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INTERNAL DOSE ASSESSMENT— OPERATION CROSSROADS

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The radiation dose commitment to ten body organs/parts, due to inhalation of resuspended nuclear contaminants from target ships exposed to the underwater burst (Test Baker) is determined for personnel who worked on the ships during and after Operation CROSSROADS. Four representative ships, INDEPENDENCE, NEW YORK, PENSACOLA, and SALT LAKE CITY, are examined for the personnel activities associated with post-BAKER reboarding. Additionally, the dose due to internal emitters is assessed for personnel who unloaded ammunition from twenty target ships at Kwajalein, for personnel engaged in maintenance and security of the entire remaining target fleet at Kwajalein, and for shipyard workers exposed to eight of the higher intensity ships at Pearl Harbor, Puget Sound, and San Francisco Naval Shipyards. For almost all activities, fifty-year bone dose commitments are less than 0.15 rem from any annual period of exposure.

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SUMMARY

Organ dose commitments for ten selected organs are calculated for personnel associated with specific activities relating to Operation CROSSROADS. These activities all involve post-Shot BAKER reboarding of target ships at Bikini, ammunition unloading of target ships at Kwajalein, maintenance and security of target ships at Kwajalein, and inspection and maintenance of target ships at three naval shipyards. These activities were performed by different organizations and units over the period of August 1946 through December 1948.

Key aspects of the methodology for calculating organ dose commitments (and corresponding film badge doses) include:

(1) Organ dose commitments are based on the inhalation of radioactive material initially deposited on ships' surfaces, above and below decks, and subsequently resuspended.

(2) The radionuclide inventory of the shipboard radioactive contamination is based on the measured characteristics of the Shot BAKER nuclear debris.

(3) Resuspension factors are estimated from available literature, amended to reflect the extent of prior decontamination actions and the degree to which the local work activity is likely to disturb the deposited contamination. The strong adhesion of the contamination to ships' surfaces makes the chosen resuspension factors high-sided.

(4) Respiratory protective devices are assumed to have been used only for those activities where available documentation clearly confirms their use.

(5) Organ dose commitments are keyed to average film badge doses for those activities for which representative film badge data is available. Where necessary, organ dose commitments are based on estimates of radiation levels and exposure times developed from Operation CROSSROADS documentation.

Except for personnel at the Puget Sound Naval Shipyard, 50-year bone dose commitments are less than 0.15 rem for each annual exposure.

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INTRODUCTION

Operation CROSSROADS, the first nuclear test series following World War II, consisted of two nuclear detonations, Shots ABLE and BAKER, at Bikini Atoll in July 1946. Shot ABLE on July 1, 1946 was a low airburst; Shot BAKER on July 25, 1946 was a shallow underwater burst. The nuclear device for each shot was a plutonium-fueled weapon having a yield of approximately 23 KT (Reference 1).

At each shot a large array of approximately eighty target ships was positioned in the Bikini lagoon around the designated surface zero to determine the effects of nuclear weapons on naval vessels. Shot ABLE, the airburst, caused considerable structural damage to close-in target ships, but did not cause significant radiological contamination. However, Shot BAKER, the underwater burst, did cause significant radiological contamination of the target ships.

Personnel who worked on the target ships following Shot BAKER were subject to exposure to both external and internal radiological hazards. An external radiation dose would accrue simply from the presence of radioactive contamination. An internal radiation dose would occur if radioactive material were ingested or inhaled.

This report presents calculations of the internal radiation dose, referred to as the organ dose commitments, for personnel associated with four specific activities relating to Operation CROSSROADS. The activities are as follows and all involve target ships that were not remanned:

- post-Shot BAKER reboarding of target ships at Bikini,
- ammunition unloading of target ships at Kwajalein Atoll,
- maintenance and security of target ships at Kwajalein, and
- inspection and maintenance of target ships at three naval shipyards.

These activities were performed by different organizations and units over the period of August 1946 through December 1948.

The basic methodology used to calculate organ dose commitments is explained in Section 2. The approach used to characterize the radiological environment created by the nuclear debris from Shot BAKER is presented. Equations for dose calculation are derived, and the key parameters for the equations are discussed.

Section 3 addresses the post-Shot BAKER reboarding of target ships at Bikini. Organ dose commitments and film badge doses are calculated for the teams that reboarded four target ships: USS INDEPENDENCE (CVL-22), USS NEW YORK (BB-34), USS PENSACOLA (CA-24), and USS SALT LAKE CITY (CA-25). These ships were selected as high-dose representatives of the approximately fifty non-remanned target ships that were reboarded at Bikini in August 1946.

The ammunition unloading of target ships at Kwajalein is addressed in Section 4. Twenty of the target ships that had survived the tests at Bikini contained large amounts of ammunition that was considered to present a serious potential hazard. Organ dose commitments are calculated for the ammunition disposal unit that unloaded those ships during the period September-November 1946.

Section 5 addresses the maintenance and security of target ships at Kwajalein. Organ dose commitments and film badge doses are calculated for the personnel who boarded the target ships to perform limited maintenance and security tasks intended to keep the ships seaworthy and to prepare them for departure from Kwajalein. Approximately fifty target ships were involved during the period of August 1946-July 1948.

Section 6 addresses the inspection and maintenance of the eight target ships at three shipyards: Pearl Harbor Naval Shipyard, Puget Sound Naval Shipyard, and San Francisco Naval Shipyard. Organ dose commitments are calculated for the personnel who boarded those ships during 1947 and 1948.

A synopsis of the calculated organ dose commitments and film badge doses is given in Section 7.

SECTION 2
TECHNICAL APPROACH

2.1 INTRODUCTION

Personnel who boarded target ships after Shot BAKER could have received internal contamination by the inhalation of the nuclear debris deposited on the ships and later resuspended into the air by some disturbance of the surface. There was a general prohibition of eating aboard target vessels that would have effectively precluded the ingestion of radioactive material. However, to expedite their rebounding duties, a limited number of reboarding team personnel remained aboard their target vessels during some meal periods. Ingestion of contamination was minimized for these personnel by providing sealed rations for consumption in designated areas.

Internal doses are either determined by bioassay or inferred from activities within the radiation environment. Some analyses of collected urine samples were performed at Operation CROSSROADS in 1946, but no cases of personnel with internal radiation contamination were reported. Only a slight beta activity was detected in 16 of the 2,600 samples collected by August 15. Later, 1,300 urine samples were taken from the men working on the target ships, but all were reported as negative (Reference 3). It has been suggested that low-level radioactivity was not detected in the urine samples due to limitations of the equipment, procedures, and facilities then available (Reference 4). However, it should be noted that procedures to detect internal contamination were also in effect at naval shipyards in 1947 (Reference 5), but no indications of internal dose could be found in the Operation CROSSROADS literature. In the absence of positive urinalyses, internal radiation doses are determined from known inhalation pathways and external doses.

Radiation film badge records, where available, provide the external radiation doses associated with internal exposure (but may overrepresent the period of inhalation). Otherwise, external radiation doses are determined from the radiation environment and times of exposure. This type of analytical approach is used to calculate external doses to CROSSROADS test participants in Reference 2.

The basic elements of the analytical approach used to calculate internal radiation doses are described in the following subsections. Section 2.2 discusses the characterization of a target ship radiological environment, the internal contamination process is described in Section 2.3, and Section 2.4 presents the basic equations for dose calculation.

2.2 RADIOLOGICAL ENVIRONMENT

The radioactive material deposited by the base surge resulting from Shot Baker on a target ship included fission products, light elements made radioactive by neutron capture or activation (e.g., Na-24), and actinides that were part of the nuclear device or resulted from neutron capture by the weapon material (e.g., Pu-239). The procedures used to characterize these components of the radiological environment on a target ship are described below.

2.2.1 Fission Products

As reported in Reference 1, the nuclear device used at Shot BAKER was of the same design as that dropped on Nagasaki in World War II. According to Reference 6, 80 percent of the yield of that device was generated by fissioning Pu-239 and 20 percent was generated by fissioning U-238. The fission product inventory of the Shot BAKER nuclear device is thus based on a mixture of Pu-239 and U-238 fission products.

The calculation of the fission product inventory was performed using the FIIDOS code (Reference 7). The basic fission product data contained in FIIDOS are based on calculations performed using Reference 8. The inventory has been modified to reflect the removal of krypton and xenon radionuclides. Since krypton and xenon are nonreactive, gaseous elements, they would not be present in the fission product mixture deposited on a target ship. Table 1 lists the 118 fission product radionuclides included in the inventory.

2.2.2 Activation Products

An underwater burst, Shot BAKER produced radionuclides by the neutron activation of trace elements in the seawater. The radionuclide inventory of seawater activation products is calculated using Reference 8 to determine the importance of such radionuclides to this dose assessment. Information on the elemental composition of seawater is obtained from Reference 9. The nuclear device is assumed to release 2 neutrons per fission, both absorbed in the seawater.

The most radiologically significant activation product was Na-24. At a post-Shot BAKER time of D+3 days (prior to the reboarding of target ships considered in this report), the specific activity of Na-24 was 2.1 x 10^{-19} Ci/fission and that of gross fission products was 2.2 x 10^{-17} Ci/fission. For calculating the dose to the total body, the inhalation dose conversion factor (see Section 2.4) is 699 rem/Ci for Na-24 and 727 rem/Ci for the D+3 day fission products. Thus, the total body dose from the inhaled fission products is one hundred times greater than the dose from Na-24 at D+3. At later times, the contribution from fission products is even more dominant, as the activation products decay more rapidly. Accordingly, seawater activation products are not included in the radionuclide inventory used for dose calculations.

2.2.3 Actinides

Since the Shot BAKER nuclear device contained U-238 and Pu-239, it is necessary to consider actinide elements in the radionuclide inventory. Two specific radionuclides of importance are Np-239 and Pu-239.

Np-239 is produced when U-238 captures a neutron and does not fission. The capture product, U-239, decays with a radioactive half-life of 24 minutes to Np-239. Np-239 itself decays with a half-life of 2.35 days to Pu-239. Because of the short half-life of U-239, the U-239 decay is neglected and Np-239 is considered to be produced at the time of fissioning.

For the fission neutron spectrum (Reference 10), the effective ratio of the capture cross section to the fission cross section for U-238 is approximately one-half (Reference 11). Since about 20 percent of the Shot BAKER device fissions occurred in U-238, the number of U-238 capture reactions per fission is approximately 0.1.

Pu-239 is produced by the radioactive decay of Np-239. At a post-shot time of D+2.35 days, half of the Np-239 will have decayed to Pu-239; by D+16 days, less than 1 percent of the Np-239 will remain and more than 99 percent of the decay product Pu-239 will have been produced. Also, the Shot BAKER nuclear device contained Pu-239, of which the unfissioned portion was present in the nuclear debris. Information on the plutonium content of Shot BAKER nuclear debris is provided in Reference 12: "...The amount of plutonium associated with fission products was found to be quite constant. The average was 0.0013 micrograms of plutonium for each microcurie of fission products...(Fission products were measured September 6, 1946)..."

The code FIIDOS is used to determine the specific activity (Ci/fission) of the Shot BAKER fission products. At a post-Shot BAKER time of D+43 days (i.e., September 6, 1946), the specific activity of the fission products was 1.21×10^{-18} Ci/fission. This value, multiplied by the above datum and the atomic mass of plutonium (6.02×10^{23} atoms / 239g), implies that the nuclear debris contained 4.0 atoms of plutonium per fission.

Of the plutonium that was measured chemically, some would have been Pu-240, which has similar alpha emissions to Pu-239, but with a half-life one-fourth as long. Thus, if up to 10 percent of the mass of plutonium were of Pu-240 (which is taken as a high-sided order-of-magnitude estimate), the activity of the combination would be $4 \times 0.1 + 0.9 = 1.3$ times that of Pu-239 alone. Effectively, there were about five atoms of Pu-239 per fission.

In summary, the radionuclide inventory for the Shot BAKER dose calculations includes two actinide element radionuclides: Np-239 and Pu-239. The initial post-shot inventory of Np-239 is 0.1 atom per fission or 1.3×10^6 Ci per KT. The effective post-shot inventory of Pu-239 is five atoms per fission or 17 Ci per KT.

2.3 INTERNAL CONTAMINATION PROCESS

Three key parameters are required in order to calculate the internal dose that could result from activities aboard a contaminated target ship. First, it is necessary to establish a resuspension factor that provides a correlation between the activity on the surface and the activity in the air. Second, the breathing rate for the shipboard personnel is specified. Third, the protection factor afforded by the use of respiratory protection devices is addressed. Each of these parameters is discussed in the following sections.

2.3.1 Resuspension Factors

Resuspension refers to a process by which previously deposited radioactive particles are removed from a surface by man-made or natural forces to form an airborne aerosol. The ratio of the airborne activity (Ci/m^3) to the surface activity (Ci/m^2) is known as a resuspension factor (m^{-1}).

The literature on resuspension provides a basis for establishing resuspension factors that are applicable to the target ship dose assessment. Some of the more pertinent studies are discussed below.

In Reference 13, resuspension data for indoor surfaces are used to suggest a resuspension factor of 2×10^{-6} m^{-1} as a generic value for deriving allowable limits of surface contamination. A cited British civil defense study examined the resuspension associated with digging through dusty building rubble in an enclosed and unventilated space and derived a resuspension factor of 4×10^{-5} m^{-1}.

Reference 14 reports resuspension experiments in a room contaminated with ZnS tracer dust. The first simulated vigorous work activity, including sweeping; the second used vigorous walking to simulate moderate work; and the third involved only light activity. The resuspension factors derived were 1.9×10^{-4}, 3.9×10^{-5}, and 9.4×10^{-6} m^{-1}, respectively.

Reference 15 reports resuspension experiments in a room coated with a dried suspension of plutonium oxide. Under quiescent conditions, the resuspension factor was 2×10^{-8} m^{-1}; with a man walking at the rate of 14 steps per minute, the resuspension factor was 10^{-5} m^{-1}; when the rate of movement was 36 steps per minute, the resuspension factor was $5 \times 10^{-5}\ m^{-1}$. When the contaminant was plutonium nitrate from a nitric acid solution, the three resuspension factors were 2×10^{-8}, 10^{-6}, and $5 \times 10^{-6}\ m^{-1}$.

