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EXPERIMENTAL IRRADIATION OF AIRFORCE PERSONNEL DURING

OPERATION REDWING — 1956

BY

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Preface

This report is based upon official documents on various aspects of the U.S. nuclear testing program. The document central to this report is the formerly secret report, now declassifed with deletions, on the experimental irradiation of personnel and aircraft by penetration of the radioactive clouds resulting from nuclear weapons' explosions entitled Early Cloud Penetrations.

This report would not have been possible without the insight and help of Robert Alvarez, Director of the Nuclear Weapons and Power Project of the Environmental Policy Institute. His intimate knowledge with the subject of nuclear testing and related matters has led him to discover and to recognize the significance of many documents and facts, among them the document Early Cloud Penetrations, which is the subject of this report. I would also like to thank E. Cooper Brown, and the National Committee for Radiation Victims which made the resources available for this project. Bernd Franke helped with the internal dose calculations. Elaine Hauschildt of Teamwork, Inc. did her usual letter perfect typing on short notice.

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TABLE OF CONTENTS

Page

Preface

1. Summary and Conclusions 1

2. Description of the Experiment 5

3. External Radiation Doses 10

4. Internal Radiation 18

CHAPTER 1
Summary and Conclusions

> **Maximum dose rates as high as 800 r/hr were encountered, and several flights yielded total radiation doses to crew of 15 r(oentgens), as measured by film badges, and 35 r(oentgens) to 40 r(oentgens), as measured by instrumentation more sensitive to low-energy (gamma) radiation.**
>
> Preliminary Report
> Early Cloud Penetrations
> Armed Forces Special Weapons Project

During Operation Redwing, a series of 17 nuclear weapons' tests at Bikini and Enewetak in 1956, the Commanders of Joint Task Force Seven conducted an experiment in which Air Force personnel and aircraft were deliberately and repeatedly flown through highly radioactive mushroom clouds. This experiment is now officially labeled as Human Experiment #133 by the Department of Energy in its communication with the House Subcommittee on Energy Conservation and Power of the U.S. Congress. The purpose of this experiment was to subject personnel and aircraft to radiation to obtain information which would enable the Air Force to plan operations in and near mushroom clouds in case of nuclear war.

The operation was undertaken with the full knowledge that it was very hazardous and would subject personnel to substantial doses of radiation. As long ago as May 1945, the chief scientist of the team that designed the first atom bomb had warned that "aircraft must avoid coming close to the cloud of (radio)active material."

Drone aircraft sent into the mushroom clouds during the tests after World War II confirmed the lethal levels of radiation

in them at times a few minutes after the detonation. A report on Operation Greenhouse said that while some penetrations may be lethal, some pilots may be able to return to base since "the effects of radiation are frequently sufficiently delayed to permit such an operation even though the crew were eventually doomed."

The penetrations of the mushroom clouds were delayed by a few minutes (to a minimum of 20 minutes after the detonation) to avoid immediate radiation sickness. High levels of radiation up to 800 roentgens per hour were encountered by the aircrews. Most of the crew members received well over the maximum permissable radiation level of 3.9 roentgens set for personnel for Operation Redwing. In anticipation of this, a different standard was adopted for the aircrews. They were permitted to receive 3.9 roentgen during a single flight and 20 roentgen during the entire operation. These limits were also exceeded. The maximum recorded dose to a crew member was 40 roentgen. Anywhere from 26 to over 100 personnel were involved in the early cloud penetrations which involved experiments as well as cloud sampling.

<u>One of the most significant aspects of the official preliminary report of the human experiment is that it admits that film badge readings of radiation doses were too low by a factor of two and a half</u>. Thus, when the film badges measured radiation levels of 15 roentgen to the crew, more sensitive instruments measured 35-40 roentgen. This fact has, however, been entirely omitted by the Defense Nuclear Agency in its official assessment

in 1982 of the radiation doses at Operation Redwing. The team that prepared the 1982 report was familiar with the special report on the early penetration experiment which stated flatly that film badges were only "minimally responsive" to low-energy radiation. Yet it chose to ignore, perhaps even suppress this fact. The claims of the Defense Nuclear Agency (and through it, those of the Veterans Administration) that film badges are the best available source of external radiation estimates is not correct. This claim has been shown to be technically untenable by the finding of its predecessor agency, the Armed Forces Special Weapons Project that film badges systematically under-record radiation exposures in at least some circumstances. If the same correction factor of 2.5 is applied to all the personnel of Operation Redwing almost 40 percent (about 5,500) of them received doses exceeding the maximum permissable of 3.9 roentgen established for the Operation.

