft copies of this report to DOD, the VA, the Office of Technology Assessment (OTA), and the National Council on Radiation Protection and Measurements (NCRP). DOD concurred with most of the draft report's findings and the first recommendation that errors in film badge exposure records should be corrected. However, DOD disagreed with the second recommendation in our draft report and indicated that film badges worn by each cloud sampler is a better representation of the individual's dose than the integron. (See app. III.)

In completing this report, we have clarified our position on this matter to indicate that we are not advocating using integron readings in lieu of those readings made by the film badge. Rather, we recommend that DOD use integron readings in conjunction with film badge readings to better define cloud-sampling aircrew dose. This recommendation, which is founded on publications of the NCRP and International Commission on Radiation Units (ICRU), recognizes that readings from two monitoring devices can better establish a radiation exposure estimate for an individual than can the reading from only one monitoring device. In addition, analytically, this recommendation recognizes that the integron reading can help establish a radiation exposure estimate for an individual when it is obvious that the film badge reading is in error. Appendix III contains our detailed evaluation of DOD's comments, including examples of obvious errors in film badge readings.

The VA stated that if DNA's reexamination results in increased dose estimates for Air Force personnel involved in cloud sampling, it would want to review the records of any of those individuals who had previously filed compensation claims that were denied on the basis of low-dose estimates. An increase in the dose estimates would constitute new and material evidence requiring reconsideration of the claims under 38 Code of Federal Regulations 3.311b, if the veteran had a radiogenic disease that became manifest during the appropriate time period. (See app. IV.)

OTA informally expressed support for the findings, conclusions, and recommendations contained in the draft report. In officially commenting on the draft report, OTA offered minor comments for us to consider. (See app. V.)

NCRP's president, the former head of the ICRU, and a distinguished radiologist and film badge expert reviewed the report. Collectively, these NCRP individuals agreed with the first recommendation that errors in film badge exposure records should be corrected. However, they interpreted the second recommendation in our draft report as suggesting that integron readings should be preferred over film badge readings in assigning radiation exposure estimates to cloud-sampling aircrew personnel and, because of that, did not favor its implementation. (See app. VI).

In completing this report, we met with each of the three NCRP individuals in question to clarify our position on the integron-film badge issue. We indicated that it is our position that because problems were or are known to exist with the film badges, the integron readings can be used in conjunction with the film badge readings to better define cloud-sampling aircrew personnel dose. Each of the three NCRP individuals agreed there was merit to using the integron readings to confirm or deny, in general terms, the readings made by the film badge.

Recorded Film Badge Exposure Doses for Cloud-Sampling Personnel

Dose Ranges (rem gamma)	Tumbler-Snapper	Redwing	Dominic I
0 - 1.0	229	74	211
1.0 - 3.0	24	66	70
3.0 - 5.0	14	73	9
5.0+	2	60	38
Total	**269**	**273**	**328**

Source: Operation Tumbler-Snapper (DNA 6019F), Operation Redwing (DNA 6037F), and Operation Dominic I (DNA 6040F).

Comparison of Assigned Versus Hypothetical Exposures for Tumbler-Snapper and Redwing Cloud-Sampling Personnel Who Have Submitted Veterans Administration Claims

	Dose Estimated (rem gamma)	
	Assigned	Hypothetical
Individual A		
Non-sampling mission dose		
Based on badges worn	2.030	2.030
Sampling mission dose		
Based on badges worn	1.860	•
Based on integron	•	2.600
Total	**3.890**[a]	**4.630**
Individual B		
Non-sampling mission dose		
Based on badges worn	1.412	1.412
Exposure from fallout not previously added to cumulative exposure (estimated)	•	2.750[b]
Sampling mission dose		
Based on badges worn	9.143	•
Based on integron	•	12.000
Total	**10.555**[a]	**16.162**
Individual C[c]		
Non-sampling mission dose		
Based on badges worn	•	•
Sampling mission dose		
Based on badges worn	3.060	•
Based on integron	•	6.000
Total	**3.060**[a]	**6.000**
Individual D[c,d]		
Non-sampling mission dose		
Based on badges worn	2.680	2.680
Sampling mission dose		
Based on badges worn	•	•
Based on integron	•	•
Total	**2.680**[a]	**2.680**
Individual E[c]		
Non-sampling mission dose		
Based on badges worn	.280	.280
Arithmetical mistake (film badge dose not previously added to cumulative exposure)	•	8.620

(continued)

	Dose Estimated (rem gamma)	
	Assigned	Hypothetical
Sampling mission dose		
Based on badges worn	14.800	•
Based on integron	•	Failed to operate. Assume film badge reading of 14.800
Total	**15.080[a]**	**23.700**
Individual F[c],[d]		
Non-sampling mission dose		
Based on badges worn	.695	.695
Sampling mission dose		
Based on badges worn	•	•
Based on integron	•	•
Total	**.695[a]**	**.695**
Individual G[c],[d]		
Non-sampling mission dose		
Based on badges worn	4.150	4.150
Sampling mission dose		
Based on badges worn	•	•
Based on integron	•	•
Total	**4.150[a]**	**4.150**
Individual H[e]		
Non-sampling mission dose		
Based on badges worn	•	•
Sampling mission dose		
Based on badges worn	•	•
Based on integron	•	•
Total	**.160[a]**	

Note: Hypothetical exposures used integron readings and observed errors.

[a]This is the individual's assigned exposure based on mission and permanent badges worn.

[b]In about 8 percent of the exposure records, radiation received from fallout during one of the nuclear tests—which fell on the islands housing cloud-sampling personnel—was not added to the recorded cumulative exposure. According to information contained in the Operation Redwing radiological safety report, the number—2.750 rem—represents the average amount of radiation that was received by an individual from this fallout.

[c]Individuals C,D,E,F, and G have claimed illnesses that are presently not included on the VA's list of radiation-related diseases.

[d]Individuals D, F, and G were ground crew members who did not fly on any cloud-sampling missions.

[e]Individual H participated in Operation Tumbler-Snapper photographing the nuclear detonations from aircraft. Because Tumbler-Snapper film badge exposure records are no longer available for review, and integron readings, if any, pertinent to this individual are unknown, no analysis of his assigned dose was possible.

Comments From the Department of Defense

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

THE UNDER SECRETARY OF DEFENSE

WASHINGTON, DC 20301

ACQUISITION

3 AUG 1987

Mr. Frank C. Conahan
Assistant Comptroller General
National Security and
International Affairs Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Conahan:

This letter and enclosures are the Department of Defense (DoD) response to the General Accounting Office (GAO) Draft Report, "NUCLEAR HEALTH AND SAFETY: Radiation Exposure Estimates For Cloud Sampling Personnel Are Understated," dated May 11, 1987 (GAO Code 301726/OSD Case 7299).

The DoD concurs with most of the GAO findings and one of the GAO recommendations. The DoD has, as a matter of fact, been correcting errors in the film badge exposure records since 1979. The Department plans to continue this effort and appreciates the GAO pointing out areas that need particular focus.

With respect to the second GAO recommendation, it continues to be the Department's position that the film badges worn by each cloud sampler are a better representation of the dose to the individual than the integron. The DoD view is supported by the five scientists involved in the project at the time and who were contacted by the GAO for this study. Also, the current President of the National Council for Radiation Protection and Measurements (NCRP) reviewed the GAO report (at the GAO request), and he independently arrived at the same conclusion. All six statements are provided (see enclosures 2 through 7). Also attached to enclosure 7 is the statement by the former head of the International Commission on Radiation Units (ICRU). Another statement by a distinguished radiologist and film badge expert is provided at enclosure 8. Since the DoD does not agree with this GAO recommendation, the GAO may want to consider submitting the analysis that forms the basis of the second recommendation for independent review, such as to the Office of Technology Assessment.

See Comment 1.

2

There are uncertainties in measuring any radiation exposure, but these uncertainties do not affect the conclusion that the dose received by most cloud sampling personnel was low. Moreover, the GAO draft report suggests that the dose was overstated as well as understated. It is, therefore, the DoD position (along with the President of the NCRP) that it is misleading to conclude the doses are understated.

See Comment 2.

One of the original GAO objectives was to ascertain if the cloud sampling personnel were experiencing adverse health effects as a result of their radiation exposure. For various reasons, the GAO could not undertake this analysis. The DoD regards this issue as important, and intends to ask the National Academy of Sciences to conduct a mortality study of the men in the cloud sampling, tracking and penetration units.