Resuspension data for indoor conditions were reviewed in Reference 16. Resuspension factors of $10^{-6}\ m^{-1}$ were suggested for quiescent conditions and $10^{-5}\ m^{-1}$, or even $10^{-4}\ m^{-1}$ in some cases, under operational conditions.

Various types of activities were performed on the target ships. The resuspension factor would be affected by the degree to which these work activities disturbed the contaminated surfaces. Those activities most closely related to any resuspension experiments involve walking below decks (enclosed spaces not previously disturbed). A resuspension factor of $10^{-5}\ m^{-1}$ is most consistent with the above data, but is likely high-sided because of the adhesion of Shot BAKER contamination to ship surfaces. For more significant mechanical disturbances of a contaminated surface, $10^{-4}\ m^{-1}$ is correspondingly appropriate.

Resuspension factors topsides were reduced as a consequence of decontamination activities. Initial decontamination of the target ships began a few days after Shot BAKER, before the ships were reboarded. The ships were washed with foam and saltwater by the salvage tugs or fire fighting ships. These washings, which generally lasted about four hours, were applied repeatedly to some of the more heavily contaminated target ships. This decontamination would have removed most of the deposited material that could easily be resuspended. These washings affected only topsides.

When the target ships were reboarded, extensive local decontamination was performed. This decontamination included scrubbing and washing ship surfaces with saltwater, foam, and, in some cases, lye. In general, this decontamination was not very effective, partly because most of the readily removable contamination had already been removed by the initial decontamination operations and partly because of the adhesion of contamination to ship surfaces. Resuspension factors for decontaminated topsides could conceivably have been as great as $10^{-6}\ m^{-1}$ for walking and

10^{-5} m^{-1} for more significant mechanical disturbances. The ineffectiveness of manual decontamination implies factors no higher, but possibly far less.

Target ship decontamination operations at Bikini ceased on August 12, 1946. No general decontamination operations of any significance were ever resumed. However, with the passage of time natural environmental factors would have caused the contamination present on the topside portions of the target ships to become even more firmly bound to the ships' surfaces.

At Bikini, the principal target ship activities included damage inspection, limited repair, and decontamination. Inspection and repair work were performed both topside and below decks. The decontamination work was primarily performed topside. A resuspension factor of $10^{-5}m^{-1}$ is used for the below decks inspection and repair work. Although this work did not involve major disturbances of the contaminated surfaces, it was performed in an area that had not been subjected to decontamination. A resuspension factor of 10^{-6} m^{-1} is used for the topside inspection and repair work, which involved only minor disturbances of the contaminated surfaces and was performed in an area that had been previously decontaminated. A resuspension factor of 10^{-6} m^{-1} is used for the topside and below decks decontamination work. This work did involve major disturbances of the contaminated surfaces, but the surfaces involved were kept continuously wet, thereby strongly suppressing resuspension.

At Kwajalein, the target ship activities included an ammunition unloading operation and ship maintenance and security work. These activities involved both topside and below decks work. A resuspension factor of 10^{-4} m^{-1} is used for the below decks ammunition unloading work. This work involved major disturbances of contaminated surfaces in areas that had not been subjected to decontamination. However, it should be noted that personnel performing this work wore respiratory protective devices (see Section 2.3.3). A resuspension factor of 10^{-5} m^{-1} is used for the topside ammunition unloading work. This work was performed in an area that had been decontaminated, but did involve disturbing some contaminated surfaces (e.g., ammunition containers) that were temporarily in the area. For the maintenance and security work, the resuspension factors are 10^{-5} m^{-1} for below decks work and

10^{-6} m^{-1} for topside work. The values are the same as those used for similar work at Bikini.

At the naval shipyards, the principal target ship activities included ship inspection and maintenance. These activities began in 1947 and ended in 1948, about two years after Shot BAKER. The shipyard activities involved resuspension factors of 10^{-5} m^{-1} for below decks work and 10^{-6} m^{-1} for topside work. These values are additionally high-sided to the extent that late-time contamination would have been more firmly bound to the ships' surfaces.

A summary of the selected resuspension factors is provided in Table 2.

2.3.2 Breathing Rate

The breathing rate is dependent upon the physical activity of an individual during his period of exposure. Breathing rates for a typical adult male include 0.45 m^3/hr for resting and 1.2 m^3/hr for light activity (Reference 17). The light activity breathing rate is representative of an individual walking on a flat surface at a speed of about 3 miles per hour (Reference 7).

Breathing rates for more vigorous activities are not given in Reference 17, but the reference does provide information on the energy expenditure rates associated with selected types of activities. By correlating energy expenditure rates with breathing rates, it is determined that for heavy work (illustrated by foundry work and ambulant postal delivery) the breathing rate is approximately 2.0 m^3/hr.

Accordingly, for the purposes of this dose assessment, a breathing rate of 2.0 m^3/hr is used for the decontamination operations at Bikini and the ammunition unloading at Kwajalein, and a breathing rate of 1.2 m^3/hr is used for the inspection and repair activities at Bikini and the inspection, maintenance, and security activities at Kwajalein and at the naval shipyards.

2.3.3 Protection Factor

During the ammunition unloading operation at Kwajalein, personnel who worked below decks and other personnel who performed work that involved disturbing a ship surface, such as scraping, welding, or sand blasting, were required to wear a protective mask or rescue breathing apparatus. Such a respiratory protective device, or respirator, reduces the concentration of the contamination breathed by the wearer.

The protection afforded by a respirator is defined in terms of its protection factor (PF). The PF is defined as the ratio of the concentration of contaminant in the ambient atmosphere to that in the wearer's protected breathing zone.

The respirator used at Kwajalein was a rescue breathing apparatus (RBA), a positive-pressure, self-generating oxygen system similar to a self-contained breathing apparatus (SCBA). Guidance on the PF afforded by such a respirator is provided in Reference 18. Self-contained breathing apparatus which use demand-type regulators have a PF of only 50, because the negative pressure created in the facepiece during inhalation increases the potential for leakage. Self-contained breathing apparatus which use pressure-demand-type regulator have PFs in the 1,000 to 10,000 range because positive pressure is maintained to the facepiece at all times.

The available information does not identify the type of regulator used in the RBAs at Kwajalein. Under such circumstances, it is appropriate to assume the RBAs used demand-type regulators. Accordingly, for the purposes of this dose assessment, a PF of 50 is used for all situations in which respirators were used.

2.4 DOSE CALCULATIONS

Internal radiation doses are calculated for the following ten body parts or organs:

Lung	Kidneys
Lower Large Intestine	Liver
Bone	Testes
Red Marrow	Thyroid
Endosteum	Total Body

The calculated doses are 50-year organ dose commitments; that is, the dose delivered over a 50-year period commencing with the initial intake of the radioactive material. The doses are primarily based on inhalation organ dose conversion factors from Reference 19.

The underlying equation used for calculating the dose commitment to organ j, D_j(rem), is:

$$D_j = SC \cdot K \cdot BR \cdot T \cdot \frac{1}{PF} \cdot DCF_j$$

where SC(Ci/m^2) is the surface activity concentration, K (Ci/m^3 per Ci/m^2, or m^{-1}) is the resuspension factor, BR (m^3/hr) is the breathing rate, T(hr) is the duration of the exposure, PF is the respiratory protection factor, and DCF_j (rem/Ci) is the dose conversion factor, the dose commitment to organ j per unit activity intake by the body. DCF_j is the activity-weighted average of the dose conversion factors for all factors for all components of the radionuclide inventory. Other terms in the equation are self-explanatory or were discussed earlier in Section 2.3.

The surface activity concentration was not directly measured, but is related to the radiation intensity, I(R/hr). This time-dependent relationship is determined for Shot BAKER nuclear debris with the computer code FIIDOS. The other item determined by FIIDOS is the dose conversion factor for BAKER debris, also time dependent because of the changing radionuclide inventory. For ease of application, the FIIDOS-calculated factors are combined. The resulting product, herein called the BAKER Inventory Factor, BIF_j, is presented in Table 3 and depicted in Figures 1 and 2 for each organ j at various times after the BAKER detonation. Units for the BAKER Inventory Factor are (rem/Ci) x (Ci/m^2)/(R/hr). However, for other quantities expressed in the above units, the purely numerical values of BIF_j presented henceforth lead properly to organ doses in rem.

The operative equation for calculating dose commitments becomes

$$D_j = I \cdot K \cdot BR \cdot T \cdot \frac{1}{PF} \cdot BIF_j \qquad (1)$$

The BAKER Inventory Factors used for this dose assessment (Table 3) include the effects of U-238 fission products, Pu-239 fission products, and the radionuclides Np-239 and Pu-239, based on the source terms described in Section 2.2. The factors are based on 50-year organ dose conversion factors for inhalation. The radiation intensity correlation used in calculating the factors are for a free-in-air, unshielded radiac meter located at a height of one meter above a contaminated surface. A technical description of the procedures used to calculate these BAKER Inventory Factors is presented in Reference 7.

Actinides contribute significantly to the BAKER inventory factors. Table 4 shows that for late-time exposures, actinides dominate the BIF_j for most organs. In contrast, the actinide contribution to radiation intensity is minimal.

Equation 1 is used for calculating organ dose commitments when the radiation intensity, I(R/hr), and the duration of the exposure, T(hr), are known. When organ dose commitments are calculated based on film badge data, the measured film badge dose, D_{FB} (rem), is related to the radiation intensity and exposure duration by the equation:

$$D_{FB} = (0.7) \cdot I \cdot T \tag{2}$$

where the factor of 0.7 is used to convert integrated intensity (R) to equivalent film badge dose (rem) (Reference 20). With the assumption that the internal exposure occurred at the same time as the external exposure, Equation 2 can be used with Equation 1 to calculate organ dose commitments based on film badge data.

Table 1. Fission Product Radionuclides

Se-79	Y-95	Ag-110m	Sb-133	Ce-143
Br-82	Zr-95	Ag-111	Te-133m	Pr-143
Br-83	Nb-95	Cd-113m	I-133	Ce-144
Br-84	Zr-97	Cd-115m	Te-134	Pr-144
Br-85	Nb-97	Sn-123	I-134	Pr-144m
Rb-86	Nb-97m	Sb-124	Cs-134	Ce-147
Rb-87	Mo-99	Sn-125	Cs-134m	Nd-147
Rb-88	Tc-99	Sb-126	I-135	Pm-147
Rb-89	Tc-99m	Te-125m	Cs-135	Sm-147
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Y-92	Rh-105m	Te-131	Ba-141	Eu-155
Sr-93	Ru-106	Te-131m	La-141	Eu-156
Y-93	Rh-106	I-131	Ce-141	Tb-160
Zr-93	Pd-107	Sb-132	Ba-142	Ho-166m
Nb-93m	Rh-109	Te-132	La-142	
Mo-93	Pd-109	I-132	La-143	

Table 2. Resuspension Factors for Internal Dose Analysis

Location	Activity	Resuspension Factor $K(m^{-1})$
Bikini	Inspection and Repair, below decks	10^{-5}
	Inspection and Repair, topside	10^{-6}
	Decontamination, below decks	10^{-6}
	Decontamination, topside	10^{-6}
Kwajalein	Ammunition Unloading, below decks	10^{-4}
	Ammunition Unloading, topside	10^{-5}
Kwajalein	Maintenance and Security, below decks	10^{-5}
	Maintenance and Security, topside	10^{-6}
Naval Shipyards	Inspection and Maintenance, below decks	10^{-5}
	Inspection and Maintenance, topside	10^{-6}