The Defense Nuclear Agency also does not deal with the high likelihood that the many crews which decontaminated the highly radioactive aircraft received internal radiation doses. They wore no respirators as they hosed down the aircraft with high pressure jets. Many marines during Operation Redwing were also in a similar position of cleaning up deliberately contaminated ships by hosing and scrubbing. This created a situation in which personnel were put in an entirely unpredictable situation for which data do not exist for the calculation of internal doses. Yet the Defense Nuclear Agency maintains that internal doses were

generally insignificant during the atmospheric testing program. It does not even discuss them in its Operation Redwing report.

The evidence here supports the general conclusion that the personnel were probably subjected to substantially higher doses of external and, in many cases, internal radiation than the Defense Nuclear Agency has admitted. It also suggests that the Defense Nuclear Agency has at best due to incompetence, or at worst deliberately, kept information regarding the inadequacy of film badge data from the veterans, their families, and the public at large.

CHAPTER 2

Description of the Experiment

Operation Redwing consisted of a series of 17 explosions of thermonuclear weapons (hydrogen bombs) at the Pacific atolls of Bikini and Enewetak in 1956. The purpose of the series was to test the effects of a variety of hydrogen bomb designs for the U.S. nuclear arsenal.[1] A number of "technical experiments were carried out in conjunction with each of the 17 detonations. These experiments measured the yield and efficiency of the devices and attempted to gauge the military effects of the explosions."[2] As a part of this experimental program, the Commander of Joint Task Force Seven, who was responsible for Operation Redwing, conducted an experiment in which Air Force personnel flew B-57B and F-84 planes through the intensely radioactive mushroom clouds that resulted from the thermonuclear explosions.

The purpose of this experiment was to secure information which would enable "the operational commands of the Air Force in their planning to insure the most effective utilization, consistent with crew safety, of aircraft in cloud areas."[3] (As we shall see, considerations of "crew safety" were not based on long term criteria.)

In order to do this operational planning, the command of Joint Task Force Seven decided to conduct Project 2.66, "Early Cloud Penetrations." This would provide detailed data on radiation doses in radioactive clouds:

"The objective of this project (2.66) was to measure the radiation dose and dose rate one would experience in flying through the cloud resulting from a megaton-range weapon and some factors affecting personnel safety in the event of an operational situation requiring flights through such clouds."[4]

A large amount of specific data was sought. As part of this program, 27 penetrations of radioactive mushroom clouds were made during 6 of the nuclear tests. These shots were code-named CHEROKEE, ZUNI, FLATHEAD, DAKOTA, APACHE, and NAVAJO. (Other planes also penetrated the mushroom clouds of several tests, as parts of other projects.) Five B-57B planes were used. The mushroom clouds were penetrated at times varying between 20 and 78 minutes after the explosions. The data obtained were "on the radiation dose rates inside the cloud, the total dose received in flying through the cloud, and the conditions of flight inside the cloud."[5] In addition, data were sought on "conditions of flight inside the radioactive cloud; i.e., turbulence and icing."[6]

Another part of this experiment consisted of flying F-84 and/or B-57 aircraft through the mushroom clouds in order "to establish the radiation levels on various sections of planes and assess the protection to the aircrew afforded by wearing different types of gloves."[7] These aircraft entered the radioactive clouds at times varying from 24 to 40 minutes after the explosion. In addition to the five B-57B aircraft, one F-84 appears to have been used.