The detailed DoD comments on the findings and recommendations are provided in enclosure 1. Thank you for the opportunity to comment on the draft report.

Sincerely,

Robert R. Barker

Richard P. Godwin

Enclosures
As stated

GAO DRAFT REPORT - DATED MAY 11, 1987
(GAO CODE 301726) OSD CASE 7299

"NUCLEAR HEALTH AND SAFETY: RADIATION EXPOSURE ESTIMATES FOR CLOUD SAMPLING PERSONNEL ARE UNDERSTATED"

DEPARTMENT OF DEFENSE COMMENTS

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FINDINGS

- **FINDING A: Manned Nuclear Cloud Sampling.** The GAO reported Department of Defense (DoD) estimates that between 1945 and 1962, nearly 200,000 Americans participated in the atmospheric nuclear weapons testing program, with more than half receiving some radiation exposure. The GAO observed that a principal activity at these tests was to confirm efficiency and nuclear yield by cloud sampling. The GAO noted that, whereas in the 1940s this was done by drone aircraft, in 1951 manned aircraft were assigned to this task. During the period 1951 through 1962, approximately 4,000 personnel (DoD estimate) were involved in manning or decontaminating the aircraft. The GAO explained that during sampling flights a monitoring device (either a dosimeter or an integron) warned when crew exposure was reaching certain limits. The GAO further explained that after the flight, ground crews removed radioactive samples and decontaminated the aircraft. The GAO referenced a November 1985 report, Experimental Irradiation of Air Force Personnel During OPERATION REDWING, by the Environmental Policy Institute, which indicated radiation exposure to personnel manning these aircraft may have been understated. Because of this, the Senate Committee on Veterans' Affairs and the House Committee on Energy and Commerce, Subcommittee on Energy Conservation and Power, asked the GAO to determine how many personnel were involved in nuclear cloud sampling work at three operations--TUMBLER-SNAPPER (1952), REDWING (1956), and DOMINIC I (1961)--and how much radiation was received. (p. 2, pp. 8-15/GAO Draft Report)

  DoD Position: Partially Concur. The DoD estimate of 4,000 men was for all the men in the units that had responsibility for cloud penetration, sampling and tracking from 1951-1962. Of this 4,000 total, only a limited number were involved in flying and decontaminating aircraft, while a large number were involved in maintenance, administration, meteorology and the other aircraft squadrons support functions.

See Comment 3.

ENCLOSURE 1

- **FINDING B: OPERATIONS TUMBLER-SNAPPER, REDWING, And DOMINIC I**. The GAO reported that Operation TUMBLER-SNAPPER consisted of eight low-to-intermediate-yield detonations conducted at the Nevada Proving Ground in the Spring of 1952, and cloud sampling was carried out by 270 Air Force personnel, about 80 of whom flew through nuclear clouds. The GAO found that the Atomic Energy Commission and the DoD established a limit of 3.0 rem of radiation exposure per 13 weeks, except for aircrews who were authorized to receive up to 3.9 rem. The GAO noted that, according to the DoD, the aircrews received an average of 1.13 rem and the entire test group averaged .55 rem. The GAO further reported that OPERATION REDWING took place in the Spring and Summer of 1956, at the Pacific Proving Ground and, of 205 Air Force personnel in the cloud sampling group, about 35 flew through nuclear clouds. The GAO found that in this case, 3.9 rem was established as the 13-week limit, except for aircrews who were authorized to receive up to 20 rem. (The GAO observed that in 1956, the annual exposure limit recommended by the National Council on Radiation Protection and Measurement was 15 rem.) The GAO further reported that, according to the DoD, the aircrews received an average radiation exposure of 6.85 rem and the entire test group averaged 4.05 rem. In addition, the GAO reported that OPERATION DOMINIC I was conducted from April to November 1962, near Christmas and Johnston Islands, and cloud sampling involved 330 Air Force personnel, about 85 of whom flew through nuclear clouds. For this operation, the GAO found the limits were set at 3.0 rem for 13 weeks, and 12 rem annually, except for aircrews who were allowed 20 rem for the operation. The GAO reported that, again according to the DoD, these aircrews received an average of 5.68 rem and the entire group averaged .68 rem. (pp. 16-19/GAO Draft Report)

  DoD Position: Concur.

- **FINDING C: Responsibilities Of The Defense Nuclear Agency**. The GAO reported that in December 1977, in response to various test participants' claims to the Veterans Administration (VA) for radiation-related disability compensation, the DoD assigned responsibility for a program of wide-ranging actions to the Defense Nuclear Agency (DNA). The GAO found that, in turn, the DNA established a nuclear test personnel review program, which has included:

  - compiling a roster of the American military personnel and civilians involved in the atmospheric nuclear test;

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- developing a historical report of each atmospheric nuclear test that involved American military personnel and civilians;
- 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
- providing assistance to veterans, the VA and others by researching and providing as complete data as possible on individual participation and radiation doses.

The GAO observed that with its October 1984 report on OPERATION CROSSROADS, the DNA completed its publication of a historical report on each of the 20 atmospheric nuclear weapons test operations. According to the GAO, each report (including those on OPERATIONS TUMBLER-SNAPPER, REDWING, and DOMINIC I) provides an overview of the operation, an identification of the principal organizations and branches of the Military Service involved, a description of the radiological safety procedures in place, and a summary of personnel exposures to external radiation. The GAO observed that these reports usually discuss specific personnel exposure to external radiation in terms of exposure to gamma radiation, in rems as measured by film badges (or where these were not worn or were lost--by dose reconstruction). The GAO noted that, in addition, the DNA is currently in the process of estimating possible personnel exposure to internal alpha and beta radiation. The GAO explained that both are hazards if the material is absorbed internally, and materials emitting beta radiation are a hazard if in contact with the skin. The GAO found that the current schedule calls for the DNA to publish its report on internal exposure by the Summer of 1987. (pp. 19-20/GAO Draft Report)

See Comment 4.

DoD Position: Partially Concur. It was not until 1980 that the DoD began an investigation of internal dose from alpha, beta and gamma. In the summer of 1987, the DNA will release its report on internal dose to DoD personnel who witnessed atmospheric nuclear tests in the continental United States. The internal dose report for tests in the Marshall Islands and the other oceanic tests will be released at a later date.

- **FINDING D: Reported Underestimates Of Exposure.** The GAO observed that, according to the report of the Environmental Policy Institute, the OPERATION REDWING early cloud penetration report admitted that film badges of aircrew members registered readings lower than actual exposure (in some cases by a factor of two and a half). The GAO examined the preliminary draft and final DNA reports, Early Cloud Penetration Report--OPERATION REDWING. The GAO observed the preliminary draft report discussed a radiation monitoring device called a P-meter installed on the nose of the aircraft that indicated radiation doses two and a half times higher than did film badges worn by aircrews. The GAO found the final report showed tests of the P-meter by the Air Force and the National Bureau of Standards indicated that the P-meter, at the extremely cold temperatures encountered in the nose of the aircraft, read two and a half times too high. The GAO reported it had contacted a radiation expert at the National Bureau of Standards, who confirmed this phenomena. (pp. 22-24/GAO Draft Report)

  DoD Position: Concur. These findings are consistent with what the DoD reported to the Congress in November 1985.

- **FINDING E: Gamma Radiation--Problems With Film Badges.** The GAO found that film badges were the official record of gamma radiation exposure for those who participated in the atmospheric nuclear weapons testing program. The GAO observed, however, that certain inaccuracy problems--beyond the inherent inaccuracies associated with all film badges--were known or are known to have existed with the film badges used at OPERATIONs TUMBLER-SNAPPER AND REDWING. For instance, the GAO reported that, at those two operations, it is acknowledged problems existed in the badge ability to effectively measure gamma radiation over particular radiation ranges. The GAO noted that, according to a film badge expert used by the DNA in preparing a 1985 report on film badges used during the atmospheric nuclear tests, the TUMBLER-SNAPPER film badge--in the range between 10 and 15 rem--had an inaccuracy of plus 60 to minus 30 percent; and the REDWING film badge--in the range between 10 and 15 rem--had an inaccuracy of plus 40 to minus 20 percent. Because of such inaccuracies, the GAO concluded that uncertainties exist in the amount of gamma radiation measured. (pp. 29-33, pp. 57-58/GAO Draft Report)

DoD Position: Partially Concur. The Department agrees that the inaccuracy of the film badges is greater in the area of overlap (10 - 15 rem) between the two badges in the film packet. It should be noted, however, that although the information provided by the GAO was correctly applied to the example given for OPERATION TUMBLER-SNAPPER, it was incorrectly applied for the example given for OPERATION REDWING. This incorrect interpretation of the statement was also used to calculate and report incorrect film badge inaccuracy ranges on page 33 of the report. These errors should be corrected.