Table 3. BAKER Inventory Factors

TIME	Lung	LLI Wall	Bone	R Marrow	Endos	Kidneys	Liver	Testes	Thyroid	Tot Body
3 Min	2.98E+01	5.49E+00	4.27E-01	4.39E-01	1.67E+00	4.00E-01	8.07E-01	1.57E-01	3.28E+01	7.16E-01
9 Min	4.75E+01	1.13E+01	8.20E-01	8.28E-01	3.30E+00	7.49E-01	1.52E+00	3.03E-01	6.66E+01	1.23E+00
30 Min	7.59E+01	2.68E+01	1.72E+00	1.71E+00	7.54E+00	1.50E+00	3.13E+00	6.26E-01	1.62E+02	2.25E+00
1 Hr	1.16E+02	5.11E+01	3.03E+00	2.94E+00	1.43E+01	2.47E+00	5.44E+00	1.05E+00	3.00E+02	3.64E+00
2 Hr	2.24E+02	1.18E+02	6.41E+00	6.05E+00	3.29E+01	4.72E+00	1.13E+01	2.03E+00	6.25E+02	7.03E+00
4 Hr	5.33E+02	3.28E+02	1.67E+01	1.54E+01	9.42E+01	1.09E+01	2.90E+01	4.79E+00	1.49E+03	1.67E+01
6 Hr	9.16E+02	6.09E+02	3.05E+01	2.80E+01	1.82E+02	1.87E+01	5.28E+01	8.38E+00	2.55E+03	2.89E+01
9 Hr	1.38E+03	9.90E+02	4.99E+01	4.55E+01	3.14E+02	2.89E+01	8.64E+01	1.32E+01	3.85E+03	4.45E+01
12 Hr	1.71E+03	1.28E+03	6.55E+01	5.96E+01	4.29E+02	3.67E+01	1.14E+02	1.67E+01	4.71E+03	5.57E+01
18 Hr	2.20E+03	1.73E+03	9.31E+01	8.43E+01	6.45E+02	4.97E+01	1.64E+02	2.25E+01	5.83E+03	7.33E+01
1 Day	2.61E+03	2.08E+03	1.19E+02	1.07E+02	8.56E+02	6.14E+01	2.12E+02	2.74E+01	5.38E+03	8.81E+01
2 Day	3.69E+03	2.81E+03	2.10E+02	1.83E+02	1.63E+03	9.81E+01	3.83E+02	4.21E+01	7.80E+03	1.29E+02
3 Day	4.34E+03	3.04E+03	2.94E+02	2.49E+02	2.38E+03	1.27E+02	5.40E+02	5.38E+01	8.24E+03	1.57E+02
4 Day	4.87E+03	3.10E+03	3.82E+02	3.18E+02	3.19E+03	1.55E+02	7.07E+02	6.53E+01	8.71E+03	1.81E+02
5 Day	5.39E+03	3.08E+03	4.80E+02	3.94E+02	4.08E+03	1.85E+02	8.91E+02	7.74E+01	9.28E+03	2.07E+02
6 Day	5.93E+03	3.02E+03	5.89E+02	4.77E+02	5.09E+03	2.17E+02	1.10E+03	9.04E+01	9.91E+03	2.34E+02
7 Day	6.53E+03	2.95E+03	7.09E+02	5.70E+02	6.23E+03	2.52E+02	1.33E+03	1.04E+02	1.06E+04	2.65E+02
10 Day	8.76E+03	2.77E+03	1.15E+03	9.11E+02	1.04E+04	3.77E+02	2.17E+03	1.55E+02	1.24E+04	3.74E+02
14 Day	1.26E+04	2.69E+03	1.89E+03	1.48E+03	1.76E+04	5.82E+02	3.61E+03	2.36E+02	1.36E+04	5.58E+02
21 Day	2.04E+04	2.91E+03	3.32E+03	2.61E+03	3.18E+04	9.82E+02	6.46E+03	3.90E+02	1.26E+04	9.16E+02
1 Mon	3.03E+04	3.33E+03	5.21E+03	4.11E+03	5.12E+04	1.51E+03	1.03E+04	5.92E+02	9.10E+03	1.38E+03
2 Mon	6.97E+04	4.61E+03	1.32E+04	1.06E+04	1.36E+05	3.80E+03	2.71E+04	1.45E+03	5.44E+03	3.29E+03
3 Mon	1.11E+05	5.59E+03	2.26E+04	1.83E+04	2.38E+05	6.50E+03	4.71E+04	2.47E+03	9.04E+02	5.44E+03
4 Mon	1.51E+05	6.39E+03	3.24E+04	2.64E+04	3.48E+05	9.34E+03	6.84E+04	3.56E+03	9.05E+02	7.64E+03
5 Mon	1.96E+05	7.29E+03	4.42E+04	3.61E+04	4.78E+05	1.27E+04	9.38E+04	4.85E+03	1.12E+03	1.02E+04
6 Mon	2.51E+05	8.42E+03	5.93E+04	4.86E+04	6.47E+05	1.71E+04	1.27E+05	6.52E+03	1.41E+03	1.35E+04
7 Mon	3.21E+05	9.87E+03	7.91E+04	6.50E+04	8.68E+05	2.28E+04	1.69E+05	8.71E+03	1.79E+03	1.77E+04
8 Mon	4.09E+05	1.17E+04	1.05E+05	8.64E+04	1.16E+06	3.02E+04	2.25E+05	1.16E+04	2.29E+03	2.32E+04
9 Mon	5.17E+05	1.39E+04	1.38E+05	1.14E+05	1.53E+06	3.97E+04	2.97E+05	1.52E+04	2.93E+03	3.02E+04
10 Mon	6.49E+05	1.65E+04	1.80E+05	1.49E+05	2.00E+06	5.17E+04	3.88E+05	1.98E+04	3.73E+03	3.89E+04
1 Y	1.02E+06	2.34E+04	3.05E+05	2.52E+05	3.40E+06	8.73E+04	6.58E+05	3.36E+04	6.08E+03	6.46E+04
1.2 Y	1.54E+06	3.20E+04	5.00E+05	4.13E+05	5.57E+06	1.43E+05	1.08E+06	5.50E+04	9.68E+03	1.04E+05
1.4 Y	2.09E+06	3.97E+04	7.30E+05	6.04E+05	8.16E+06	2.08E+05	1.57E+06	8.03E+04	1.39E+04	1.49E+05
1.7 Y	2.80E+06	4.63E+04	1.07E+06	8.90E+05	1.20E+07	3.05E+05	2.32E+06	1.18E+05	2.00E+04	2.15E+05
2 Y	3.30E+06	4.73E+04	1.38E+06	1.14E+06	1.54E+07	3.90E+05	2.97E+06	1.51E+05	2.52E+04	2.71E+05
3 Y	4.44E+06	3.79E+04	2.26E+06	1.88E+06	2.54E+07	6.37E+05	4.88E+06	2.48E+05	3.99E+04	4.31E+05
5 Y	6.52E+06	1.87E+04	3.92E+06	3.26E+06	4.42E+07	1.10E+06	8.46E+06	4.29E+05	6.71E+04	7.28E+05
10 Y	9.06E+06	7.28E+03	5.74E+06	4.77E+06	6.48E+07	1.61E+06	1.24E+07	6.29E+05	9.68E+04	1.06E+06
30 Y	1.48E+07	7.64E+03	9.30E+06	7.78E+06	1.06E+08	2.63E+06	2.03E+07	1.03E+06	1.54E+05	1.72E+06
70 Y	3.72E+07	1.18E+04	2.32E+07	1.95E+07	2.67E+08	6.62E+06	5.12E+07	2.57E+06	3.79E+05	4.32E+06

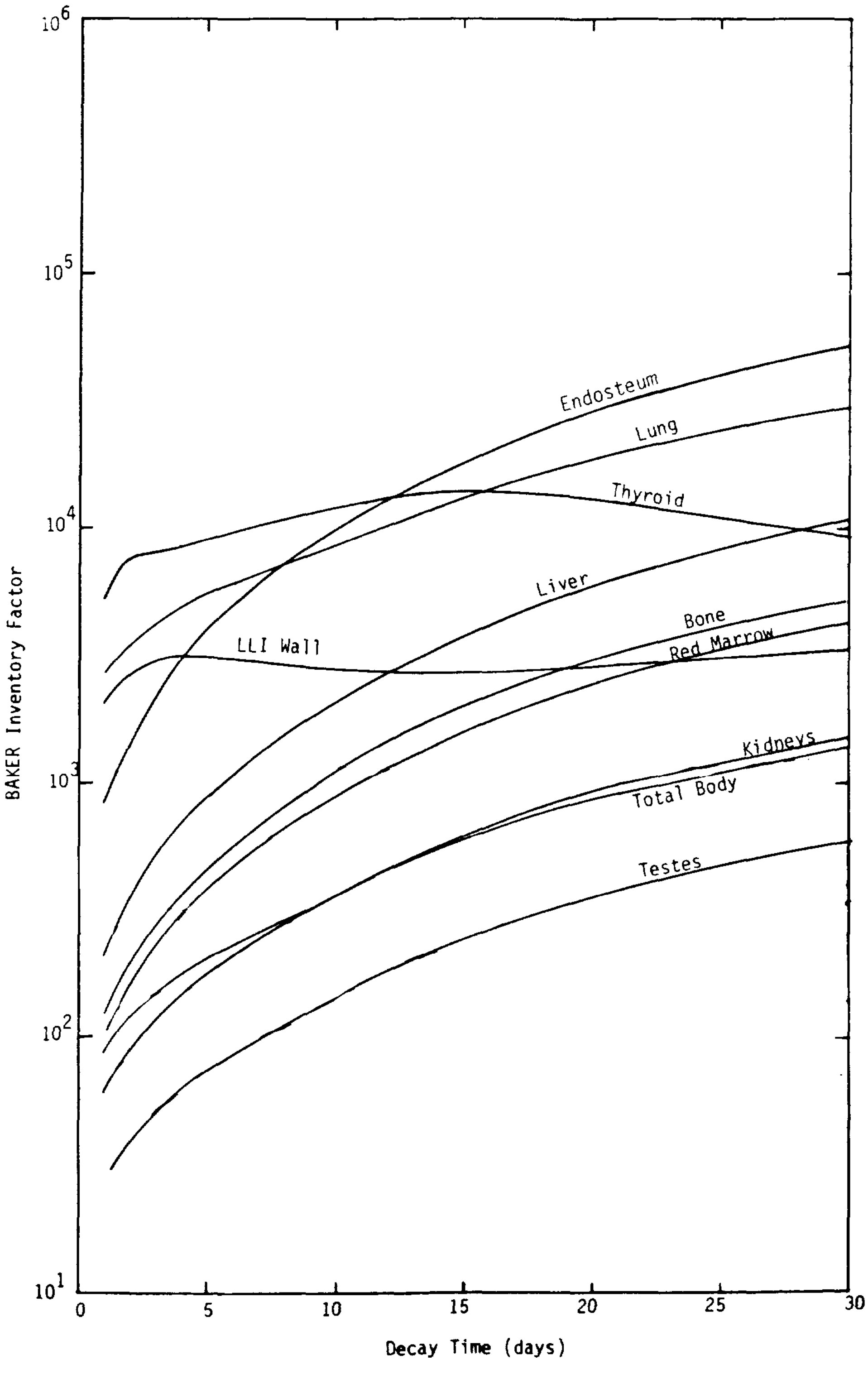

Figure 1. BAKER Inventory Factor, 1-30 days

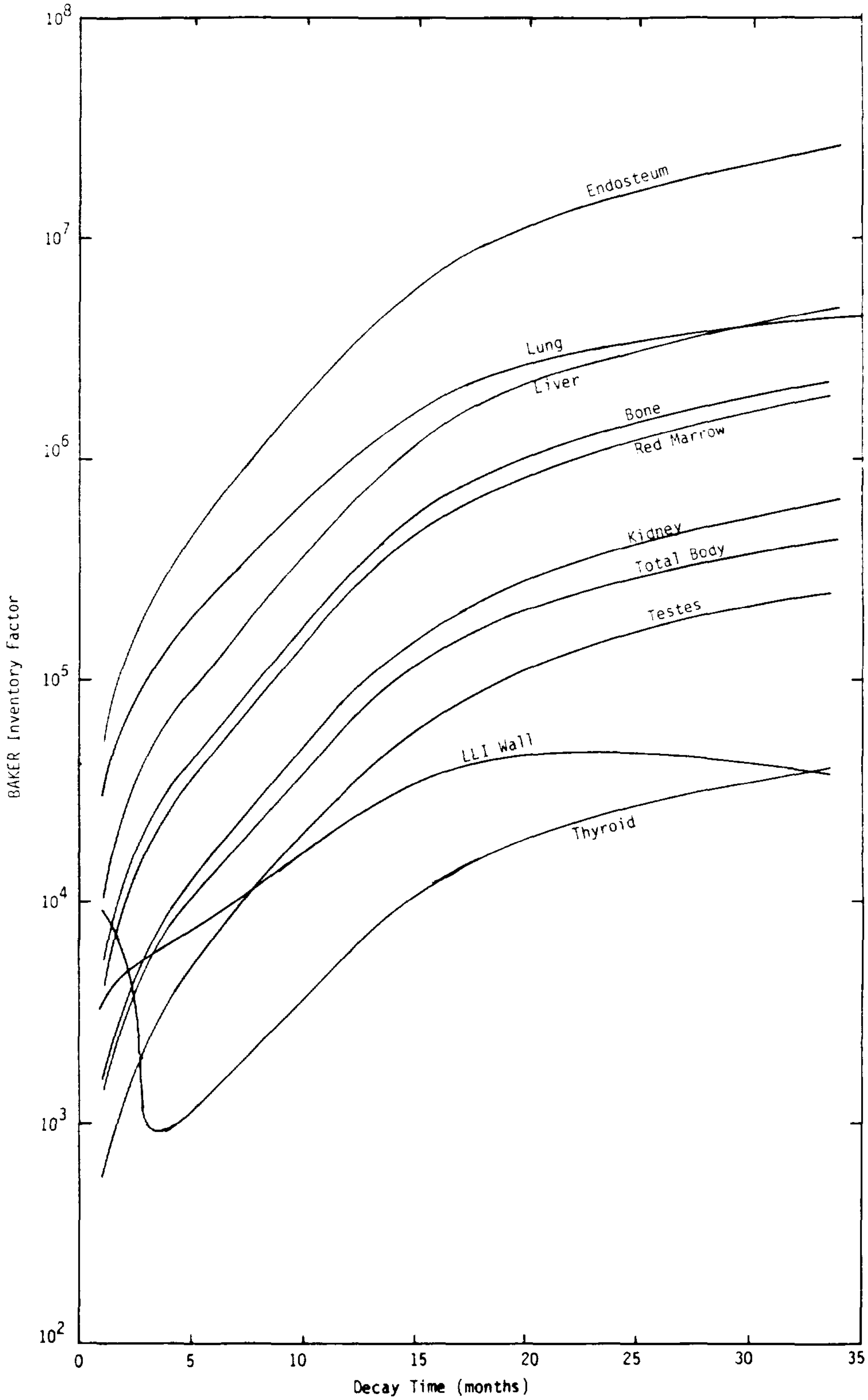

Figure 2. BAKER Inventory Factor, 1-35 months

Table 4. Fission Product and Actinide Components of BIF

Organ	10 Days		3 Months		6 Months		1 Year	
	FP	ACT	FP	ACT	FP	ACT	FP	ACT
Lung	72	28	70	30	64	36	54	46
LLI Wall	58	42	>99	<1	>99	<1	>99	<1
Bone	23	77	10	90	6	94	4	96
R Marrow	17	83	6	94	3	97	2	98
Endosteum	2	98	1	99	<1	>99	<1	>99
Kidneys	32	68	10	90	7	93	4	96
Liver	10	90	4	96	2	98	1	99
Testes	35	65	8	92	5	95	3	97
Thyroid	>99	<1	64	36	36	64	22	78
Total Body	49	51	30	70	23	77	16	84

SECTION 3
POST-BAKER REBOARDING AT BIKINI

In August 1946, about a week after Shot BAKER, personnel reboarded the target ships to attempt decontamination, to inspect the damage, and, in some cases, to repair the damage. Limited film badge data are available for these personnel; however, information on the time of ship boarding, the type of activity performed, and the exposure time aboard the ship is available. This information provides the basis for calculating organ dose commitments and film badge doses for the ship boarding personnel.

Approximately 50 target ships were reboarded at Bikini after Shot BAKER. Four of these ships--USS INDEPENDENCE (CVL-22), USS NEW YORK (BB-34), USS PENSACOLA (CA-24), AND USS SALT LAKE CITY (CA-25)--are considered in this analysis. The numbers of reboarding personnel were 49, 536, 354, and 335, respectively. An additional 50 non-crew personnel were also involved.