Each aircraft involved in the Early Cloud Penetration experiment was equipped with several specifically designed instruments. The instruments were designed to measure radiation rates, total radiation, degree of aircraft contamination, the

time of flight through the radioactive clouds, etc. Since there were only six aircraft involved, each one was used several times. Some aircraft made more than one run through a particular radioactive cloud.

The official report issued by the Defense Nuclear Agency on Operation Redwing as part of its Nuclear Test Personnel Review series has identified only twelve people who were the crews of the six aircraft involved.[8] If this is correct, then it is important to note that these twelve men were involved in several early penetrations of highly radioactive clouds.

While the Early Cloud Penetration experiment was a specific project, with a designated project number, designed to experimentally irradiate the men and aircraft, there was also a program of collecting samples of the radioactive particles in mushroom clouds. This sampling program involved at least five other B-57 and six other F-84G aircraft. Presumably this program gave the Joint Task Force Seven and the Atomic Energy Commission data on the characteristics and efficiency of the explosion. (A similar, complementary effort to collect land fall-out data was also conducted.) The mushroom cloud sampling program involved more than 130 flights into radioactive clouds, at short times after the bombs were detonated. We do not know the number of people involved in this program.

Table 1 shows the number of aircraft involved in each test in the Early Penetration irradiation experiment and in the sampling program. There were a total of 156 flights involved in early radioactive cloud penetrations. The number of penetrations

was higher because of multiple penetrations by some aircraft during a single flight.

The largest number of aircraft involved in a single test was 16, according to the Defense Nuclear Agency. This was during shot ZUNI, a three-and-a-half megaton explosion over Bikini on May 28, 1956. Ten of these were B-57's and six were F-84's. The B-57's normally had a crew of two, and the F-84's a crew of one. Thus, at least 26 personnel were involved in the cloud sampling. According to Langdon Harrison, who was present at Operation Redwing, and was a crew member on many cloud sampling flights, over 100 personnel may have been involved in the sampling program alone.

TABLE 1

Number of Aircraft Involved in Early Radioactive Cloud Penetrations During Operation Redwing

		Early Penetration Experiment, Project 2.66		Sampling Program	
SHOT	NAME	# of B-57's	# of B-84's	B-57's	F-84's
1.	CHEROKEE	1	1	4	6
2.	ZUNI	5	-	5	6
3.	FLATHEAD	4	-	5	-
4.	DAKOTA	(Note 2)	(Note 2)	5	6
5.	NAVAJO	5	-	5	4
6.	TEWA	-	-	5	4
7.	LACROSSE	-	-	2	6
8.	YUMA	-	-	-	4
9.	ERIE	-	-	2	6
10.	SEMINOLE	-	-	2	6
11.	BLACKFOOT	-	-	1	6
12.	KICKAPOO	-	-	1	6
13.	OSAGE	-	-	1	6
14.	INCA	-	-	1	6
15.	MOHAWK	-	-	6	2
16.	APACHE	4	-	5	4
17.	HURON	-	-	4	4
TOTAL FLIGHTS		19+	1	53	82

Source: Operation Redwing - 1956, Defense Nuclear Agency, Report No. DNA 6037F, Washington, DC, August 1, 1982; Chapters 4 and 5.

Note 1: The first six tests listed were at Bikini atoll. The test were an Enewetak.

Note 2: The DAKOTA test was part of Project 2.66, but participating aircraft are not shown in the list in the Defense Nuclear Agency report.

CHAPTER 3

External Radiation Doses

> Maximum radiation dose rates as high as 800 r/hr. were encountered, and several flights yielded total radiation doses to crew of 15 r, as measured by film badges, and 35 to 40 r as measured by instrumentation more sensitive to low-energy radiation.[10]

Air Force personnel were sent into the radioactive mushroom clouds with the full knowledge that it was dangerous and could result in heavy radiation doses. As early as May 11, 1945, more than 2 months before the first atomic explosion near Alamogordo in New Mexico, J. Robert Oppenheimer, who headed the scientific team that designed that first atomic bomb, had warned against it. In his prediction of the effects of the first atomic bomb he warned that "(a)ircraft must maintain a minimum distance from the detonation in order to avoid radiation.... Following aircraft must avoid coming close to the could of (radio)active material, and monitoring to determine the extent and disposition of the (radio)activity will be necessary if aircraft are to enter the area within hours of the primary detonation."[11] In Operation Redwing, aircraft entered the radioactive cloud as early as 20 minutes after the detonations.