See Comment 5.

In addition, even though the badges used in the operations cited did have some additional error in this range, it should be clarified that no VA claim has been filed in which a single film badge fell in the overlap range. This is true for all operations that used this type of film badge packet. If a VA claim should be forwarded that involves a single film badge reading in the overlap range, the DoD will certainly bring this error variation to the attention of the VA. It should also be noted that individuals with recorded exposures in this range are already part of the over-5-rem medical follow-up program and were informed of the potential hazards that might be associated with their exposure.

See Comment 6.

- **FINDING F: Film Badge Exposure Records Contained Errors.** The GAO reported that, beyond the need to accurately measure radiation exposure, there is the equal need to maintain an accurate, cumulative record of each film badge worn. The GAO, however, found errors in about 26 percent and 13 percent of the records used to tabulate the readings from all film badges worn by personnel at OPERATIONS REDWING and DOMINIC I, respectively. For example, at OPERATION REDWING, an estimated 2 to 3.5 rem of radiation fell on islands housing cloud sampling personnel, but this radiation was not added to about 8 percent of the individual cumulative exposure totals. In other instances, a film badge was lost or not turned in, and no radiation dose was credited to the particular individual's exposure record. Also, the GAO found arithmetical mistakes in about 6 percent of the REDWING individual exposure records--most being understatements of less than 1 rem, but one understatement was over 8 rem. The GAO concluded that the net effect of these and other errors identified during its review generally was an understatement of gamma radiation exposure dose, and that these errors should be corrected. The GAO further concluded that, given the frequency of the identified errors, a review should be made to identify similar errors in each Air Force film badge exposure record for each individual who participated in the atmospheric nuclear weapons testing program. (p. 4, pp. 33-42, p. 58/GAO Draft Report)

DoD Position: Partially Concur. Since 1979, the DoD has been aware that some source documents have arithmetic errors, and that reconstructions are necessary for periods when badges were lost or not issued. For VA claims, it is the DoD policy to conduct individual analyses of the records before responding to the VA, and will continue to conduct these rigorous analyses. The DoD has also corrected errors in the records for selected operations and will continue this effort until those source documents have been checked.

See Comment 7.

The DoD nonconcurs, however, with the GAO presumption that if REDWING film badges were not turned in at four week intervals, then the badges were lost. There are, in fact, records of issue and turn-in dates for the badges that show badges were not lost, but were worn more than four weeks (at REDWING, this would result in an overestimated dose). Moreover, at REDWING, there was an organized system to account for all badges, and any lost badges should have been noted on the source documents.

- **FINDING G: Monitoring Devices Read Higher Levels Of Radiation Than Anticipated Compared To The Film Badges Worn By The Aircrew.** The GAO reported that for personnel who flew aircraft through nuclear clouds, exposure to gamma radiation was not only monitored by film badges worn on or inside their clothing, but also by other devices positioned within the aircraft cockpit itself. The GAO noted that one device, the integron, was used at each of the three operations included in its review and was capable of providing both an immediate measure of gamma radiation and a check against the radiation readings on the film badges worn by the crew. The GAO found that at TUMBLER-SNAPPER, the integron and the film badges worn provided comparable readings. The GAO reported that, because of this and other experiences with the use of the integron, prior to OPERATION REDWING in 1956, a ratio of 1.25 between the readings measured by the integron and the film badges worn under a lead vest was known to exist. The GAO review of both REDWING and DOMINIC I, however, showed that in a large percentage of the missions flown, the integron readings exceeded the 1.25 ratio. The GAO noted that several different explanations were offered as to why the integron may have read measurably higher, including integron malfunction or improper calibration with a radiation source. The GAO concluded, however, that none of these explanations seemed to adequately account for these higher readings. The GAO also concluded that, if indeed accurate, the integron readings suggest that the film badges had read low and that cloud sampling personnel received a larger amount of gamma radiation exposure than has been officially recorded and, therefore, a reexamination of integron readings should be made. (pp. 43-49, p. 59/GAO Draft Report)

DoD Position: Nonconcur. The ratio of 1.25 plus or minus 25 percent between the integron and the film badge measurements may be valid for the earlier tests, but is not applicable to REDWING or DOMINIC I. In OPERATION REDWING, both the B-57 and the F-84 aircraft were used. The ratio of the integron to film badge measurements for the B-57 at REDWING was 1.23 plus or minus 15 percent. The ratio for the F-84 aircraft at REDWING was 1.61 plus or minus 30 percent. The higher ratio for the F-84 aircraft does not indicate that the film badge measurements were inaccurate, but does indicate that the relative shielding afforded the integron by the B-57 aircraft at REDWING was higher, thus bringing down the ratio between the integron and the film badges worn by the crew.

See Comment 8.

In OPERATION DOMINIC, where only B-57 aircraft were used, the ratio between the integron and the personnel film badge measurements was 1.39 plus or minus 30 percent. The reason for the increase over the previously established ratio of 1.25 was a change in the relative radiation environments, not errors in film badge measurements.

See Comment 9.

At DOMINIC, a film badge was also placed on the ion chamber of the integron where it would be exposed to the same radiation environment as the integron. These film badges exposed to the same radiation environment as the integron gave slightly higher readings on the average than the integron. The correlation between the film badge on the integron and the integron was close: 0.97 plus or minus 30 percent. This data demonstrate that the difference in readings between the integron and the film badges worn by personnel was due to differences in the radiation environment they were exposed to and not errors in either the integron or the film badges, and confirms that the film badge provided an accurate indication of radiation exposure.

See Comment 10.

Because the DoD conclusion that the radiation environment varied with location in the aircraft is in conflict with the GAO statement that "radiation in the cockpit was fairly uniform and positioning should not alter the integron and the crew's film badge readings by more than a few percent," the DoD contacted the five scientists interviewed by the GAO and asked them to review the DoD analysis of the data. All five scientists concurred in the DoD analysis of the data. Their statements are provided as enclosures 2 through 6.

See Comment 11.

- **FINDING H: Gamma Radiation--Film Badges Worn Under A Lead Vest.** The GAO reported that in 1952, the military began using protective barriers to reduce the crew radiation exposure, and that lead-lined vests were introduced with later operations. The GAO noted that a 1978 report by the National Council on Radiation Protection and Measurements stated that if a lead-lined apron is worn and only one film badge is used, the film badge should be worn underneath the apron to estimate the radiation exposure to the person's whole body. The GAO observed that the report also noted greater face and neck exposure and, therefore, that recorded doses should be increased to express thyroid and/or eye lens doses. The GAO found that, according to the DNA assistant nuclear test personnel review program manager, the DNA has not done this. The GAO observed that the lead vest covered only a small portion of the cloud sampling person's body. The GAO concluded, therefore, that the gamma radiation exposure, which affected the unshielded portion of the person's body, including the thyroid, eye lens, and area possibly below the abdomen, could lie somewhere between the readings recorded on the integron and the film badges shielded by the lead vest. The GAO further concluded that, as part of the DNA reexamination of integron readings, an analysis should also be made of each person's total gamma radiation exposure based on film badges worn underneath a lead vest. (pp. 14-15, pp. 46-47, pp. 59-60/GAO Draft Report)

See Comment 12.

DoD Position: Partially Concur. The DoD agrees that lead vests were used during OPERATIONS TUMBLER-SNAPPER and REDWING, but not OPERATION DOMINIC I.

The DoD provides the VA with a whole body dose, not an organ dose. According to the assistant scientific director for cloud sampling at REDWING, the lead vest covered the front

See Comment 13.

of the body from the shoulders down to and including the bladder and gonads. According to a 1957 study of cloud samplers, the vest reduced the level of radiation by 6 percent. Based on a 1962 study of cloud samplers at DOMINIC I, the pilot's seat offered at least as much shielding from radiation as a lead vest would have provided.