Tables 5 through 8, based on data from deck logs, decontamination reports, and other documentary sources, provide ship boarding information for each of the four target ships during the post-BAKER period at Bikini. Each table identifies the ship boarding teams by describing their activities or functions aboard the ship, and gives the dates and the duration of each boarding. Each team thus represents a group of people who boarded a target ship for a specific purpose on the stated days and were aboard for a specified period of time.

Organ dose commitments and film badge doses are calculated for each target ship boarding team. A target ship crewmember can normally be associated with a single boarding team; however, some individuals may have belonged to more than one of the identified boarding teams. Simple proportioning of team doses according to the time involved yields appropriate dose commitments.

Equation 1 (Section 2) is the basic equation used for calculating organ dose commitments. For calculating doses for the post-BAKER reboarding at Bikini, Equation 1 is applied to the topside and to the below decks exposure situations. Since respiratory protective devices were not used, the protection factor is omitted. The resulting equation for the dose commitment to organ j, D_j(rem) is:

$$D_j = f_{TS} \cdot I_{TS} \cdot K_{TS} \cdot BR \cdot T \cdot BIF_j + f_{BD} \cdot I_{BD} \cdot K_{BD} \cdot BR \cdot T \cdot BIF_j \quad (3)$$

where the TS indicates topside and the BD indicates below decks; f_{TS} is the fraction of time spent topside and f_{BD} is the fraction spent below decks.

Equation 2 (Section 2) is the basic equation used for calculating film badge doses. For the post-BAKER reboarding at Bikini, the modified equation for the film badge dose D_{FB}(rem), is:

$$D_{FB} = f_{TS}\,(0.7)\,I_{TS} \cdot T + F_{BD}\,(0.7)\,I_{BD} \cdot T \quad (4)$$

Equations 3 and 4 are used to calculate organ dose commitments and film badge doses for the target ship boarding teams. For a given boarding team, the equations are applied to each boarding episode and the results are added to give the total organ dose commitments and the total film badge dose for the team. The procedure for applying Equations 3 and 4 to a boarding episode and the selection of the values of the parameters in the equations are discussed below.

For the selected ship boarding team, information on the boarding episode is obtained from Table 5, 6, 7, or 8. The date of the boarding episode is used to determine the time at which the boarding occurred relative to Shot BAKER expressed in days (e.g., D+27 days); the time of the boarding is used to determine the shipboard radiation intensity and the value of the BAKER inventory factors for the boarding episode. The tables also give the value of T, the duration of the exposure, for specified boarding episodes.

Table 9 provides values of the breathing rate, BR, the fraction of time topside, F_{TS}, and below decks, f_{BD}, and the topside and below decks resuspension factors, K_{TS} and K_{BD}, for the ship boarding teams. The basis for the selection of the breathing rate and resuspension factor values is provided in Section 2.

Figures 3 through 6 show the post-Shot BAKER radiation intensity aboard the target ships (Reference 2). Table 10 gives the average target ship topside radiation intensity, I_{TS}. Based on Figures 3 through 6, the average below decks radiation intensity, I_{BD}, is taken as 10 percent of the average topside radiation intensity.

The remaining parameter for the equations is the BAKER Inventory Factor, BIF_j. The factors are given in Table 3. The factors are keyed to the time at which the exposure occurred relative to Shot BAKER. Factors for times not specifically identified in the table are obtained by interpolation.

Figure 7 illustrates the calculation of an organ dose commitment for a specific boarding team.

The calculated organ dose commitments and film badge doses for the post-BAKER reboarding teams at Bikini are given in Tables 11 and 12, respectively.

Table 5. Post-BAKER Reboarding of USS INDEPENDENCE (CVL-22) at Bikini*

Team	Date (1946)	Time Aboard (hours)
Inspection	18 Aug	4.2
	19 Aug	3.9
	20 Aug	5.2
Anchor	21 Aug	4.0

*Only 49 members of the 343-man crew reboarded after Shot BAKER. All personnel are identified by name in the ship's deck log.

Table 6. Post-BAKER Reboarding of USS NEW YORK (BB-34) at Bikini*

Team	Date (1946)	Time Aboard (hours)	Remarks
Survey	5 Aug	0.05	Non-crewmembers
Decontamination	5 Aug	1.0	
	6 Aug	0.73	
	7 Aug	2.0	
	8 Aug	2.0	
	9 Aug	2.0	
	10 Aug	2.0	
Engineer-1	7 Aug	7.0	
Engineer-2	8 Aug	16.0	
Engineer-3	9 Aug	24.0	
Engineer-4	10 Aug	24.0	
Engineer-5	11 Aug	10.5	
Engineer-6	16 Aug	3.2	
Inspection	13 Aug	4.0	Non-crewmembers
	15 Aug	4.0	Non-crewmembers
Pump Detail	17 Aug	4.0	
	18 Aug	4.0	
	19 Aug	3.0	
	20 Aug	3.5	
Ordnance	21 Aug	4.6	
Anchor	19 Aug	4.6	
	20 Aug	4.0	
	21 Aug	7.2	
	22 Aug	1.0	
	24 Aug	1.0	

*It is assumed that all members of the 536-man crew reboarded after Shot BAKER for one or more of the activities.

Table 7. Post-BAKER Reboarding of USS PENSACOLA (CA-24) at Bikini[1]

Team	Date (1946)	Time Aboard (hours)
Advance-1[2]	1 Aug	0.4
	5 Aug	0.9
	6 Aug	0.1
	7 Aug	1.5
	8 Aug	1.0
Advance-2	2 Aug	1.4
Decontamination-1	10 Aug	0.9
Decontamination-2[3]	12 Aug	1.0
	14 Aug	1.0
	16 Aug	1.0
	19 Aug	1.0
	21 Aug	1.0
Inspection	13 Aug	1.0
	15 Aug	1.0
	18 Aug	1.0
	20 Aug	1.0
	22 Aug	1.0
Anchor	24 Aug	2.0
	26 Aug	2.0

(1) It is assumed that all members of the 354-man crew reboarded after Shot BAKER for one or more of the activities.

(2) Non-crewmembers.

(3) Function changed to Inspection after 12 August.

Table 8. Post-BAKER Reboarding of USS SALT LAKE CITY (CA-25)(1)

Team	Date (1946)	Time Aboard (hours)
Advance(2)	1 Aug	2.0
Decontamination-1	2 Aug	2.0
	4 Aug	2.0
	6 Aug	2.0
	8 Aug	2.0
	12 Aug	2.0
Decontamination-2(3)	3 Aug	2.0
	5 Aug	2.0
	7 Aug	2.0
	9 Aug	2.0
	13 Aug	2.0
Inspection	19 Aug	4.0
	20 Aug	3.0
Anchor	17 Aug	3.2
	23 Aug	2.0
	25 Aug	2.0

(1) It is assumed that all members of the 335-man crew reboarded after Shot BAKER for one or more of the activities.

(2) Non-crewmembers.

(3) Function changed to Inspection after 12 August.

Table 9. Parameters for Post-BAKER Reboarding Teams at Bikini

Team	Breathing Rate (m^3/hr)	Topside: Fraction of Time	Topside: Resuspension Factor (m^{-1})	Below: Fraction of Time	Below: Resuspension Factor (m^{-1})
Decontamination					
-On/Before 12 Aug	2.0	0.75	10^{-6}	0.25	10^{-6}
-After 12 Aug	1.2	0.25	10^{-6}	0.75	10^{-5}
Anchor	1.2	0.50	10^{-6}	0.50	10^{-5}
All Other Teams*	1.2	0.25	10^{-6}	0.75	10^{-5}

*These teams engaged in ship inspection and limited repair work. Includes Advance, Engineer, Inspection, Ordnance, Pump Detail, and Survey Teams.

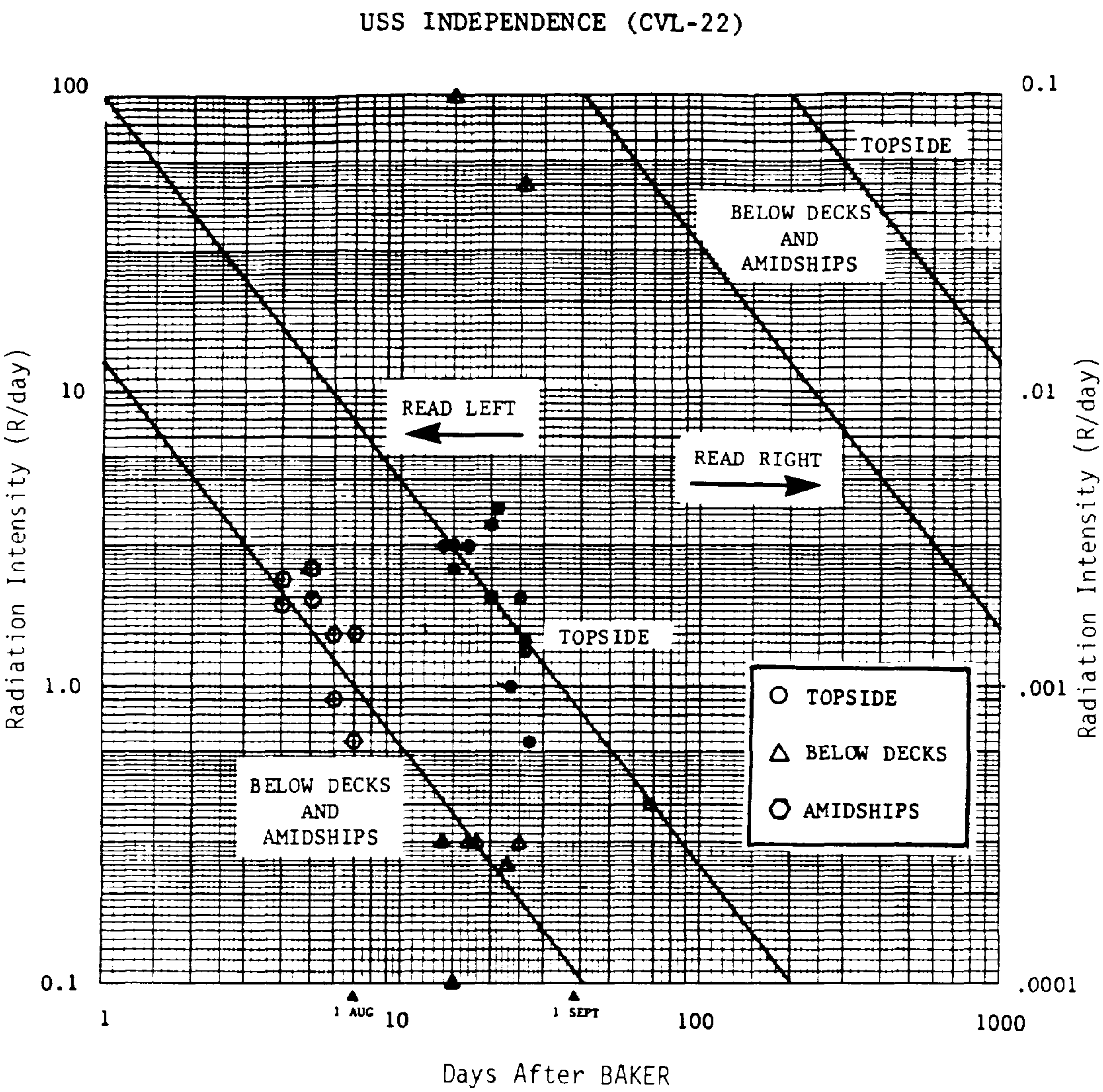

Figure 3. Radiation Intensity of USS INDEPENDENCE (CVL-22)

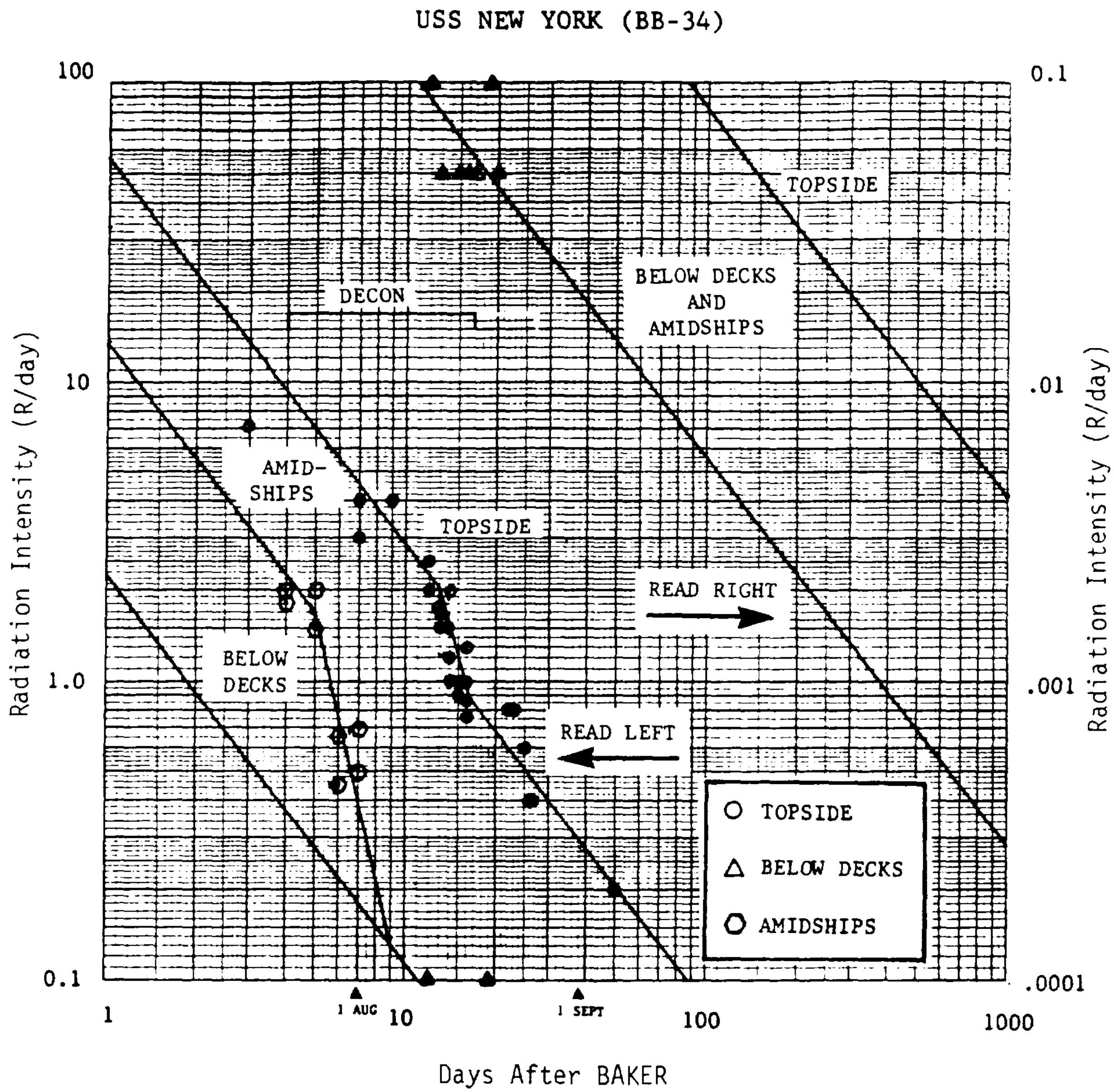

Figure 4. Radiation Intensity of USS NEW YORK (BB-34)