In atomic bomb tests after the World War II, drone aircraft were used to measure radiation levels inside the radioactive clouds. Drones were sent into the clouds of the three atomic explosions of Operation Sandstone, at Bikini atoll in 1948. These drones measured radiation levels of up to 1,000 roentgens per minute at times about 7 minutes after the detonation.[12] A report of the subject concluded that radiation in radioactive

clouds "would be sufficiently high as to provide considerable hazard and therefore such contact should be avoided (by personnel). If the mushroom head of the cloud is penetrated the external radiation would frequently be ... lethal."[13] The report also speculated on the question as to whether the crew of a manned flight would be too sick to return to base:

> However, such a return (to base) does not appear to be ruled out. For the effects of radiation exposure are frequently sufficiently delayed to permit such an operation even though the crew were eventually doomed.[14]

Subsequent drone penetrations of mushroom clouds during Operation Greenhouse in 1951, confirmed the high levels of radiation and danger of entry. Yet, the first manned penetrations were conducted during Operation Teapot in 1955.[15] We have not studied the manned penetrations during Operation Teapot.

The manned penetrations during Operation Redwing were delayed to 20 minutes or more, which was sufficient to prevent immediate symptoms, and to allow return to base. They were, however, made in full recognition of the great danger of high radiation rates. The radiation standards for the aircrews of the experiment were quite different from those of the rest of the personnel of Operation Redwing.

The crews involved in the Early Penetration experiment encountered high radiation levels on most flights. The recorded radiation rates ranged up to 800 roentgens/hour (approximately 800 rads/hour) during the early penetrations.[16] Since the decision-makers of Joint Task Force Seven had anticipated high

radiation levels, they set different standards for the experimental personnel than for the other personnel involved in Operation Redwing. The total maximum permissible exposure to external (gamma) radiation established for the 13-week duration of Operation Redwing was 3.9 roentgens.[17] The limit "for the aircrews on this project was 50 r(oentgens) with a limiting planning dosage of 25 r for any single penetration."[18] It appears from this passage that the limits were the sum of the external radiation to be received by the two crew members. The maximum dose for each crew member, therefore, appears to have been 25 rads, with a sublimit of 12.5 rads per penetration. The exposure standards, as distinct from the "planning" figures above were different. According to this, the maximum exposure to external radiation per crew member was to be 20 roentgens (gamma only).

In addition, there was a "stipulation that if an aircrew member accumulated 3.9 r or more on any one mission, no second mission would be authorized before a lapse of 13 weeks had occurred."[19]

The standards were apparently violated, as best as we have been able to determine. Even the planning figures were exceeded on several occasions. The most sensitive electronic instruments on the aircraft recorded total exposure to the crew of 35 to 40 roentgens on several flights. The film badges recorded only 15 roentgens. The discrepancies were not due to recording errors. They were attributed by the project report to the fact that the electronic instruments were able to measure relatively low-energy

of 2.5, it would mean that the highest dose of external radiation alone was 40 roentgens and that 12 persons got more than 25 roentgens. The number of people with over 10 roentgens would increase from 12 to over 1,100. A similar adjustment of all external doses by a factor of 2.5 would increase the estimate of the number of personnel who received more than the official limit of 3.9 roentgens from about 1,200 to about 5,500 or about 40 percent of the personnel who participated in Operation Redwing. In practice, external dose estimates would not be so easy to determine. Besides the well-known problems with interpretation of badge dark spots (which indicate irradiation of the badges), deterioration of badges with wear, etc., a simple scaling up does not address the question of the proportion of low-energy gamma radiation encountered by operation personnel. Since this proportion varies with time, a detailed knowledge of each individual's activities and the time of these activities is necessary. In such an endeavor, a detailed survey of every atomic veteran would appear to be essential. This the Defense Nuclear Agency and the Veterans Administration has refused to do.