Thus, a pilot at REDWING was shielded by both the vest and seat. With the exception of the eye, this shielding effectively covered what the National Council on Radiation Protection and Measurements (NCRP) calls the "whole body." The NCRP defines whole body exposure as that to the blood forming organs, gonads, and the lens of the eye.

See Comment 14.

See Comment 15.

Since the vest and seat shielded the gonads and more than 80 percent of the blood forming organs, the only uncovered area was the eye lens (which the VA does not regard as a site for radiogenic illness). Consequently, the film badge worn under the lead vest reflects the whole body dose as defined by the NCRP. If the VA submits a request for dose information on a case involving thyroid cancer or some eye lens disability, and the man wore a lead vest with a film badge under it (which has not occurred to date), the DoD will inform the VA that the dose to the eye or thyroid could be 6 percent higher.

- **FINDING I: Internal Radiation.** The GAO observed that, in addition to gamma radiation, cloud sampling personnel were subject to alpha and beta radiation, resulting in possible internal radiation exposure. The GAO found, however, that OPERATION DOMINIC I air and ground crew personnel were fully protected from such exposure. For instance, where airborne radioactive particles were possibly present, ground crews wore respirators. The GAO also found that at OPERATIONS TUMBLER-SNAPPER and REDWING, it appeared that necessary precautions to preclude internal radiation exposure were generally followed by aircrews. The GAO concluded, however, that respiratory protection devices were not consistently worn by ground crews at these two operations. The GAO further concluded that the lack of consistency in wearing such devices during the various test operations should be recognized by the DNA in its internal radiation exposure evaluation. The GAO also concluded that this evaluation should include estimating the internal radiation exposure received by REDWING cloud sampling personnel exposed to fallout from one of the test shots and possibly breathing in radioactive materials, or swimming in Bikini lagoon and possibly swallowing radioactive materials. (The GAO noted that the DNA is generally aware of the possibilities for internal radiation exposure and currently in the process of estimating such exposure for cloud sampling personnel participating at all atmospheric nuclear weapons tests.) (pp. 50-52, pp. 55, p. 60/GAO Draft Report)

DoD Position: Partially concur. The DNA dose reconstruction methodology has been, and continues to be, fully consistent with this GAO finding. Respiratory protective devices, although available, were not consistently worn by ground crews at certain nuclear testing operations. The devices were on hand and the decision to wear them was up to the radiation safety officer who supervised the work. The DNA modifies internal dose estimates by protection factors attributed to respiratory protective devices when there is evidence concerning the thorough testing and use of the devices and the magnitude of the protection offered. Otherwise, internal doses are high-sided by the presumption that no respiratory protection was used. In so doing, the DNA overstates the dose to personnel who wore respiratory protective devices, but never underestimates the dose to those who did not.

See Comment 16.

The GAO discusses a person who was swimming in Bikini Lagoon, even though he lived at Enewetak Atoll. It is noted that Bikini Lagoon is not adjacent to Enewetak Atoll, but some 190 miles away. Notwithstanding, the individual would have received a lower dose while swimming than if he had been on land where his film badge would have been.

- **FINDING J: Testing For Internal Radiation.** The GAO reported that internal exposures, which can occur through three pathways--inhalation, ingestion, or cuts or open wounds--cannot be measured by an integron or a film badge. The GAO found that no personnel at OPERATION TUMBLER-SNAPPER and only a few personnel at OPERATION REDWING were monitored for internal radiation exposure, and the limited monitoring that was done may not have been reliable. The GAO noted, for example, that to test REDWING personnel for plutonium, only one 24-hour urine sample was taken after possible exposure. The GAO reported that, according to four health physicists it (the GAO) contacted, it is now recognized that repeated urine samples should be collected over several days to accurately estimate plutonium exposure. The GAO concluded that, as part of its internal radiation exposure assessment, the DNA should recognize the protective breathing devices were not consistently worn for cloud sampling ground personnel at OPERATIONs TUMBLER-SNAPPER and REDWING. The GAO noted that Public Law 98-542, The Veterans Dioxin and Radiation Exposure Compensation Standards Act, requested the Secretary of Health and Human Services to prepare a report on the reliability and accuracy of urinary or other bioessay testing techniques in determining previous radiation exposure. The GAO concluded that, to the extent the Secretary of Health and Human Services reports back to the Congress that such techniques can reliably and accurately determine previous radiation exposure, then possible testing of TUMBLER-SNAPPER and REDWING ground crew personnel may be more prudent than estimating the internal radiation exposure doses they received. (pp. 6-7, p. 50, pp. 53-55, p. 60/GAO Draft Report.)

See Comment 17.

- **DoD Position:** Partially Concur. The monitoring conducted at REDWING was reliable for determining if any significant exposure occurred. While additional tests might have refined low dose estimates--it would not have changed a low dose to a high dose. Therefore, there is no reason to disagree with the REDWING Early Cloud Penetration report (WT 1320), which states as follows:

"1. No internal radiation hazards (sic) arises from flights through thermonuclear clouds, regardless of the oxygen control setting. Urine samples showed no significant amounts of gamma-emitting fission product, beta-emitting fission products, or unfissioned plutonium.

"2. Flight through thermonuclear clouds may lead to some external fission-product contamination, but the amount is not significant from the standpoint of radiation hazard.

"3. Individuals who participate in nuclear test operations, but who do not fly through thermonuclear clouds, do not exhibit internal activity which is significantly different from the ordinary population."

The DoD concurs that the HHS investigation of possible bioassay techniques for determining previous radiation exposure is worthwhile and would welcome the application of any reliable technique to TUMBLER-SNAPPER and REDWING cloud sampling and decontamination personnel.

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RECOMMENDATIONS

- **RECOMMENDATION 1:** The GAO recommended that the Secretary of Defense direct the DNA to correct the GAO-identified errors in the film badge exposure records of cloud sampling personnel participating in OPERATIONs REDWING and DOMINIC I and, given the frequency of such errors identified, review for similar errors each Air Force individual film badge exposure record. (p. 61/GAO Draft Report)

  DoD Position: Concur, but this recommendation is essentially moot. Since 1979, the DoD has been carrying out error correction. To date, source document errors have been corrected for about two thirds of the test series. The DoD will continue to work on the remaining records and anticipates that this project will be completed in another four years.

  See Comment 18.

  In addition, it is (and has been) DoD policy to check the source documents before responding to VA requests for doses. To make sure this policy has been followed, the DoD recently conducted an internal review of VA cases. Moreover, the DNA will assume the responsiblities of the Services to ensure consistency and sustain the effort required for this task. (The Navy and Marine Corps responsibilities have already been assumed by the DNA; the Army and Air Force responsibilities will be assumed in October 1987.)

- **RECOMMENDATION 2:** The GAO recommended that the Secretary of Defense direct the DNA to reexamine, for all atmospheric nuclear weapons tests including OPERATIONS REDWING and DOMINIC I, the radiation readings measured by the integron in comparison to film badges worn and adjust, as necessary, the radiation doses assigned to cloud sampling aircrew personnel. (p. 61/GAO Draft Report)

  See Comments 1, 8, 9, 10, and 11.

  DoD Position: Nonconcur. The data cited by the GAO not only fail to indicate that there were possible errors in the film badge measurements as opposed to those of the integron, but the GAO data actually confirm the accuracy of film badge measurements (see DoD response to Finding G).

The following are GAO's comments on the Under Secretary of Defense Acquisition's letter dated August 3, 1987.

GAO Comments

1. It is not our belief nor our report's position that integron readings should be used in lieu of film badge readings in assigning radiation exposure estimates to cloud-sampling aircrew personnel. Rather, we believe—in view of the problems known to exist with film badges—that integron readings used in conjunction with film badge readings can be helpful in better defining cloud-sampling aircrew personnel dose. This position, in our view, has an adequate scientific and analytical basis.

For instance, according to the NCRP's report #57 on Instrumentation and Monitoring Methods for Radiation Protection,

> "Unless the body is subjected to a uniform distribution of dose, the 'whole body dose' and doses to critical organs cannot be strictly determined from measurements at one point or a few points. . .. At levels approaching or exceeding the maximum permissible dose, the dose to the whole body and the critical organs should be more carefully evaluated and correction factors relating to the circumstances of the exposure should be applied."

Given that there is no certainty that cloud-sampling aircrews were subjected to a uniform distribution of dose, use of integron readings in conjunction with film badge readings to better define aircrew dose would seem advisable.