USS PENSACOLA (CA-24)

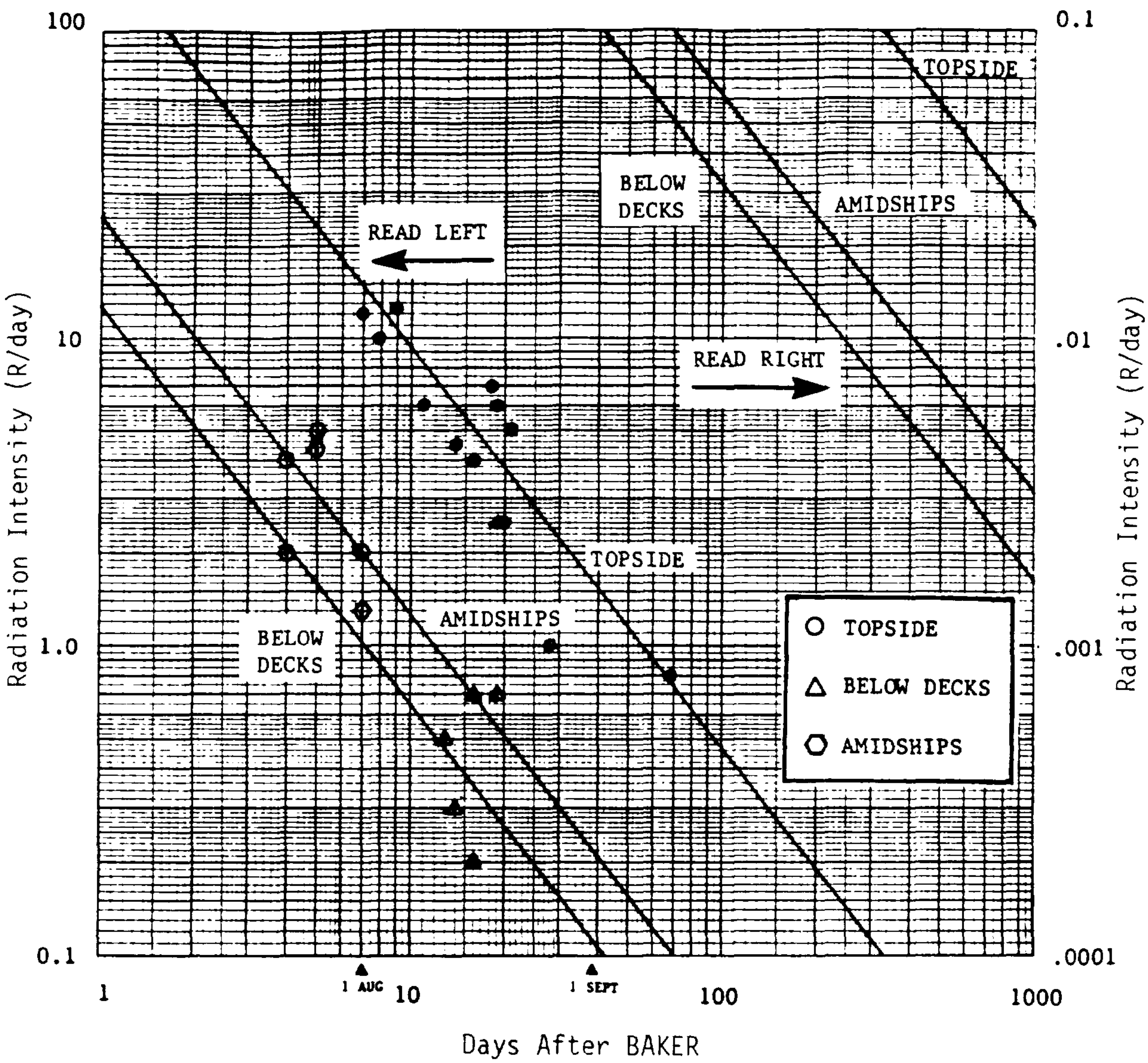

Figure 5. Radiation Intensity of USS PENSACOLA (CA-24)

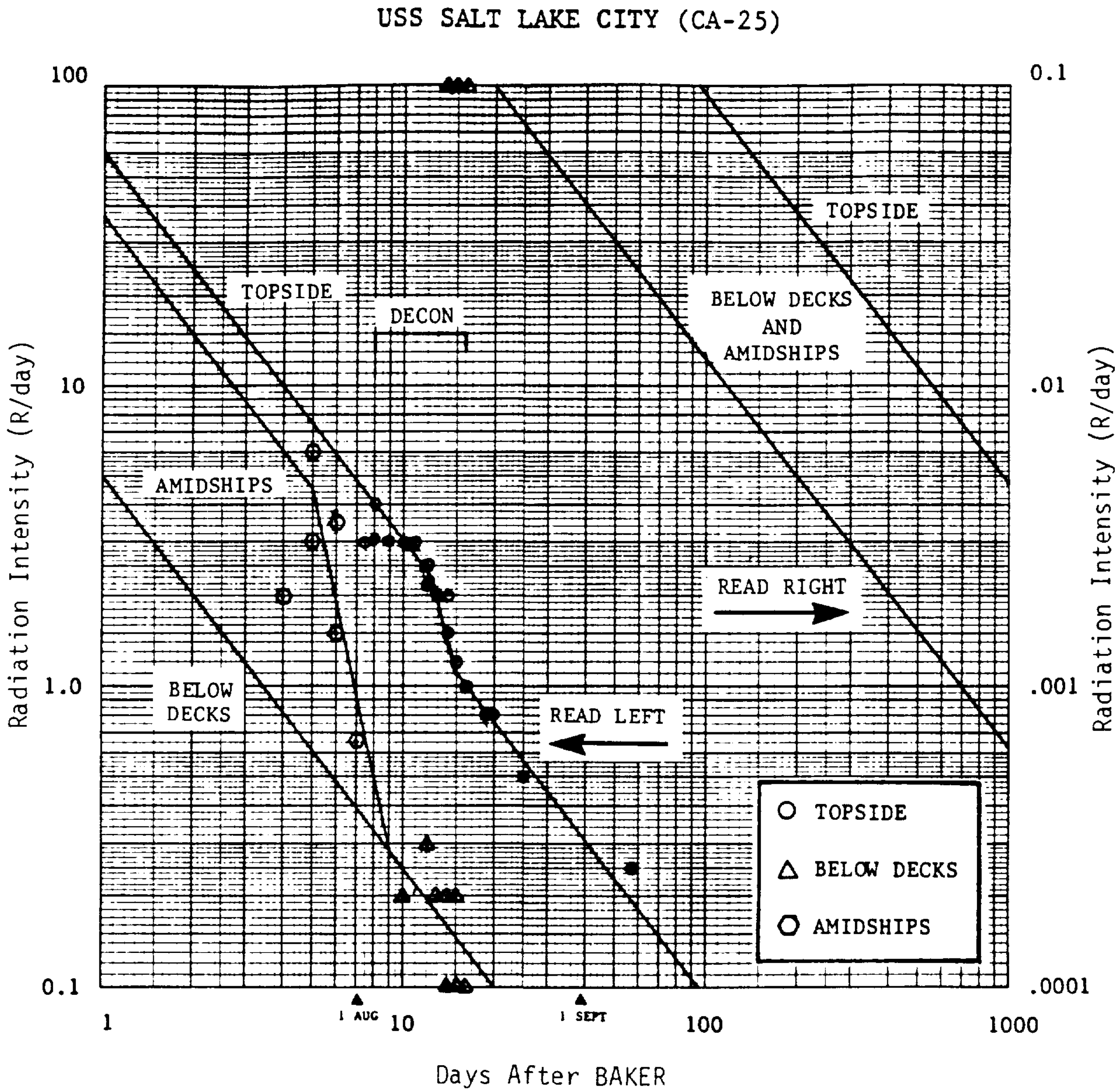

Figure 6. Radiation Intensity of USS SALT LAKE CITY (CA-25)

Table 10. Radiation Intensity of Target Ships at Bikini

Average Topside Radiation Intensity (R/hr)

Date	D+	INDEPENDENCE	NEW YORK	PENSACOLA	SALT LAKE CITY
1 Aug	7	*	*	0.613	0.198
2 Aug	8	*	*	0.517	0.166
3 Aug	9	*	*	*	0.143
4 Aug	10	*	*	*	0.124
5 Aug	11	*	0.103	0.341	0.110
6 Aug	12	*	0.0925	0.305	0.0979
7 Aug	13	*	0.0833	0.275	0.0833
8 Aug	14	*	0.0625	0.250	0.0583
9 Aug	15	*	0.0479	*	0.0458
10 Aug	16	*	0.0375	0.210	*
11 Aug	17	*	0.0347	*	*
12 Aug	18	*	*	0.180	0.0362
13 Aug	19	*	0.0300	0.168	0.0337
14 Aug	20	*	*	0.157	*
15 Aug	21	*	0.0263	0.147	*
16 Aug	22	*	0.0248	0.139	*
17 Aug	23	*	0.0234	*	0.0263
18 Aug	24	0.0663	0.0222	0.124	*
19 Aug	25	0.0625	0.0210	0.118	0.0236
20 Aug	26	0.0596	0.0200	0.112	0.0224
21 Aug	27	0.0567	0.0190	0.106	*
22 Aug	28	*	0.0181	0.101	*
23 Aug	29	*	*	*	0.0195
24 Aug	30	*	0.0166	0.0925	*
25 Aug	31	*	*	*	0.0178
26 Aug	32	*	*	0.0850	*

*Ship not boarded.

This illustrates the calculation of the 50-year dose commitment to the lung for the Anchor Team of the USS INDEPENDENCE (CVL-22). As shown in Table 5, the Anchor Team boarded INDEPENDENCE only once, on 21 Aug 46, 27 days after shot BAKER.

The dose calculation equation is:

$$D_{Lung} = \left[f_{TS} \cdot I_{TS} \cdot K_{TS} \cdot BR \cdot T \cdot BIF_{Lung}\right] + \left[f_{BD} \cdot I_{BD} \cdot K_{BD} \cdot BR \cdot T \cdot BIF_{Lung}\right]$$

The value of the parameters are:

f_{TS}	=	0.50	- *Fraction of time Topside for Anchor Team*, from Table 9,
I_{TS}	=	0.0567 (R/hr)	- Topside radiation intensity for INDEPENDENCE at post-Shot BAKER time of D+27 days, from Table 10,
K_{TS}	=	10^{-6} (m^{-1})	- Topside resuspension factor for Anchor Team, from Table 9,
f_{BD}	=	0.50	- Fraction of time Below Decks for Anchor Team, from Table 9,
I_{BD}	=	0.00567 (R/hr)	- Below Decks radiation intensity, taken as 10% of Topside radiation intensity,
K_{BD}	=	10^{-5} (m^{-1})	- Below Decks resuspension factor for Anchor Team, from Table 9,
BR	=	1.2 (m^3/hr)	- Breathing rate for Anchor Team, from Table 9,
T	=	4.0 (hr)	- *Duration of exposure for Anchor Team aboard* INDEPENDENCE on 21 Aug, from Table 5,
BIF_{Lung}	=	$2.69 \times 10^{+4}$	- BAKER inventory factor for lung at post-Shot BAKER *time of* D+27 days, obtained by interpolation between D+21 days and M+1 month unit dose factors in Table 4.