The question of the validity of film badge data goes far beyond this particular experiment or even the entire operation. It goes to the heart of the "dose reconstruction" method used by the Defense Nuclear Agency. These data are also the basis on which the Veterans Administration makes its decisions on veterans' claims. Both these agencies have treated film badge data as accurate. The entire reporting of doses by the Defense Nuclear Agency for all external doses is based almost solely on

film badge data. When badge data are not available for individuals, the data of others are used to infer the doses. In spite of many criticisms of its methods, the Defense Nuclear Agency has persisted in using the badge data as the best and most accurate estimating method for radiation doses.

The preliminary report Early Cloud Penetrations which is the subject of the present analysis was, however, an official report of the Armed Forces Special Weapons Project, which was the name of the Defense Nuclear Agency in the 1950's. In effect, one of the Agency's own reports noted almost 30 years ago that film-badge data were systematic underestimates of external gamma radiation doses because the badges were only "minimally responsive" to low-energy gamma radiation. It also had instruments available which could have been used to improve readings and estimates. Instead, it appears that the Defense Nuclear Agency had deliberately chosen not to report this large under-recording of radiation doses by film badges.

It is, perhaps, also significant that the official Defense Nuclear Agency Report of Operation Redwing issued in 1982, lists the Early Cloud Penetrations as "not available" to the public, and among those documents which may "become available during the declassification review process."[26] However, the preliminary report entitled Early Cloud Penetration was declassified in April 1960, and available to the public by the Office of Technical Services of the Department of Commerce as long ago as 1960. The author of the present analysis obtained his copy from the Library of Congress. It is remarkable that a report which had been

declassified (with deletions) for over 20 years, with all copies presumably so marked, was listed as "not available" by the Defense Nuclear Agency in 1982.

There are further questions regarding the Defense Nuclear Agency's assessment of doses for the aircrews involved in the early cloud penetration experiment. It lists the highest recorded (film-badge) external dose as 16.4 roentgens. The Early Cloud Penetration report states that the "maximum total dose received by a crew member during a penetration flight ... was approximately 16 r, as measured by film dosimetry."[27] Further, the report states that total dose to the crew exceeded 15 roentgens on "several flights." This is more than 7.5 roentgens per crew member. Thus, for the maximum dose over the entire experiment to have been 16.4 roentgens would probably have required a considerably larger number of crew members than the 12 acknowledged in the 1982 Defense Nuclear Agency report.

Many of the cloud sampling crews also probably received large doses of radiation. Cloud sampling involved flying into the mushroom cloud or through the stem of the mushroom cloud in order to collect outside air laden with radioactive particles. This was pumped into compressed air tanks carried in the aircraft. According to Langdon Harrison, who was part of the sampling crew, collection of a sufficient quantity of air often required several passes through the stem.[28]

It is difficult to form an accurate picture of the external radiation doses received by the aircrews involved in the early penetration experiment and in cloud sampling. However, we have

enough data to know that many received large doses of whole body radiation. A dozen or more may have received over 25 rads of external radiation during the flights above, when the film-badge dose rates are adjusted for under-recording. They undoubtedly received further doses during the rest of their stay and in their other activities during Operation Redwing.

CHAPTER 4

Internal Radiation

There is practically no discussion of internal radiation during Operating Redwing in the official report of the Defense Nuclear Agency. This question is also not mentioned in the edited, public version of the report on early cloud penetrations. We understand that the cloud penetration aircrews wore masks and were supplied with pure oxygen for breathing.[29] We do not know if the radioactive air from the cloud was filtered and taken in to maintain internal cabin pressure. In that case, it is likely that the internal surfaces of the aircraft and its equipment may have become substantially contaminated. Of course, the external aircraft surfaces and engines became intensely radioactive. About 15 percent of the external radiation dose to the crews during flight was during the return flight, after exit from the mushroom cloud. The flights through the mushroom clouds varied between 1 and 5 minutes, and return flights were about 50 minutes. Some sampling crews who repeatedly penetrated the radioactive cloud may have had higher doses if they stayed in flight longer.