In addition, there is an adequate analytical basis for using integron readings in conjunction with film badge readings, particularly when it is clear a film badge reading is in error. Table III.1 shows readings from four actual cloud-sampling missions performed by two-person aircraft to illustrate this point.

Table III.1: Comparison of Film Badge Readings With Integron Reading on Two-Person Sampling Missions

In rem gamma

	Redwing		Dominic I	
	Example 1	**Example 2**	**Example 1**	**Example 2**
Pilot's film badge reading	.330	2.675	1.000	1.700
Observer's film badge reading	2.157	7.100	0	0
Integron reading	4.100	1.800	1.500	2.950

In each of the four examples, it is clear, we believe, that because of the disparity in readings, either the pilot's film badge reading or the observer's film badge reading is incorrect. For such situations, the integron reading could arbitrate which film badge reading is correct and which is not.

Moreover, we discussed our position regarding the use of integron readings with NCRP's president, the former head of the International Commission on Radiation Units, and a distinguished radiologist and film badge expert, each of whom agreed there was merit to using the integron readings to confirm or deny, in general terms, the readings made by the film badge. Furthermore, we asked OTA to review a draft of the report, and that office, in response, informally expressed support for the findings, conclusions, and recommendations contained in the draft report.

2. Our report title has been changed to focus on the need to reexamine exposure levels. However, it is our position that far more of the radiation exposure estimates assigned to cloud-sampling personnel are understated than overstated. This position is essentially based on our review of film badge exposure records. For Operation Redwing, we found that about 26 percent of the records were in error and nearly all of that 26 percent represented understatements. For Operation Dominic I, we found that about 13 percent of the records were in error and 11 of the 13 percent represented understatements.

We also discussed with the president of the NCRP whether our report was misleading because it did not include certain information that might suggest radiation exposure estimates were overstated. In our evaluation of NCRP comments (see app. VI), we present our reasons why certain information was not included in our draft report.

3. Between 1951 and 1962, DOD estimates that approximately 4,000 personnel were in units responsible for manning or decontaminating aircraft that flew through nuclear clouds or that tracked nuclear clouds downwind, but that only a portion of the men in those units performed these specific tasks. Because we only reviewed cloud-sampling activities at three atmospheric test operations—Tumbler-Snapper, Redwing, and Dominic I—we were unable to independently develop our own estimate of the number of individuals between 1951 and 1962 involved in the aforementioned tasks. Thus, our final report has been revised to reflect the caveats placed by DOD on the 4,000 personnel estimate.

4. As provided to DOD for official review, our draft report indicated that DOD began its internal dose investigation in 1980. We also said that DOD

planned to release its internal dose assessment reports in two installments. For those DOD personnel who witnessed atmospheric nuclear tests in the continental United States, we indicated that DOD planned to release a report in the summer of 1987 and, for those DOD personnel who witnessed oceanic atmospheric nuclear tests, we indicated that DOD was preparing a similar report. However, our final report has been revised to reflect the fact that DOD's internal dose assessment will include an evaluation of the hazards of internal alpha, beta, and gamma radiation.

5. Our final report has been revised to more precisely reflect the opinions of DOD's film badge expert on the accuracy of the Redwing film badge. According to that expert, in the region of 10 to 15 rem of radiation, the two components in the Redwing film badge were able to distinguish radiation to an accuracy of plus 40 to minus 20 percent. In other words, this expert said, if the film badge were exposed to 10 rem of radiation, the film components could interpret that as being anywhere between 8 and 14 rem.

6. Contrary to DOD's statement, there has been at least one VA claim for radiation-related disability compensation in which the claimant had a film badge reading that fell in the overlap range. The claimant participated in early cloud penetration work at Operation Redwing. His total assigned dose was 15.08 rem, which included a single cloud penetration mission dose of 14.8 rem. Interestingly, we observed that this individual's film badge record included an arithmetical understatement of 8.62 rem, bringing his correct total dose to over 23 rem. This individual claimed compensation for varicose veins, defective hearing, hemorrhoids, heart disease, and a degenerative spine, none of which is considered radiation-related. Thus, it is uncertain whether his claim for radiation-related disability compensation would have been granted even if his correct total dose had been reported to the VA.

7. We disagree. Our review of available records confirms that, for 18 Redwing cloud-sampling personnel, film badges were issued and not turned in, and their film badge records did not note the missing badges. We also question whether a film badge worn for more than 4 weeks would result in an overestimated dose. Specifically, we found that 13 Redwing cloud-sampling personnel apparently wore particular film badges for more than 6 weeks. Under the environmental conditions that were present at Operation Redwing of about 80 degrees Fahrenheit temperature and about 80 percent relative humidity, several scientific publications we reviewed suggest that film badges tend to fade or underestimate dose. For instance, according to a 1963 article, "Accuracy

and Sensitivity of Film Measurements of Gamma Radiation - Part III," in Health Physics, decreases in film badge radiation readings as low as 50 percent were found in all experiments at 80 degrees Fahrenheit temperature as relative humidity increased above 60 to 70 percent.

8. In an April 16, 1956, memo, a Los Alamos cloud-sampling scientific advisor identified a 1.25 integron-to-film badge ratio, based on observed differences in readings by these two devices at earlier atmospheric nuclear tests. To independently confirm this advisor's observations, we compared integron and film badge readings from cloud-sampling flights held at Operation Teapot in 1955. On 59 Teapot cloud-sampling missions in which the single seat F-84 aircraft was used, we found that the average integron-to-film badge ratio was 1.24. However, on 61 Redwing cloud-sampling missions in which the single seat F-84 aircraft was used, we found that the average integron-to-film badge ratio was 1.64. This change in ratio on identical aircraft used during atmospheric nuclear weapons testing operations held in consecutive years shows, we believe, that a further examination of integron readings compared with film badge readings should be made.

9. According to the April 16, 1956, memo prepared by the Los Alamos cloud-sampling scientific advisor, the 1.25 integron-to-film badge ratio was based on film badges being worn underneath a lead vest. At Dominic I, aircrews did not wear a lead vest. Thus, it would be expected that the integron's and the film badge's reading would be in closer agreement than the 1.25 ratio, inasmuch as neither device was shielded from the radiation present. Because the ratio at Dominic I was higher than 1.25, as DOD has calculated, a further examination of integron readings compared with film badge readings seems warranted. Though DOD said the increase in ratio was caused by a change in the relative radiation environments, it could offer us no proof that this caused the increase. Until that proof is developed, it cannot be ruled out that the increase in ratio was not caused by errors in film badge measurements.

10. In reviewing our draft report, an NCRP distinguished radiologist and film badge expert prepared a series of calculations that illustrated why the integron and the film badge worn by the aircraft crew may read differently even when both devices operated as intended. Those calculations showed, in part, that because radiation was hitting each crew member from all directions and because each crew member's body was shielding some of the radiation from reaching the film badge worn on the chest, the film badge could conceivably read only one-half of the amount of radiation present in the surrounding environment.

Those calculations, we believe, seriously challenge DOD's assertion that the film badge provided an accurate indication of radiation exposure. At a minimum, the film badge would not have accurately recorded the radiation that was absorbed by the crew member's body and shielded from reaching the film badge. In view of those calculations, our report recommends that DOD use integron readings in conjunction with film badge readings to better define cloud-sampling aircrew dose.