The dose is:

$$D_{Lung} = [(0.50)\ (0.0567)\ (10^{-6})\ (1.2)\ (4.0)\ (2.69 \times 10^{+4})]$$
$$+ [(0.50)\ (0.00567)\ (10^{-5})\ (1.2)\ (4.0)\ (2.69 \times 10^{+4})]$$

$$D_{Lung} = [3.66 \times 10^{-3}] + [3.66 \times 10^{-3}]$$

$$D_{Lung} = 7.32 \times 10^{-3}$$

$$D_{Lung} = 0.007 \text{ rem.}$$

Figure 7. Example Calculation of Reboarding Dose

Table 11. Organ Dose Commitments for Post-BAKER Reboarding Teams at Bikini

Ship/Team	Organ Dose Commitment (rem)									
	Lung	LLI Wall	Bone	R. Marrow	Endos	Kidneys	Liver	Testes	Thyroid	Total Body
USS INDEPENDENCE (CVL-22)										
Inspection	0.025	0.003	0.004	0.003	0.040	0.001	0.008	<.001	0.011	0.001
Anchor	0.007	0.001	0.001	0.001	0.012	<.001	0.002	<.001	0.003	<.001
USS NEW YORK (BB-34)										
Survey	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Decontamination	0.012	0.003	0.002	0.001	0.016	0.001	0.003	<.001	0.013	0.001
Engineer-1	0.008	0.002	0.001	0.001	0.011	<.001	0.002	<.001	0.009	<.001
Engineer-2	0.015	0.003	0.002	0.002	0.021	0.001	0.004	<.001	0.016	0.001
Engineer-3	0.019	0.004	0.003	0.002	0.027	0.001	0.006	<.001	0.019	0.001
Engineer-4	0.016	0.003	0.002	0.002	0.023	0.001	0.005	<.001	0.015	0.001
Engineer-5	0.007	0.001	0.001	0.001	0.010	<.001	0.002	<.001	0.006	<.001
Engineer-6	0.002	<.001	<.001	<.001	0.003	<.001	0.001	<.001	0.001	<.001
Inspection	0.005	0.001	0.001	0.001	0.008	<.001	0.002	<.001	0.003	<.001
Pump Detail	0.009	0.001	0.002	0.001	0.015	<.001	0.003	<.001	0.004	<.001
Ordnance	0.003	<.001	<.001	<.001	0.005	0.001	0.001	<.001	0.001	<.001
Anchor	0.011	0.001	0.002	0.001	0.018	<.001	0.004	<.001	0.004	<.001
USS PENSACOLA (CA-24)										
Advance-1	0.015	0.004	0.002	0.002	0.020	0.001	0.004	<.001	0.019	0.001
Advance-2	0.006	0.003	0.001	0.001	0.007	<.001	0.001	<.001	0.010	<.001
Decontamination-1	0.004	0.001	0.001	0.001	0.006	<.001	0.001	<.001	0.004	<.001
Decontamination-2	0.019	0.003	0.003	0.002	0.030	0.001	0.006	<.001	0.011	0.001
Inspection	0.018	0.002	0.003	0.002	0.028	0.001	0.006	<.001	0.009	0.001
Anchor	0.013	0.001	0.002	0.002	0.023	0.001	0.005	<.001	0.004	0.001
USS SALT LAKE CITY (CA-25)										
Advance	0.003	0.001	<.001	<.001	0.003	<.001	0.001	<.001	0.005	<.001
Decontamination-1	0.015	0.004	0.002	0.002	0.018	0.001	0.004	<.001	0.019	0.001
Decontamination-2	0.013	0.003	0.002	0.001	0.017	0.001	0.004	<.001	0.016	0.001
Inspection	0.005	0.001	0.001	0.001	0.008	<.001	0.002	<.001	0.002	<.001
Anchor	0.005	0.001	0.001	0.001	0.008	<.001	0.002	<.001	0.002	<.001

Table 12. Calculated Film Badge Doses for Reboarding Teams at Bikini

Ship/Team	Film Badge Dose (rem)
USS INDEPENDENCE (CVL-22)	
Inspection Team	0.19
Anchor Team	0.087
USS NEW YORK (BB-34)	
Survey Team	0.001
Decontamination Team	0.34
Engineer-1 Team	0.13
Engineer-2 Team	0.23
Engineer-3 Team	0.26
Engineer-4 Team	0.21
Engineer-5 Team	0.083
Engineer-6 Team	0.018
Inspection Team	0.051
Pump Detail Team	0.072
Ordnance Team	0.020
Anchor Team	0.13
USS PENSACOLA (CA-24)	
Advance-1 Team	0.28
Advance-2 Team	0.17
Decontamination-1 Team	0.10
Decontamination-2 Team	0.22
Inspection Team	0.15
Anchor Team	0.14
USS SALT LAKE CITY (CA-25)	
Advance Team	0.090
Decontamination-1 Team	0.52
Decontamination-2 Team	0.43
Inspection Team	0.037
Anchor Team	0.061

SECTION 4
AMMUNITION UNLOADING AT KWAJALEIN

In late August and early September of 1946, target ships that had survived the tests at Bikini were taken to Kwajalein. Twenty of the target ships contained large amounts of ammunition that had been stored on the ships prior to Operation CROSSROADS to test the effects of nuclear weapons on munitions. Due to the effects of the heat and humidity aboard the target ships, the ammunition was becoming unstable and its removal was required.

A special ammunition disposal unit was formed to remove the ammunition from the target ships. The unit consisted of an Initial Boarding Team and five Ammunition Unloading Teams, with a total of 268 personnel. The Initial Boarding Team inspected the ships for potential hazards and measured radiation intensities; after the ship was declared safe, the Team opened up the ship and rigged hoists and other equipment to handle the ammunition. The Ammunition Unloading Teams subsequently boarded the ships and removed the ammunition. Each team was commanded by an officer and accompanied by a radiological safety monitor. Film badges were worn at all times and the use of a rescue breathing apparatus (RBA) was required when working below decks. All personnel were processed through a change ship for issue of clothing and equipment on the way to the target ships and for decontamination and monitoring on return from the target ships. The activities of the ammunition disposal unit and the safety regulations for the activities are given in References 21, 22, and 23.

Table 13, based on data from messages, reports, and other documentary sources, shows the schedule for operations of the ammunition disposal unit. Table 14, based on data contained in Reference 24, summarizes the film badge data recorded for the unit. The schedule of operations and the film badge data provide the basis for calculating organ dose commitments for the ammunition disposal unit.

Organ dose commitments are calculated for each team of the ammunition disposal unit; these organ dose commitments are based on the average film badge dose for the team. Film badge data are available for the members of the unit and most members can be identified with one of the specified teams. Organ dose commitments for these individuals can be determined from the ratio of the individual's film badge dose to the team's average film badge dose.

Equation 1 (Section 2) is the basic equation used for calculating organ dose commitments. For calculating doses for the ammunition unloading work at Kwajalein, Equation 1 is applied to the topside and to the below decks exposure situations. Using the subscripts TS for topside and BD for below decks, the resulting equation for the dose commitment to organ j, D_j(rem), is:

$$D_j = f_{TS} \cdot I_{TS} \cdot K_{TS} \cdot BR \cdot T \cdot BIF_j \; + \; f_{BD} \cdot I_{BD} \cdot K_{BD} \cdot BR \cdot T \cdot \frac{1}{(PF)} \cdot BIF_j \qquad (5)$$

where f_{TS} is the fraction of the time aboard a ship spent topside and f_{BD} is the fraction of the time spent below decks. PF is the respiratory protection factor; since respiratory protective devices were not required for topside work, PF is omitted from the portion of Equation 5 dealing with topside exposure.

Equation 2 (Section 2) is the basic equation used for calculating film badge doses. For the ammunition unloading work at Kwajalein, the modified equation for the film badge does, D_{FB}(rem), is:

$$D_{FB} = f_{TS}\,(0.7)\,I_{TS} \cdot T \; + \; f_{BD}\,(0.7)\,I_{BD} \cdot T \qquad (6)$$

It should be noted that Equation 6 is not used to calculate film badge doses since such data are already available; as shown below, the equation is used to replace the radiation intensity and exposure duration in the organ dose equation with a film badge dose.

Equations 5 and 6 are simplified by assigning specific values to some of the variables. As discussed in Section 2, for the ammunition unloading work at Kwajalein, the breathing rate, BR, is 2.0 m^3/hr; the respiratory protection, PF, is 50; and the resuspension factors topside, K_{TS}, and below decks, K_{BD}, are $10^{-5}\ m^{-1}$ and $10^{-4}\ m^{-1}$, respectively. For the ammunition unloading work, the fraction of time topside, f_{TS}, is

0.25 and the fraction of time below decks, f_{BD}, is 0.75. Based on Figures 3 through 6 (Section 3), the average below decks radiation intensity, I_{BD}, is 10 percent of the average topside radiation intensity, I_{TS}.

Using the above values, Equations 5 and 6 are simplified to:

$$D_j = (5.30 \times 10^{-6}) I_{TS} \cdot T \cdot BIF_j \qquad (7)$$

$$D_{FB} = (0.2275) I_{TS} \cdot T \qquad (8)$$

Using Equation 8 to eliminate the parameters I_{TS} and T in Equation 7 gives:

$$D_j = (2.33 \times 10^{-5}) D_{FB} \cdot BIF_j \qquad (9)$$

Equation 9 is the basic equation used for calculating organ dose commitments for the ammunition unloading work at Kwajalein. The equation is applied for each day that shipboard work was performed and the results are summed to give the total organ dose commitments. BIF_j is the value of the BAKER Inventory Factor, interpolated from Table 3 for each day of exposure.

The daily film badge dose is obtained from the total dose by allocating the doses in Table 14 to the work schedules in Table 13. The total dose is proportioned into daily doses in accordance with the intensity of a specific ship on the day that the team was aboard. When two target ships are boarded in one day, the intensities are averaged. The intensity of each ship is obtained by $t^{-1.3}$ decay of the value given in Table 15. Figure 8 illustrates the lung dose calculation for Ammunition Unloading Team No. 1.

Some personnel of the ammunition disposal unit cannot be associated with a specific team, as seen in Table 14. To treat this category (i.e., Unassigned Personnel), organ dose commitments are calculated using the work schedules of the six identified teams and the film badge dose of the unassigned personnel. The results are then averaged to give organ dose commitments for the unassigned personnel.

The calculated organ dose commitments for personnel of the ammunition disposal unit at Kwajalein are given in Table 16.

Table 13. Ammunition Unloading Schedule

Date (1946)	Initial Boarding Team	AMMUNITION UNLOADING TEAM No. 1	No. 2	No. 3	No. 4	No. 5
4 SEP	Carteret	Carteret	Carteret	Carteret	Carteret	Carteret
5 SEP			Carteret			
6 SEP	New York		Carteret, New York		Wainwright	New York
7 SEP	New York		Carteret, New York		Wainwright	New York
9 SEP	New York	Skipjack		Carteret	Wainwright	New York
10 SEP	New York	Skipjack	Carteret	Prinz Eugen	Hughes	New York
11 SEP	Hughes, Pensacola		Gasconade,Hughes	Salt Lake City		New York
12 SEP	Pensacola		Independence	Salt Lake City	Wainwright	
13 SEP	Gasconade, Pensacola	Hughes	Gasconade	Salt Lake City	Wainwright	New York
14 SEP	Crittenden, Pensacola		Crittenden, Gasconade	Mayrant	Wainwright	Gasconade
16 SEP	Pensacola	Hughes	Gasconade		Hughes	
17 SEP	Pensacola	Hughes	Pensacola		Hughes	
18 SEP	Pensacola	Hughes	Gasconade, Pensacola		Hughes	
19 SEP	Independence	Hughes	Gasconade	Rhind	Hughes	Crittenden
20 SEP	Pensacola	Hughes	Gasconade	Trippe	Hughes	Crittenden
21 SEP	Independence, Pensacola		Gasconade	Rhind	Gasconade	Crittenden
22 SEP			Gasconade			
23 SEP	Independence	Gasconade		Barrow, Bracken	Gasconade	Crittenden
24 SEP	Gasconade	Gasconade				Crittenden
25 SEP	Fallon, Pensacola			Butte		Crittenden
26 SEP	Pensacola	Pensacola		Salt Lake City		Crittenden
27 SEP		Pensacola		Pensacola		
28 SEP	Independence					
30 SEP	Hughes		Fallon			
1 OCT	Pennsylvania					
3 OCT	Pensacola	Pensocola				
5 OCT	Pennsylvania					
8 OCT	Pensacola					
9 OCT	Independence		Independence			
10 OCT			Fallon			
11 OCT			Fallon		Pensacola	
12 OCT			Pennsylvania			
14 OCT			Pennsylvania	Nevada	Pensacola	
15 OCT			Pensacola		Pensacola	
17 OCT					Independence	
26 OCT	Nevada	Nevada				
28 OCT	Nevada	Nevada	Nevada			
29 OCT	Nevada	Nevada	Nevada			
30 OCT	New York	Nevada	Nevada			
31 OCT	New York	Nevada	Nevada			
1 NOV	Independence					
4 NOV			Nevada			Pensacola
5 NOV			Nevada			

Table 14. Film Badge Doses of Ammunition Disposal Unit at Kwajalein

Team	Number of Personnel*	Average Film Badge Dose (rem)
Initial Boarding Team	33	0.340
Ammunition Unloading Team No. 1	43	0.312
Ammunition Unloading Team No. 2	42	0.378
Ammunition Unloading Team No. 3	42	0.468
Ammunition Unloading Team No. 4	41	0.315
Ammunition Unloading Team No. 5	44	0.281
Unassigned Personnel	23	0.173
	268	

*All personnel of the ammunition disposal unit are identified by name in the unit's muster roll. Data from Reference 24.

Table 15. Radiation Intensity of Target Ships

Target Ship	Average Topside Radiation Intensity On 19 Aug 46 (D+25) (R/day)
USS BANNER (APA-60)	0.30
USS BARROW (APA-61)*	0.63
USS BRACKEN (APA-64)*	0.34
USS BRISCOE (APA-65)	0.83
USS BRULE (APA-66)	3.1
USS BUTTE (APA-68)*	0.074
USS CARTERET (APA-70)*	0.025
USS CARTON (APA-71)	1.2
USS CRITTENDEN (APA-77)*	1.5
USS DAWSON (APA-79)	0.50
USS FALLON (APA-81)*	2.3
USS GASCONADE (APA-85)*	1.1
USS HUGHES (DD-410)*	0.55
USS INDEPENDENCE (CVL-22)*	1.5
USS LST-52	3.8
USS LST-133	1.1
USS LST-220	0.37
USS LST-545	0.16
USS LST-661	3.0
USS MAYRANT (DD-402)*	0.90
USS MUGFORD (DD-389)	0.20
USS MUSTIN (DD-413)	0.20
USS NEVADA (BB-36)*	1.1
USS NEW YORK (BB-34)*	0.51
USS PENNSYLVANIA (BB-38)*	0.74
USS PENSACOLA (CA-24)*	2.8
PRINZ EUGEN*	0.41
USS RALPH TALBOT (DD-390)	0.46
USS RHIND (DD-404)*	0.60
USS SALT LAKE CITY (CA-25)*	0.56
USS SKATE (SS-305)	0.50
USS SKIPJACK (SS-184)*	0.50
USS STACK (DD-406)	0.64
USS TRIPPE (DD-403)*	1.2
USS WAINWRIGHT (DD-419)*	0.026
USS WILSON (DD-408)	0.97

*Denotes target ship with ammunition.