The radiation danger to the crews did not stop with the flight, of course. Like all other personnel they were exposed to the hazards of living and working in a radioactive environment during most of the 13-week duration of Operation Redwing.

We do not have a description of the other activities of the aircrews. However, much of the work on the ground associated with the project, in particular the decontamination of the early

penetration and sampling aircraft, is quite likely to have resulted in substantial internal radiation. It was apparently not the practive to wear masks while decontaminating aircraft and other equipment. These were hosed down by personnel using high-pressure water jets, as can be seen from the photographs in Figures 1 and 2. The high-pressure jets undoubtedly caused substantial quantities of radioactive contaminants to be come suspended in the air. Figure 3 shows the forehead of a person marked as contaminated as the rest of him is being checked. The amounts of radioactive materials that were inhaled by the personnel probably varied greatly from one person to the next and there is now no way to determine what these were. Given the heavy contamination of the aircraft and the clearly dangerous nature of the practice, and the failure to issue respirators (which were available), there is a strong case to be made for presuming that the atomic veterans who have radiation-related diseases that their official duties during the tests caused or contributed to their diseases.

The case for this is especially strong since it was common to conduct hazardous decontamination activities without respirators. For example, three ships, YAG-39, YAG-40, and Crook County, were experimentally contaminated with fall-out during Operation Redwing. Experimental decontamination methods "such as firehosing, hand-scrubbing, and hot liquid jet cleaning" were tried out on these ships.[30] The Defense Nuclear Agency lists external doses (film-badge) only for two civilian personnel. However, the actual decontamination was probably caried out by

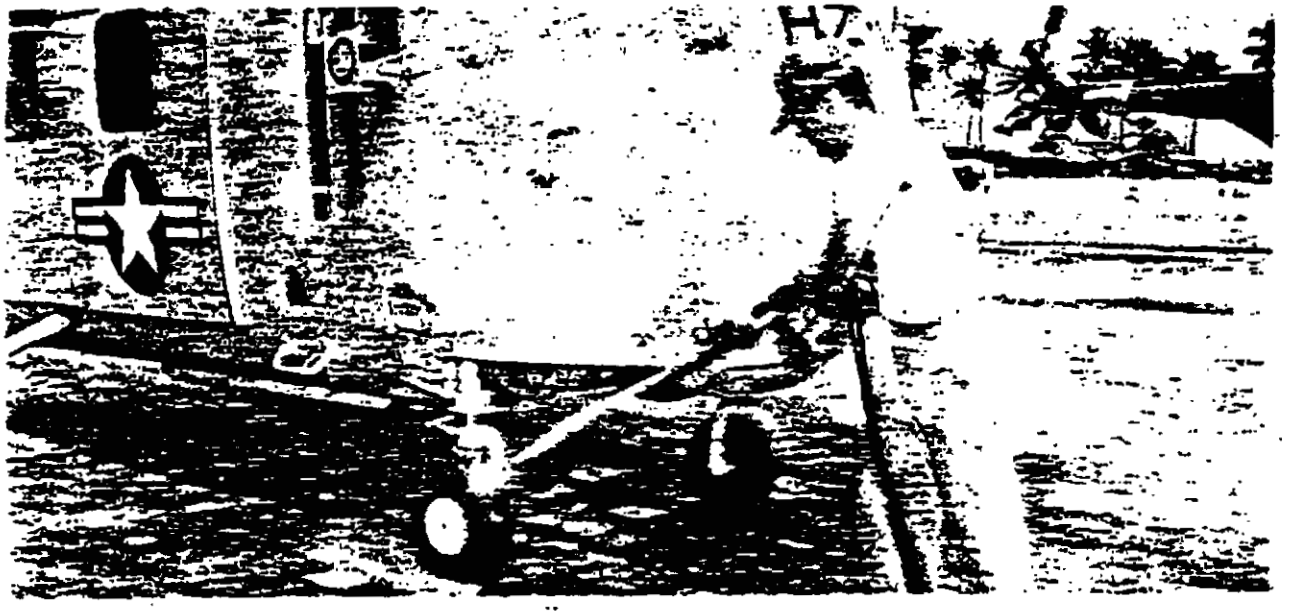

Figure 1 Removing radioactivity from a helicopter, REDWING.