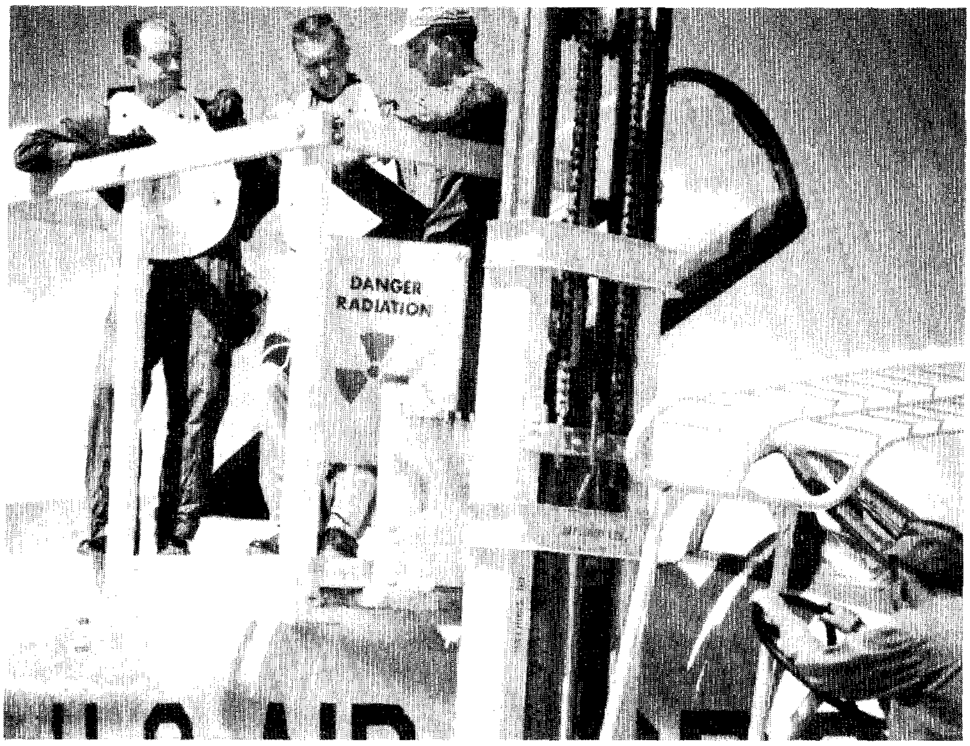
11. In responding to our draft report, DOD contacted five cloud-sampling scientific advisors and provided them with an analysis of Redwing integron-to-film badge comparisons separately for the F-84 single seat and B-57 double seat cloud-sampling aircraft. The DOD analysis showed that the average integron-to-film badge ratio for the F-84 aircraft was 1.61 and for the B-57 aircraft was 1.23. Because the integron was not similarly positioned in both aircraft at Operation Redwing, DOD concluded that positioning accounted for the difference in average ratio for each aircraft, and the five scientific advisors agreed.

If DOD had also provided these advisors with a similar analysis of data for Operation Teapot, held in 1955 (the year before Operation Redwing), the analysis would have shown that the average integron-to-film badge ratio for the F-84 aircraft was 1.24 and for the B-57 aircraft was 1.35. Whereas, at Operation Redwing, the integron-to-film badge ratio was higher in the F-84 as opposed to the B-57 aircraft, at Operation Teapot the reverse was true. Thus, an historical review of other test operations would not support DOD's conclusion that differences in radiation readings can simply be explained on the basis of the type of aircraft used.

12. Our report does not state that lead vests were worn at Operation Tumbler-Snapper. To our knowledge, no protective lead clothing was worn at that operation, but beginning with Operation Ivy, which succeeded Tumbler-Snapper, lead-glass cloth shrouds were used. According to the 1963 History of Air Force Atomic Cloud Sampling, lead vests were instituted at Operation Upshot-Knothole in 1953.

13. In preparing our report, different opinions were provided to us on the area of the body covered by the lead vest. Figure III.1 of cloud-sampling personnel at Operation Plumbbob (1957) shows that the lead vest extended from the shoulders down to just below the waist but did not cover the bladder or gonads. Redwing cloud-sampling pilots whom we contacted indicated that the lead vest used at that operation was of similar design and provided similar protection, and did not cover the bladder or gonads.

Figure III.1: Cloud-Sampling Personnel Participating in Operation Plumbbob (1957)



Source: DOD Still Media Depository

14. The NCRP defines whole body exposure as exposure to the blood-forming organs, or specifically the red bone marrow, gonads, and to the lens of the eye. According to an NCRP distinguished radiologist and film badge expert, 50 percent of a person's red bone marrow lies below the waist. To the extent that the lead vest extended from the shoulders down to only just below the waist, the film badges worn underneath the lead vest would not reflect the radiation dose to about 50 percent of the red bone marrow (lying below the waist), the gonads, or the lens of the eye.

15. According to the early cloud penetration report for Operation Teapot (1955), the lead vest worn during that operation reduced the level of radiation exposure to the chest by about 15 percent. Thus, DOD may want to review the available information on the effectiveness provided by the lead vest for the various atmospheric nuclear weapons testing operations before it reports any adjusted dose to the bladder, eye, or thyroid to the VA.

16. Our final report has been revised to show that the name of the lagoon adjacent to the island where cloud-sampling personnel were stationed was Enewetak, rather than the Bikini lagoon. Irrespective of that change, it may be speculative for DOD to assume, without further analysis, that a person's dose would be lower, while swimming, than if he had been on land wearing his film badge. A film badge measures external gamma radiation. While swimming, a person could swallow or ingest internal alpha, beta, and gamma radiation. According to an official Operation Redwing report, high radiation intensity levels were reported for the Enewetak lagoon on July 22, 1956 and, because of that, restrictions on swimming were imposed.

17. At our request, DNA and four health physicists whom we had contacted were asked to calculate a 50-year radiation dose for certain Redwing early cloud penetration personnel who were detected as having traces of plutonium in their urine. The doses calculated varied considerably. For instance, for one individual, DNA calculated a 50-year radiation dose to the bone of less than 1 rem. However, for that same individual, one health physicist from the Brookhaven National Laboratory calculated a 50-year radiation dose of 1500 rem to the bone and another health physicist from the Battelle Pacific Northwest Laboratories calculated a 50-year radiation dose to all tissues and organs (bone included) of 137 rem. The two remaining health physicists were unable to complete the calculations because of their concerns regarding uncertainties in the information. Collectively, these calculations showed that, contrary to DOD's dose estimate of less than 1 rem, the internal exposure dose could have been significantly higher. It is because of the variation in the calculations that our report concludes that it may be more prudent to use urinary or other bioassay testing to determine previous internal radiation exposure than to simply estimate the internal radiation exposure dose received.

18. It is unclear when DOD began checking source documents before responding to VA requests for dose information. As stated in our report and confirmed by DNA's assistant nuclear test personnel review program manager, the Air Force had not been performing such a check prior to our review. As part of our review, we did not independently determine when and if the other military services had been performing this check.

Comments From the Veterans Administration

Office of the
Administrator
of Veterans Affairs

Washington DC 20420

Veterans
Administration

JUN 23 1987

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

Dear Mr. Fogel:

This responds to your request that the Veterans Administration (VA) review and comment on the General Accounting Office (GAO) May 11, 1987, draft report NUCLEAR HEALTH AND SAFETY: Radiation Exposure Estimates for Cloud Sampling Personnel Are Understated. The GAO review addressed the level of external and internal radiation doses received by Air Force personnel involved in nuclear cloud sampling work at three operations--Tumbler-Snapper (1952), Redwing (1956), and Dominic I (1961). GAO questions the accuracy of some of the film-badge readings, and reports that it also identified errors in the film-badge exposure records of certain personnel that in some cases resulted in understatements of gamma radiation doses. In addition, it noted that recorded doses do not include any measure of the internal commitments of radioactive particles, something the Defense Nuclear Agency (DNA) is currently analyzing.

The report recommends that the Secretary of Defense direct the DNA to correct the GAO-identified errors in the records of personnel participating in Operations Redwing and Dominic I and, given the frequency of the errors identified, review for similar errors the film badge exposure record for each Air Force individual who participated in any other atmospheric nuclear weapons tests. GAO also recommends that DNA reexamine the readings of the integrons (cockpit-mounted measuring devices) in comparison to film-badge readings to determine if adjustments in assigned doses are warranted.

If DNA's reexamination results in increased dose estimates for Air Force personnel involved in cloud sampling, we would want to review the records of any of those individuals who had previously filed compensation claims that were denied on the basis of low dose estimates. An increase in the dose estimates would constitute new and material evidence requiring reconsideration of the claims under 38 CFR 3.311b, if the veteran had a radiogenic disease that became manifest during the appropriate time period.

Sincerely,

THOMAS K. TURNAGE
Administrator

Comments From the Office of Technology Assessment

Congress of the United States
OFFICE OF TECHNOLOGY ASSESSMENT
WASHINGTON, DC 20510-8025

JOHN H. GIBBONS
DIRECTOR

June 10, 1987

The Honorable J. Dexter Peach
Assistant Comptroller General
General Accounting Office
Washington, D.C. 20548

Dear Dexter:

As requested by you, Anthony Fainberg of OTA's International Security and Commerce Program has reviewed your draft report Nuclear Health and Safety: Radiation Exposure Estimates for Cloud Sampling Personnel are Understated.

Dr. Fainberg had already discussed contents of earlier drafts with Robert J. Baney of GAO, and has only a few minor comments or questions to add. These are listed below by page number and line.