Source: Reference 2

Date (1946)	Target Ship (1)	Time Since Shot BAKER (days)	Average Topside Radiation Intensity On Specified Day (2) (R/day)	Percent of Film Badge Dose Received On Specified Day (3) (%)	Film Badge Dose Received On Specified Day (4) (rem)	Lung BIFj For Specified Day (5)	Lung Dose Commitment Received On Specified Day (6) (rem)
4 Sep	CARTERET	41	0.013	0.23	0.001	4.11E+04	0.001
9 Sep	SKIPJACK	46	0.226	3.95	0.012	4.73E+04	0.013
10 Sep	SKIPJACK	47	0.220	3.84	0.012	4.86E+04	0.014
13 Sep	HUGHES	50	0.223	3.89	0.012	5.28E+04	0.015
16 Sep	HUGHES	53	0.207	3.61	0.011	5.74E+04	0.015
17 Sep	HUGHES	54	0.202	3.53	0.011	5.90E+04	0.015
18 Sep	HUGHES	55	0.197	3.44	0.011	6.07E+04	0.015
19 Sep	HUGHES	56	0.193	3.37	0.011	6.24E+04	0.016
20 Sep	HUGHES	57	0.188	3.28	0.010	6.41E+04	0.015
23 Sep	GASCONADE	60	0.353	6.16	0.019	6.97E+04	0.031
24 Sep	GASCONADE	61	0.345	6.02	0.019	7.08E+04	0.031
26 Sep	PENSACOLA	63	0.842	14.70	0.046	7.30E+04	0.078
27 Sep	PENSACOLA	64	0.825	14.40	0.045	7.42E+04	0.078
3 Oct	PENSACOLA	70	0.734	12.82	0.040	8.14E+04	0.076
26 Oct	NEVADA	93	0.199	3.48	0.011	1.15E+05	0.030
28 Oct	NEVADA	95	0.194	3.39	0.011	1.17E+05	0.030
29 Oct	NEVADA	96	0.191	3.34	0.010	1.18E+05	0.028
30 Oct	NEVADA	97	0.189	3.30	0.010	1.19E+05	0.028
31 Oct	NEVADA	98	0.186	3.25	0.010	1.21E+05	0.028
			5.727	100.00	0.312		Total = 0.56

(1) Based on work schedule of Ammunition Unloading Team No. 1 given in Table 13.
(2) Radiation intensity calculated for specified target ship (column 2) for specified day (column 3) using data given in Table 15.
(3) Percent of film badge dose calculated from radiation intensity (column 4 and total of column 4) based on Equation 12. For example, (0.013 ÷ 5.727) x (100%) = 0.23%.
(4) Film badge dose, D_{FB}, based on percent of total film badge dose (column 5) and average film badge dose for Ammunition Unloading Team No. 1 given in Table 14 as 0.312 rem.
(5) BIF_j values obtained from Table 4 of Section 2 by interpolation. Example organ is lung.
(6) Based on Equation 9: $D_j = (2.33 \times 10^{-5}) \cdot D_{FB} \cdot BIF_j$.

Figure 8. Example Dose Calculation for Ammunition Unloading Team No. 1

Table 16. Organ Dose Commitments for Ammunition Disposal Unit at Kwajalein (rem)

Organ	Initial Boarding Team	Ammunition Unloading Teams No. 1	No. 2	No. 3	No. 4	No. 5	Unassigned Personnel
Lung	0.53	0.56	0.66	0.71	0.58	0.44	0.29
LLI Wall	0.03	0.03	0.04	0.05	0.03	0.03	0.02
Bone	0.10	0.11	0.13	0.13	0.11	0.09	0.06
R Marrow	0.08	0.09	0.10	0.11	0.09	0.07	0.05
Endosteum	1.0	1.1	1.3	1.4	1.2	0.85	0.57
Kidneys	0.03	0.03	0.04	0.04	0.03	0.03	0.02
Liver	0.21	0.22	0.26	0.27	0.23	0.17	0.11
Testes	0.011	0.012	0.014	0.015	0.013	0.010	0.006
Thyroid	0.04	0.03	0.04	0.06	0.03	0.03	0.02
Total Body	0.03	0.03	0.03	0.03	0.03	0.02	0.01

SECTION 5
MAINTENANCE AND SECURITY AT KWAJALEIN

As mentioned in Section 4, target ships that had survived the tests at Bikini were taken to Kwajalein. At Kwajalein, personnel boarded the target ships to perform limited maintenance and security tasks intended to keep the ships seaworthy and to prepare them for sinking near Kwajalein or for transfer to naval shipyards. In the first year after the tests, approximately 500 personnel were involved in this activity. After July 1947, however, personnel decreased to 146, and by July 1948, the effort was complete as the last ship departed.

The safety precautions specified for personnel boarding the target ships were the same as those used for the ammunition disposal unit discussed in Section 4 (Reference 22). However, as discussed in Reference 1, these precautions were not always strictly followed, especially during 1947. Accordingly, it is assumed that respiratory protective devices, such as a rescue breathing apparatus (RBA), were not used when working on target ships.

Fifty target ships were at Kwajalein. These included fourteen small craft, such as landing craft and fuel barges, and thirty-six large ships, such as troop transports and destroyers. Since most of the maintenance and security work was performed on the large ships, the average radiation intensity to which a shipboard worker was exposed is best determined by considering only the large ships. Table 17, based on information provided in Reference 1, gives the arrival and departure schedule of the large target ships at Kwajalein. As is discussed later, this schedule information in conjunction with the radiation intensity of the specified target ships is used to determine the average radiation intensity of the set of target ships present at Kwajalein as a function of time.

The maintenance and security work at Kwajalein began on 20 August 1946 with the arrival of USS STACK (DD-406) and ended on 25 July 1948 with the departure of LST-661. Film badge and exposure time data are available only for the period of August 1947 through July 1948 (Reference 25). The available data are summarized in Table 18.

Since the available film badge data do not cover the period of August 1946 through July 1947, organ dose commitments for personnel exposed during this period are based on an estimated daily exposure. As seen in Table 18, for the period of August 1947 through July 1948 the average monthly figure indicates that a worker spent approximately one hour per day aboard target ships. Because this period is rather long and includes all types of shipboard activities that were performed as part of the maintenance and security work, the average monthly exposure time for the period is a reasonable estimate of the average monthly exposure time for the August 1946 - July 1947 period. Accordingly, organ dose commitments and film badge doses for personnel exposed during the period of August 1946 through July 1947 are calculated for a worker who spends one hour per day aboard target ships.

To maintain consistency, organ dose commitments and film badge doses for personnel exposed during the period of August 1947 through July 1948 are also calculated for a worker who spends one hour per day aboard target ships. However, since film badge data is available for this period, the organ dose commitments can be referenced to the actual film badge dose, thus eliminating any assumptions about exposure duration.

Organ dose commitments and film badge doses for the maintenance and security work at Kwajalein are calculated on a monthly basis. As mentioned above, the calculations are based on a worker spending one hour per day, approximately 30 hours per month, aboard target ships. For personnel who served at Kwajalein during the period of August 1947 through July 1948 (the period for which film badge data are available), organ dose commitments to an individual can be determined from the actual film badge data.

Equation 1 (Section 2) is the basic equation used for calculating organ dose commitments. For calculating doses for the maintenance and security work at Kwajalein, Equation 1 in applied to the topside and to the below decks exposure situations. Since respiratory protective devices were not used, the protection factor is omitted. The resulting equation for the dose commitment to organ j, D_j(rem) is:

$$D_j = f_{TS} \cdot I_{TS} \cdot K_{TS} \cdot BR \cdot T \cdot BIF_j \quad + \quad f_{BD} \cdot I_{BD} \cdot K_{BD} \cdot BR \cdot T \cdot BIF_j \tag{10}$$

where TS indicates topside and BD indicates below decks; f_{TS} is the fraction of time aboard the ship spent topside and f_{BD} is the fraction spent below.

Equation 2 (Section 2) is the basic equation used for calculating film badge doses. For the maintenance and security work at Kwajalein, the modified equation for the film badge dose is:

$$D_{FB} = f_{TS}\,(0.7) I_{TS} \cdot T \quad + \quad f_{BD} (0.7) I_{BD} \cdot T \tag{11}$$

Equations 10 and 11 are simplified by assigning values to some of the variables. As discussed in Section 2, for the maintenance and security work at Kwajalein, the breathing rate, BR, is 1.2 m^3/hr and the resuspension factors topside, K_{TS}, and below decks, K_{BD}, are 10^{-6} m^{-1} and 10^{-5} m^{-1}, respectively. The fraction of time topside, f_{TS}, is 0.5 and the fraction of time below decks, f_{BD}, is 0.5. Based on Figures 3 through 6 (Section 3), the average below decks radiation intensity, I_{BD} (R/hr), is 10 percent of the average topside radiation intensity I_{TS}. The duration of the exposure, T, is 1 hour per day, the estimated daily exposure discussed earlier.

Using the above values, Equations 10 and 11 are simplified to:

$$D_j = (1.20 \times 10^{-6}) I_{TS} \cdot BIF_j \tag{12}$$

$$D_{FB} = (0.385) I_{TS} \tag{13}$$

The above equations are used to calculate the organ dose commitments and the film badge dose on a daily basis; the doses are summed to give the total doses for a monthly period.

BIF_j is the BAKER Inventory Factor, interpolated from Table 3 for each day of exposure.

The parameter I_{TS} (R/hr) in Equations 12 and 13 is the average topside radiation intensity of the set of target ships present at Kwajalein on a given day. An average radiation intensity is used because it is not possible to determine the specific target ships that were worked on a given day. The procedure for calculating this average radiation intensity is discussed below.

Table 15 gives the average topside radiation intensity of each of the thirty-six target ships at twenty-five days after Shot BAKER (Reference 2). From the standard CROSSROADS decay (proportional to $t^{-1.3}$), the radiation intensity of the target ships on a given day is calculated for the first six months after the test. Because fallout decay is known to accelerate after six months (Reference 29), the standard decay is no longer applicable. Decay determined by the FIIDOS code (Reference 7) is used through 1948, approximately $t^{-2.3}$ for the period. Based on the arrival and departure information given in Table 17, the target ships present at Kwajalein on a given day are identified. During the two-year maintenance and security period, the radiation intensities of those target ships present at Kwajalein on each day are summed and then divided by the number of ships present to give the average radiation intensity. This procedure is illustrated in Figure 9 for the first five days of the maintenance and security period.

Figure 10 shows the average radiation intensity of target ships at Kwajalein for the full two-year period. During the first three weeks, the average changes significantly as more target ships arrive. From September 1946 through March 1948, the average radiation intensity drops steadily due to radioactive decay, and the effect of a target ship's departure is not readily apparent because departures occur almost uniformly during the period. During the last four months of the operation, the average radiation intensity changes significantly because, with few target ships present, the departure of a single target ship greatly affects the average.

For those cases in which monthly film badge data is available, monthly organ dose commitments can be determined from the actual film badge dose, thus eliminating the assumption regarding the daily exposure conditions. When Equation 12 is divided by Equation 13, it is seen that the ratio of the organ dose commitment to the film badge dose is equal to a constant:

$$\frac{D_j}{D_{FB}} = \frac{(1.2 \times 10^{-6})}{(0.385)} \cdot BIF_j \qquad (14)$$

Through the BAKER Inventory Factor, BIF_j, the value of the dose ratio is dependent on the time after the shot at which the exposure occurs. It should be noted that the value is not explicitly dependent on the radiation intensity or the duration of the exposure.

The calculated organ dose commitments for the maintenance and security work at Kwajalein are given in Table 19. It may be noted that the actual film badge doses from August 1947 to July 1948 are higher for most months than the calculated monthly averages. This is apparently because only that portion of the detachment assigned to the higher intensity ships was actually badged--about 20 men per month average. These personnel were badged for periods of one to six months, two months on the average. The annual average for the detachment, however, would likely be as calculated; that is, no individual would have received the sum of all monthly film badge (actual) doses. As stated previously, dose commitments are based on film badge doses. When dosimetry is available for an individual, it should be used. When it is not available, the calculated film badge doses, although possibly high-sided for unbadged intervals, are appropriate for determination of organ doses.

Table 17. Schedule of Target Ship Arrivals and Departures at Kwajalein

Target Ship	Date Arrived Kwajalein	Date Departed Kwajalein*
USS BANNER (APA-60)	29 Aug 46	16 Feb 48
USS BARROW (APA-61)	27 Aug 46	11 May 48
USS BRACKEN (APA-64)	21 Aug 46	10 Mar 48
USS BRISCOE (APA-65)	22 Aug 46	6 May 48
USS BRULE (APA-66)	29 Aug 46	11 May 48
USS BUTTE (APA-68)	30 Aug 46	12 May 48
USS CARTERET (APA-70)	27 Aug 46	19 Apr 48
USS CATRON (APA-71)	28 Aug 46	6 May 48
USS CRITTENDEN (APA-77)	26 Aug 46	1 Dec 46
USS DAWSON (APA-79)	21 Aug 46	16 Apr 46
USS FALLON (APA-81)	3 Sep 46	10 May 48
USS GASCONADE (APA-85)	26 Aug 46	15 Jan 47
USS HUGHES (DD-410)	28 Aug 46	15 May 47
USS INDEPENDENCE (CVL-22)	27 Aug 46	15 Jun 47
USS LST-52	27 Aug 46	15 Apr 48
USS LST-133	30 Aug 46	11 May 48
USS LST-220	30 Aug 46	12 May 48
USS LST-545	30 Aug 46	12 May 48
USS LST-661	27 Aug 46	25 Jul 48
USS MAYRANT (DD-402)	29 Aug 46	4 Apr 48
USS MUGFORD (DD-389)	21 Aug 46	22 Mar 48
USS MUSTIN (DD-413)	30 Aug 46	28 Apr 48
USS NEVADA (BB-36)	22 Aug 46	15 May 47
USS NEW YORK (BB-34)	24 Aug 46	15 Mar 47
USS PENNSYLVANIA (BB-38)	24 Aug 46	10 Feb 48
USS PENSACOLA (CA-24)	27 Aug 46	15 Apr 47
PRINZ EUGEN	22 Aug 46	22 Dec 46
USS RALPH TALBOT (DD-390)	29 Aug 46	15 Mar 48
USS RHIND (DD-404)	1 Sep 46	22 Mar 48
USS SALT LAKE CITY (CA-25)	25 Aug 46	15 Jul 47
USS SKATE (SS-305)	24 Aug 46	26 Aug 46
USS SKIPJACK (SS-184)	7 Sep 46	11 Sep 46
USS STACK (DD-406)	20 Aug 46	24 Apr 48
USS TRIPPE (DD-403)	22 Aug 46	3 Feb 48
USS WAINWRIGHT DD-419)	25 Aug 46	5 Jul 48
USS WILSON (DD-408)	21 Aug 46	8 Mar 48

*For ships sunk or scuttled at Kwajalein, the departure date is taken as the date the ship was sunk or scuttled. For those ships where only month and year of Kwajalein departure is known, the departure date is taken as the 15th of the month.