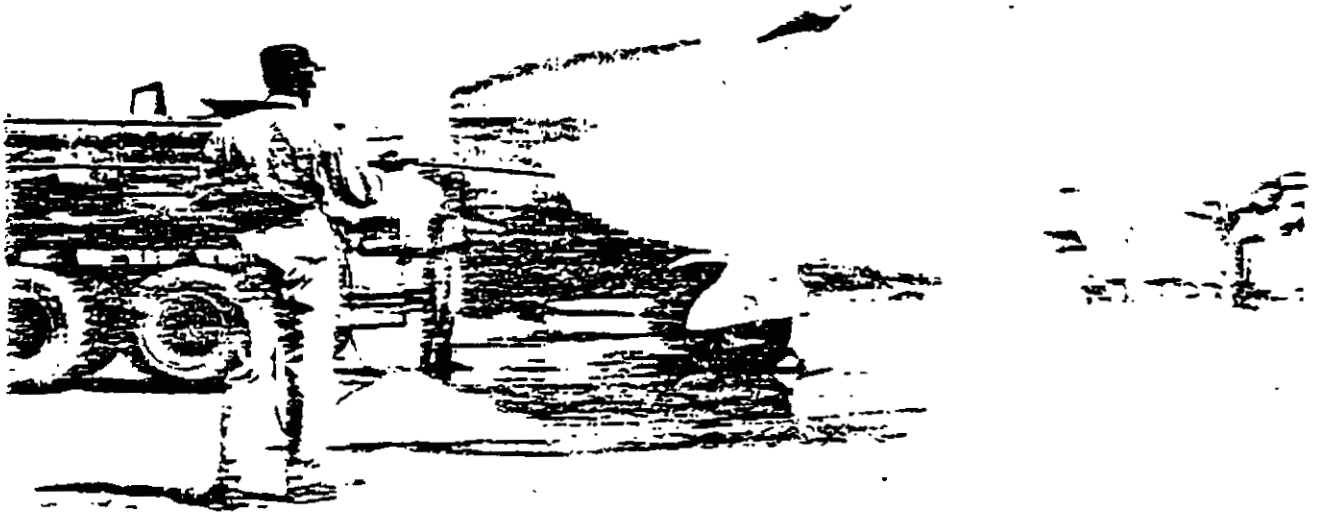

Figure 2 Decontaminating a B-57 samoler aircraft after flight through a nuclear cloud, REDWING.

Figure 3 Decontamination monitor locating and marking spots of radioactivity on personnel returning from a radex area, REDWING.

marines based on the USS Estes and the USS Curtis, and possibly by other personnel. The official record on this point is "not clear."[31] Radiation levels on these ships were sometimes quite high and the surfaces heavily contaminated. It is likely that much, perhaps all, of this decontamination work was done without the benefit of respirators.

There are other examples of decisions which resulted in increased personnel exposure and internal radiation hazards. The largest single case was the decision not to evacuate Enewetak after fall-out from shot TEWA at Bikini drifted toward Enewetak and came down on it for 17 hours, accompanied by several rain showers. Rain samples were found to be heavily contaminated as were puddles of rainwater on the runway and parking area.[32] There was a substantial increase in external gamma radiation doses due to this fall-out -- the initial estimate was 2.5 roentgens. "Later estimates indicated ... about 3 to 6 R actual exposure."[33] Thus, many of the large number of personnel stationed on Enewetak were subjected to radiation doses exceeding the total allowable limit for the operation during this one fall-out episode above.

The Joint Task Force command, instead of evacuating Enewetak "later authorized raising the maximum permissable exposure from 3.9 R to 7 R for the Redwing Operation."[34] In spite of the likelihood of internal doses to at least some participants, the Defense Nuclear Agency's report contains no discussion or estimates of such doses.