1. 44-5-"it" has no clear antecedent, although presumably referring to DNA.

2. 46-18-The number of 22 persons receiving more than 10 rem is based on integron readings. Does this assume and use the nominal ratio of 1.25 of integron to film badge results, or does it assume that the integron readings are absolutely correct when doses are calculated? This is not clear. If the latter, there seems to be no justification for using this calculation as a measure.

3. 47-19-A nit-pick, but the bladder is generally considered to lie within, not below the abdomen. The operative question is whether the lead vest protected this portion of the abdomen or not.

4. 49-18-The dismissal of airborne particles as a cause of increased integron to film badge ratios is not entirely convincing. Couldn't the different test series produce different size particles containing different amounts of radiation? Then, if those particles were responsible for the differences in integron from film badge readings in the first place, couldn't the ratios between those readings also change from test to test?

5. 49-Last sentence. Same comment as 2: does the integron-based calculation assume the integron readings are absolutely correct or that they are 1.25 times the film badge readings?

6. 57-19-Doubling the doses recorded would certainly raise some individuals' levels above the annual Federal limit, but apparently some of the doses exceed the 5 rem/year limit as they stand.

Thank you for the opportunity to review the draft. We are pleased to be of help in this matter. If there are any questions regarding the above comments, please contact Tony Fainberg at 226-2017.

Sincerely,

John H. Gibbons

Comments From the President, National Council on Radiation Protection and Measurements

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

NCRP

National Council on Radiation Protection and Measurements

7910 WOODMONT AVENUE SUITE 1016, BETHESDA, MARYLAND 20814-3095 AREA CODE (301) 657-2652

WARREN K. SINCLAIR, Ph.D., *President*
S. JAMES ADELSTEIN, M.D., *Vice President*
W. ROGER NEY, J.D., *Executive Director*

June 5, 1987

J. Dexter Peach
Assistant Comptroller General
U.S. General Accounting Office
Wasington, D.C. 20548

Dear Mr. Peach:

Thank you for the opportunity to review the draft report of the GAO on "Nuclear Health and Safety: Radiation Exposure Estimates for Cloud Sampling Personnel are Understated".

I have made a number of comments and suggestions that I hope will be helpful. However, I think the main point is that there is very probably a rational explanation for the integron readings to be higher than film badges on the body and that the latter readings are not invalidated as a result. In my view therefore, even the words "are understated", in the title, are inappropriate. I trust the GAO will find it possible to revise its approach in the light of this important point.

See Comment 1.

Dr. Harold Wyckoff, Scientific Councellor to the ICRU and former Chairman of the ICRU, has also made some comments at my request, mainly dealing with the lack of rigor in some of the terminology used. I enclose his comments. While it is not noted in his comments, in discussion with me, Dr. Wyckoff has stated that he agrees with my explanation for the difference in integron/film badge readings.

Dr. Ted Webster, physicist at Massachusetts General Hospital, a member of the NCRP and an expert on film badge dosimetry, has also made comments, which are being sent to you separately. Again, in discussion he agrees with my explanation for the difference in integron/film badge readings and I think his comments will reflect that.

See Comment 2.

I hope these reviews will be helpful to the GAO in its work. If there are any questions or I can be of further assistance, please contact me.

Yours sincerely,

Warren K. Sinclair

Warren K. Sinclair
President

A NON-GOVERNMENT, NOT-FOR-PROFIT, CONGRESSIONALLY CHARTERED, PUBLIC SERVICE ORGANIZATION

Comments on GAO Draft Report:
Nuclear Health and Safety:
Radiation Exposure Estimates for Cloud
Sampling Personnel are Understated

Warren K. Sinclair
May 1987

I think the title is misleading. I would delete "are understated". I think this is not proven. "May be understated" could be true but its implications are unnecessary. I recommend deleting "are understated".

Executive Summary

Page 3, Results in Brief, Line 8. "is understated" is too strong. This is not proven later. It may be understated at most and probably isn't.

Page 4, Paragraph 1, Lines 9-10. "... could not effectively measure radiation between 4 to 9 rem." I don't understand why this would be and I hope it gets explained later (unless the film pack included one film with a maximum of four rem and another with a minimum of nine rem). However, in any event at Tumbler-Snapper among 1,803 badged personnel, 48 had doses between 3 and 5 and 10 only above 5. Thus, the impact is not large.

Page 4, Paragraph 2. Not mentioned here is that in the Dominic operation, about 5% had arithmetical errors, of which understatements and overstatements were about equal (page 42). This fairer statement could have been quoted as well.

Page 5, Paragraph 1, Line 4. I don't know who this individual would be. According to the list supplied to me the maximum individual exposure was 16.4 rem.

Page 5, Paragraph 2. There is a possible explanation for the differences and the variability in integron vs film badge readings. Granted that film badges have many inaccuracies they have usually been agreed to be the record of choice and they probably still are the best measure of what the wearer actually received (see later).

Pages 6-7. Of course, it would be desirable to establish what can be said (even at this late date) about internal exposure.

-1-

Page 7, Recommendations. The first one on correcting identified arithmetic and other errors is, of course, sound and sensible. On the face of it, there seems to be more of these than one would expect but fortunately the individual errors seem mainly to be small.

Second. Assuming there is more information available somewhere to reexamine, a reexamination of the film badge/integron readings may well be worth doing, with the aim of throwing more light on the probable physical explanation for the difference in integron vs film badge readings. However, the second portion of this recommendation "adjust, as necessary, the radiation doses assigned to cloud sampling aircrew personnel." seems to have the implication of revising the film badge readings upward according to the integron readings. If my explanation is correct there is no need to do this (see below, re pages 43-49). The film badge has its limitations as is well known. These are noted specifically in the NAS* report which includes a positive bias of up to 40% for up to 100 mr and of the order of ±30 to ±40% for random errors in higher exposures, but these limitations may be no worse in these circumstances than in many other occupational circumstances.

*Review of the Methods Used to Assign Radiation Doses to Service Personnel at Nuclear Weapons Tests. NAS 1985.

Page 37, Paragraph 2. "... the 10 mission badges did not record all radiation received." Not necessarily, the 10 mission badges may have recorded all the missions he actually undertook. I doubt this can be established one way or the other, now.

Pages 39 and 40. Since the permanent badge record extended to 22 and 23 of July, except for the matter of swimming, it could have included the fallout dose. Thus, it is difficult to assert that the mission total is strictly too low, since it is substantially higher than the permanent record, probably including fallout.

Page 42. Certainly the absence of a record on an issued film badge is of concern. How to allow for that now? If the highest previous exposure were added to the record it would rise from 2.4 to 3.3 rem. Neither dose is large.

-2-

Pages 43-49. The differences between the integron and the film badge worn on the body is probably quite real and has a physical explanation. Any instrument (integron ion chamber or film badge) placed in a radiation field which may be isotropic or approximately so (i.e., radiation coming in equally from all directions) will read a certain dose (kerma) value depending on how it was calibrated. Presumably, the integron, apart from a few pieces of surrounding matter, mainly cockpit and etc., is essentially or at least approximately, "free in air" and receives radiation from a 4π solid angle. However, the film badge on the body has the solid angle of radiation reduced from 4π by the presence of the body, especially from the back. This will reduce the apparent reading by an amount probably less than a factor of two but very likely of the order of 1.2 to 1.6 or so. Evidence for this explanation is available from three sources:

1) it is noted, page 48-49, that two film badges situated in the cockpit like the integron but not on the pilot, read slightly higher than the integron! This strongly supports this explanation.
2) In the Redwing series DNA gives information on ratios of integron to film badge and finds it different for two different aircraft. It is about 1.25 for B-57 and about 1.6 for the F84. Presumably, the configuration of the integron vis-a-vis the pilot in the two cockpits is different. One would guess that the integron on the F84 had less material around it and was perhaps further from the pilot.
3) Variations in the integron/film badge ratio are considerable and this would be expected if the radiation field itself were not constant. Even the size of the pilot could make a difference, so also would the configuration of the radiation field, (whether fully isotropic or not, whether the airplane was at the edge of the cloud or in the center, etc.) and the energy of the radiation field.

In view of the above, I see no reason not to assume that the film badge on the wearer's body is not as good (or as poor) a record of his exposure as for other occupational circumstances when film badges are used. In my opinion, the GAO should revise its text to take account of this very likely explanation. Thus, statements like, page 48, paragraph 1, line 6 "... should have been about the same." are incorrect, they should have been different.

-3-

Another point that should be made is that the composition of the radiation field at different points in the cloud (and at different flight times after the burst) might be quite variable. It might include not only gammas, betas, alphas, some fission products and possibly neutrons and the energies may cover a broad range. The response of both the film badge and the integron may be primarily to gammas, but possibly other particles could influence one or the other reading and perhaps differently. Much more would need to be known about the circumstances, which have probably varied in individual cases. Again this probably accounts for some of the variation seen, but does not indicate, without further information, any preference for the integron over the film badge.

Another relevant matter is just exactly how the integron and for that matter, the film badge, was calibrated. It seems unlikely that an isotopic field would be used for this purpose. Then the angular response of the integron and of the film badge both become highly relevant. It would have been very helpful if the integron itself and the method of calibration had been much more fully described.

Indeed this problem of the aircrew doses touches on an interesting general question on what doses should be specified in occupational circumstances? Choices might be, 1) the free field kerma into which a person may be put (the integron reading may approximate this), 2) the dose at the surface of the body in the field, the film badge presumably approximates this, 3) a dose to a specified organ(s) in the body such as bone marrow [this will usually be substantially less than (1) or (2)], or 4) an average dose throughout the body which may be less or more than (3) or about the same depending on the organ considered in (3). It will be less than (1) or (2).

In current occupational practice, the dose at the surface of the body as measured by the film badge on the body, is the dose that is measured and recorded. Pending a different approach to the specification of occupational doses by authoritative bodies, such as ICRU, ICRP and NCRP, it would seem that the film badge reading in this case of these aircrews is as likely to be correct as in other occupational circumstances.

-4-

Page 45, Footnote. This clearly shows that the lead vests were essentially irrelevant and at most 15% reduction. Thus the dose to the bladder, to the eye and the thyroid could only be 15% higher at most and perhaps not at all if allowance is made for the depth of the critical tissue in the body (even the lens is 1 cm or so deep).

In Summary

I have made a number of suggestions for improvement in this draft report (starting with the title) which I hope will be found helpful.

On the recommendations, first, I think the GAO report correctly recommends that arithmetic and like errors be corrected.

Second, a reexamination of the integron vs film badge readings could be very useful, assuming there is more material to examine, in order to throw more light on the probable fact that there is a real physical explanation for the integron (in "free air") to read higher than the film badge on the body.

However, given this fact, the integron readings do not invalidate the film badge readings on the body, which presumably therefore, are as true a record of the exposures of the aircrews as film badges are for other occupational circumstances.

-5-

The following are GAO's comments on the president of the NCRP's letter dated June 5, 1987.

GAO Comments

1. Our report title has been changed to focus on the need to reexamine exposure levels. However, it is our position that far more of the radiation exposure estimates assigned to cloud-sampling personnel are understated than overstated. This position is essentially based on our review of film badge exposure records. For Operation Redwing, we found that about 26 percent of the records were in error and nearly all of that 26 percent represented understatements. For Operation Dominic I, we found that about 13 percent of the records were in error and 11 of the 13 percent represented understatements.

We also discussed with the president of the NCRP whether our report was misleading because it did not include certain information that might suggest radiation exposure estimates were overstated. In that context, two specific documents were mentioned and thus further examined by us. Those documents were a 1979-80 reevaluation of approximately 1,350 Dominic I film badges, which showed that nearly half had been environmentally damaged and that the environmental damage, likely as not, had overstated the doses on those film badges, and the National Academy of Sciences' 1985 report, Review of the Methods Used to Assign Radiation Doses to Service Personnel at Nuclear Weapons Tests, which indicated that film badges irradiated under laboratory conditions with the radiation source essentially perpendicular to the badges overstated radiation by 40 percent.

Our reasons for believing that information from the first document cited may not be relevant to our review of cloud-sampling personnel were twofold. First, Dominic I cloud-sampling personnel were members of the Air Force stationed on an island, whereas the approximately 1,350 Dominic I film badges included in the reevaluation were worn by Navy personnel stationed on ships. Second, in comparison with Navy personnel, Dominic I cloud-sampling personnel wore their film badges for a shorter duration and, thus, their film badges were susceptible to less environmental damage.

Similarly, we questioned the direct relevance of the information from the second document cited on two counts. First, cloud-sampling personnel did not wear their film badges under laboratory conditions and, second, it cannot be presumed that the radiation environment in which cloud-sampling personnel functioned was essentially perpendicular to the film badge worn. Recognizing the lack of direct relevance of the National Academy of Sciences' 1985 report to the film badges used throughout the atmospheric nuclear weapons testing program, DOD contracted with the National Academy of Sciences to specifically examine the accuracy of film badges used during that program.

That contract began in April 1987 and is due to be completed near the end of 1988.

2. In finalizing this report, we met with Drs. Sinclair, Wyckoff, and Webster to clarify our position on the integron-film badge issue. We indicated that it is our position that because problems were or are known to exist with the film badges, the integron readings can be used in conjunction with the film badge readings to better define cloud-sampling aircrew personnel dose. Each of the three NCRP individuals agreed there was merit to using the integron readings to confirm or deny, in general terms, the readings made by the film badge.

Major Contributors to This Report

Resources, Community, and Economic Development Division Washington, D.C.

Keith O. Fultz, Associate Director, (202) 275-1441
Carl J. Bannerman, Group Director
Robert J. Baney, Evaluator-in-Charge
Robert P. Lilly, Evaluator
Renae M. Gilbert, Secretary

Glossary

Alpha Radiation	Radiation that 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 Radiation	Radiation that 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.
Calibrating	Checking an instrument by testing its ability to accurately measure a known amount of radiation emitted from a particular radiation source.
Cloud Sampling	A process of obtaining samples of the cloud resulting from a nuclear detonation to determine the amount of airborne radioactivity, both particulate and gaseous, contained in the cloud.
Depressurization	A reversal of the process of creating a nearly normal atmospheric environment. See pressurization.
Drone	A pilotless, radio-controlled aircraft.
Film Badge	A small piece of film or films sensitive to ionizing radiation that are encased in a metal or plastic container usually clipped to the wearer's clothing.
Film Badge Dosimetry	The measurement and recording of radiation exposure doses by the use of film badges.
Gamma Radiation	Electromagnetic radiation accompanying many nuclear reactions. Gamma rays can travel great distances through the air and can penetrate a considerable thickness of material.

Integron	An ion chamber device used on cloud-sampling aircraft to provide an immediate measure of gamma radiation present.
Ion Chamber	One of three basic types of gas ionization detectors. The typical detector consists of a cylindrical or rectangular chamber with a positively charged wire strung through the center. The chamber is filled with air or a gas, such as argon. Radiation that enters the chamber ionizes—removes electrons from—the gas. Because they are negatively charged, the electrons are attracted to the wire and reduce its charge. This reduction in charge can be measured and used as an indication of the amount of radiation present.
Low-Energy Radiation	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.
National Council on Radiation Protection and Measurements	A private, non-profit organization chartered by the Congress that publishes reports on all aspects of radiation protection.
Particulate Matter	Matter having the form of an atom or minute particle.
P-Meter	An automatic recording radiation ratemeter installed in the nose section of aircraft used on early cloud penetration flights at Operation Redwing.
Pressure Suit	A suit designed to maintain normal respiration and circulation, especially on high altitude or space flights.
Pressurization	A process of creating a nearly normal atmospheric environment, as in an aircraft, where normal breathing is possible without the aid of any apparatus. However, even on pressurized cloud-sampling missions, according to one cloud-sampling scientific advisor, aircrews breathed 100 percent oxygen from the aircraft's oxygen-breathing system.

Rem

A unit of dose of any ionizing radiation that produces the same biological effect as a unit of absorbed dose of ordinary x-rays. One millirem is one one-thousandth of a rem. The present permissible radiation dose for radiation workers in the United States is 5 rem per year.

Whole Body Counter

In 1956, a large, long cylindrical device in which a human subject was placed to measure radiation emanations from the subject's body. Since 1956, the design and configuration of the whole body counter has changed.

Yield

The total effective energy released in a nuclear detonation. It is usually expressed in terms of the TNT equivalent required to produce the same energy release in an explosion. Nuclear detonation yields are commonly expressed in kilotons or megatons (thousands or millions of tons) of TNT equivalent.

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