In one accident connected with a project on neutron flux measurements, "a plutonium foil split open, releasing an estimated 100 mg of oxidized plutonium into the counting trailer. Alpha contamination was spread to other areas, unfortunately, as project personnel continued to use the trailer after the accident. Monitoring subsequently showed that 10 persons had been contaminated. Twenty-hour urine specimens contained low levels of plutonium."[35] Urine samples are well recognized to be poor indicator of the amount of ingestion or inhalation. However, since plutonium was definitely present in 10 people, some estimates of the internal dose could have been given. But the Defense Nuclear Agency did not do so in its report on dose estimates.

Like the problem of film badges, and perhaps more insidious, the Defense Nuclear Agency has consistently taken the position that internal doses were insignificant during the U.S. atmospheric testing program. This conclusion is unwarranted. Few measurements were actually made. Fall-out patterns are erratic with unpredictably located "hot spots." Individuals did widely varying kinds of work, some very dangerous such as hosing and scrubbing, often with poor protection against inhalation and sometimes ingestion. A study of Operation Crossroads in 1946, based on the papers of the Chief of the Radiological Safety Section, Colonel Stafford Warren, done two years ago, quoted documents saying that due to the "extensive and unpredictable" extent of the alpha (plutonium) contamination, "no one can say any place is safe for any length of time" from the dangers of

ingestion or inhalation of radioactive particles.[36] Yet the Defense Nuclear Agency continues to insist that almost all occupied places were safe almost all of the time and that interval doses were insignificant. This is an unscientific claim.

Even the maximum limits for radioactive materials' concentration in air and water adopted by Joint Task Force Seven were questionable, at best. The standard adopted initially for air was 10^{-6} microcuries per cc of particles less than 5 microns in air. Even this was apparently later abandoned.[37] A hypothetical calculation will illustrate how dangerous this can be. If the entire contamination were due to strontium-90, and the air had the maximum permissable contamination, the lifetime dose to the bone marrow due to breating such air for 13 weeks would be over 3,000 rems.[38] This would be very likely to cause leukemia. Of course, in practice, most radionuclides are not as effective in irradiating bone marrow, so that the actual dose to the bone marrow from a "typical" mixture might be a factor of 100 less or 30 rem -- still large. However, other organs would also be irradiated, and hence the chances of other cancers would also increase. A rough estimate is that the absolute risk of contracting some cancer due to a dose of 30 rem over the entire body is about 3 percent. Similar figures are obtained if one attempts computations based on the drinking water standard of 5×10^{-3} microcuries per cc adopted for Operation Redwing.

We do not know whether the actual contamination was above or below these limits, or how much it varied over time and from

place to place. This reinforces the conclusion that it is exceedingly difficult in any specific case to determine such doses. The best way would actually be to do a thorough epidemiological study, estimate the increases in radiation related diseases over the expected (in a well defined control group). Special epidemiological studies of high risk personnel such as cloud penetration experiment and cloud sampling air crews are also critically needed. From such a study, it may be possible to infer internal dose magnitudes. However, the Defense Nuclear Agency and the Veterans Administration have consistently refused to do such a study, while at the same time denying atomic veterans the benefit of the very serious doubts and uncertanties which exist.

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17. Reference #2; p. 92.

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20. Reference #3; p. 23-27. (Page 23-27 appears as one page n the edited, public version of the report.)

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22. Reference #3; p. 14.

23. Reference #3; p. 22.

24. Reference #3; p. 23-27.

25. Reference #2; p. 4 and p. 333. The numbers of personnel receiving more than 10 roentgens after adjusting for the under-recording of low-energy gamma radiation was obtained by adding up the total number of personnel receiving 4 roentgens or more as measured by film badges, shown in p. 333. A similar adjustment was done for the 3.9 roentgen limit.

26. Reference #2; p. 336 and p. 345.

27. Reference #3; p. 28-32. (Page 28-32 is one page in the public edited version of the report.)

28. Reference #9.

29. Reference #9.

30. Reference #2; p. 147.

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38. Dose conversion factors obtained from J.E. Till and H.R. Meyer, Radiological Assessment; NUREG/CR-3332, September 1983; Table 7.19.