Table 18. Exposure Data for Kwajalein

Month	Number of Workers(1)	Total Monthly Exposure Time(2) (hr)	Average Monthly Exposure Time (hr)
Aug 47	19	38	2
Sep 47	20	155	8
Oct 47	52	585	11
Nov 47	20	391	20
Dec 47	33	630	19
Jan 48	23	268	12
Feb 48	17	429	25
Mar 48	20	359	18
Apr 48	21	892	42
May 48	14	958	68
Jun 48	6	410	68
Jul 48	7	514	73
	252	5629	22(3)

(1) The total number of workers is greater than the 146 men identified by name in the Kwajalein dosimetry data base (Reference 25); most of the men worked more than one month on the target ships.

(2) During the 6-month period of August 1947 to January 1948, the total exposure time is 2067 hours; during the 6-month period of February 1948 to July 1948, the total exposure time is 3562 hours. During the first period, the work involved only maintenance and security of the target ships, whereas during the second period, 25 target ships were prepared for sinking. This activity presumably accounts for the increased exposure time during the second period.

(3) Obtained by dividing the sum of all monthly exposure times by the sum of the monthly number of workers.

Target Ship[1]	Topside Radiation Intensity (R/day) on Specified Date (1946) 19 Aug[2] (D+25)	20 Aug (D+26)	21 Aug (D+27)	22 Aug (D+28)	23 Aug (D+29)	24 Aug (D+30)
STACK	0.64	0.608	0.579	0.552	0.528	0.505
BRACKEN	0.34		0.308	0.293	0.280	0.268
DAWSON	0.50		0.452	0.432	0.412	0.394
MUGFORD	0.20		0.181	0.173	0.165	0.158
WILSON	0.97		0.878	0.837	0.800	0.765
BRISCOE	0.83			0.716	0.684	0.655
NEVADA	1.10			0.949	0.907	0.868
PRINZ EUGEN	0.41			0.354	0.338	0.323
TRIPPE	1.20			1.036	0.989	0.947
NEW YORK	0.51					0.402
PENNSYLVANIA	0.74					0.584
SKATE	0.50					0.394
Total (R/day)	=	0.608	2.398	5.342	5.103	6.263
Number of Ships	=	1	5	9	9	12
Average Intensity (R/day)	=	0.608	0.480	0.594	0.567	0.522
Average Intensity (R/hr)	=	0.025	0.020	0.025	0.024	0.022

(1) Listed in order of arrival at Kwajalein.
(2) From Table 18.

Figure 9. Calculation of Average Radiation Intensity of Target Ships

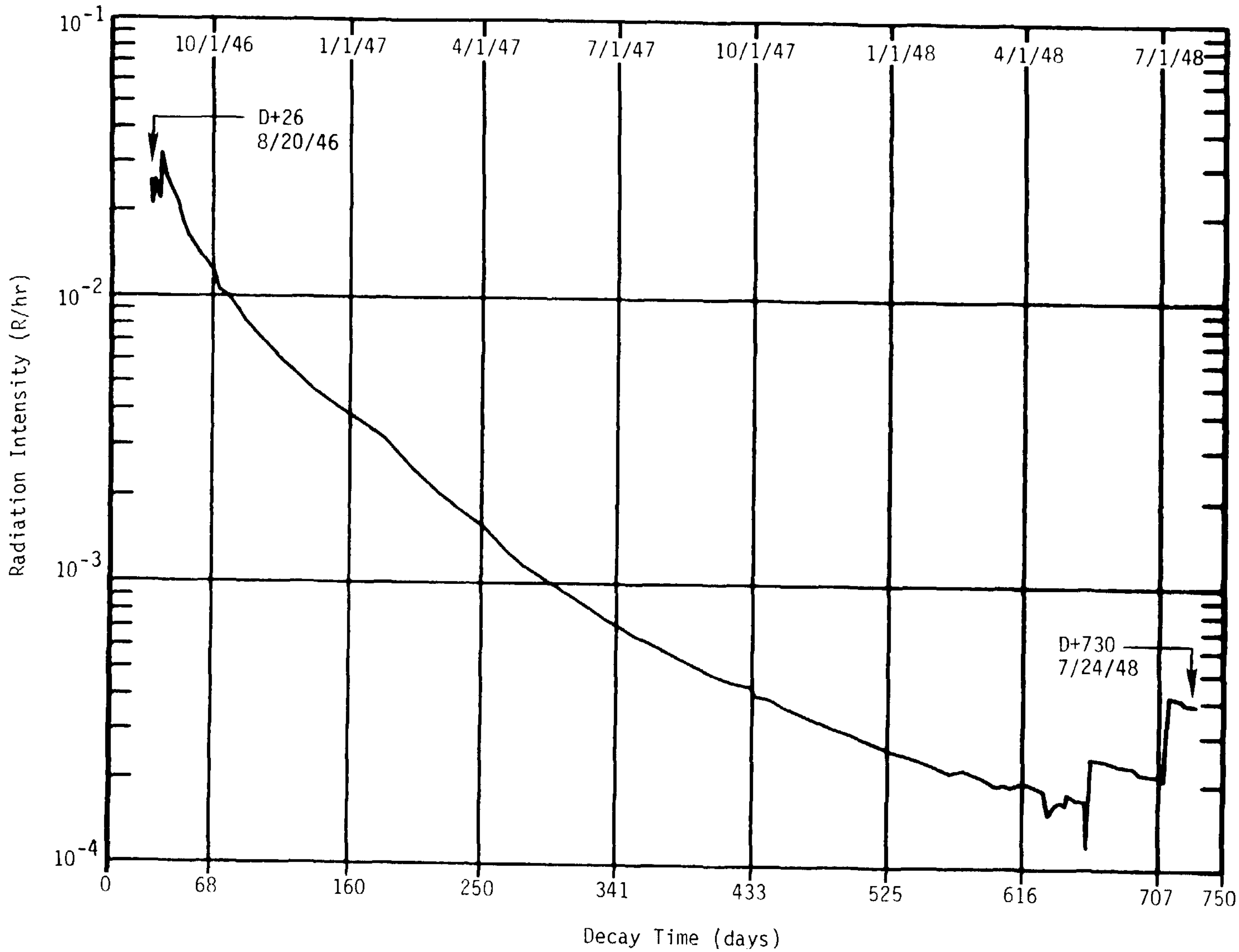

Figure 10. Average Radiation Intensity of Target Ships at Kwajalein

Table 19. Organ Dose Commitments and Film Badge Doses for Maintenance and Security Work at Kwajalein, August 1946 - July 1948

	Organ Dose Commitment (rem)										Film Badge Dose (rem)	
Month	Lung	LLI Wall	Bone	R Marrow	Endos	Kidneys	Liver	Testes	Thyroid	Total Body	Calculated	Actual
Aug 1946[1]	0.011	0.001	0.002	0.002	0.018	0.001	0.004	<.001	0.004	<.001	0.113	—
Sep 1946	0.033	0.002	0.006	0.005	0.060	0.002	0.013	0.001	0.003	0.001	0.188	—
Oct 1946	0.033	0.002	0.006	0.005	0.067	0.002	0.013	0.001	<.001	0.002	0.105	—
Nov 1946	0.029	0.001	0.006	0.005	0.067	0.002	0.013	0.001	<.001	0.002	0.067	—
Dec 1946	0.029	0.001	0.006	0.005	0.071	0.002	0.015	0.001	<.001	0.002	0.050	—
Jan 1947	0.029	0.001	0.007	0.006	0.076	0.002	0.015	0.001	<.001	0.002	0.039	—
Feb 1947	0.025	0.001	0.006	0.005	0.069	0.002	0.014	0.001	<.001	0.002	0.027	—
Mar 1947	0.026	0.001	0.007	0.006	0.074	0.002	0.015	0.001	<.001	0.002	0.022	—
Apr 1947	0.024	0.001	0.006	0.005	0.069	0.002	0.014	0.001	<.001	0.001	0.015	—
May 1947	0.022	0.001	0.006	0.005	0.072	0.002	0.014	0.001	<.001	0.001	0.012	—
Jun 1947	0.023	0.001	0.006	0.005	0.072	0.002	0.013	0.001	<.001	0.001	0.009	—
Jul 1947	0.024	0.001	0.007	0.006	0.078	0.002	0.015	0.001	<.001	0.002	0.008	—
Total Period	0.31	0.013	0.072	0.059	0.79	0.023	0.16	0.009	0.009	0.018	0.66	—
Aug 1947	0.024	0.001	0.007	0.006	0.082	0.002	0.016	0.001	<.001	0.002	0.006	0.001
Sep 1947	0.023	0.001	0.007	0.006	0.081	0.002	0.016	0.001	<.001	0.002	0.005	0.043
Oct 1947	0.023	<.001	0.007	0.006	0.086	0.002	0.016	0.001	<.001	0.002	0.005	0.103
Nov 1947	0.022	<.001	0.008	0.006	0.083	0.002	0.016	0.001	<.001	0.002	0.004	0.028
Dec 1947	0.022	<.001	0.008	0.007	0.087	0.002	0.017	0.001	<.001	0.002	0.003	0.022
Jan 1948	0.021	<.001	0.007	0.006	0.085	0.002	0.017	0.001	<.001	0.002	0.003	0.030
Feb 1948	0.019	<.001	0.007	0.006	0.079	0.002	0.015	0.001	<.001	0.001	0.003	0.055
Mar 1948	0.020	<.001	0.008	0.006	0.085	0.002	0.016	0.001	<.001	0.002	0.002	0.002
Apr 1948	0.018	<.001	0.007	0.006	0.081	0.002	0.016	0.001	<.001	0.001	0.002	0.010
May 1948	0.024	<.001	0.010	0.008	0.11	0.003	0.021	0.001	<.001	0.002	0.002	0.033
Jun 1948	0.025	<.001	0.010	0.009	0.11	0.003	0.022	0.001	<.001	0.002	0.003	0.020
Jul 1948[2]	0.035	<.001	0.015	0.019	0.16	0.004	0.031	0.001	<.001	0.003	0.003	0.019
Total Period	0.28	0.005	0.10	0.084	1.1	0.028	0.22	0.011	0.001	0.020	0.041	

(1) First target ship arrived at Kwajalein on 20 August 1946.
(2) Last target ship departed Kwajalein on 25 July 1948.

SECTION 6
INSPECTION AND MAINTENANCE AT NAVAL SHIPYARDS

As mentioned in Section 5, some of the target ships that had been taken to Kwajalein were later transferred to naval shipyards. The naval shipyards were the Pearl Harbor Naval Shipyard, the Puget Sound Naval Shipyard, and the San Francisco Naval Shipyard. At a shipyard, a ship was inspected for damage and limited maintenance was performed. When a target ship was determined to be of no potential use, it was taken out to sea and sunk. As is discussed below, most of the work on the target ships at the naval shipyards was performed during 1947 and 1948. The number of personnel involved at Pearl Harbor was about 150 per year; at Puget Sound, 288 in 1947 and 116 in 1948; and at San Francisco, 130 in 1947 and 397 in 1948. Some personnel shown for 1948 were also present in late 1947 at Puget Sound and San Francisco.

Safety regulations for work on target ships at naval shipyards were issued by the US Navy Bureau of Medicine and Surgery in January 1947 (Reference 5). As discussed in Reference 1, these regulations emphasized the potential internal radiation hazards and appeared to codify the safety practices that had been developed earlier at Bikini and at Kwajalein. As before, these new regulations specified the use of respiratory protective devices, such as a rescue breathing apparatus (RBA), to prevent the inhalation of airborne radioactivity. However, the radiation intensities of the target ships in 1947, and especially in 1948, were so low that it is likely that RBAs were not always used when appropriate. Accordingly, it is assumed that RBAs were not used when working on the target ships at the naval shipyards.

Table 20, based on information provided in Reference 1, gives the arrival and departure schedule of the target ships at the three naval shipyards. As is discussed later, this schedule information in conjunction with the radiation intensity of the specified target ships is used to determine the average radiation intensity of the set of target ships present at a naval shipyard as a function of time.

Film badge data are recorded for personnel at the Puget Sound Naval Shipyard and the San Francisco Naval Shipyard in References 26, 27, and 28. For Puget Sound, the film badge data that cover the 1947-1948 period are provided for two periods, with the division occurring at 1 March 1948. The film badge data for San Francisco are annual data for 1947 and 1948. No film badge data are available for the Pearl Harbor Naval Shipyard. As discussed later, annual film badge data for Pearl Harbor are estimated from the Puget Sound film badge data, based on a comparison of the time-integrated average radiation intensities at the two shipyards.

Equation 1 (Section 2) is the basic equation used for calculating organ dose commitments. For calculating doses for the inspection and maintenance work at the naval shipyards, Equation 1 is applied to the topside and to the below decks exposure situations. Since respiratory protective devices were not used, the protection factor is omitted. The resulting equation for the dose commitment to organ j, D_j(rem) is:

$$D_j = f_{TS} \cdot I_{TS} \cdot K_{TS} \cdot BR \cdot T \cdot BIF_j + f_{BD} \cdot I_{BD} \cdot K_{BD} \cdot BR \cdot T \cdot BIF_j \qquad (15)$$

where TS indicates topside and BD indicates below decks; f_{TS} is the fraction of time aboard the ship spent topside and f_{BD} is the fraction spent below decks.

Equation 2 (Section 2) is the basic equation used for calculating film badge doses. For the inspection and maintenance work at the naval shipyards, the modified equation for the film badge dose D_{FB}(rem), is:

$$D_{FB} = f_{TS}\,(0.7)\,I_{TS} \cdot T + f_{BD}\,(0.7)\,I_{BD} \cdot T \qquad (16)$$

Equations 15 and 16 are simplified by assigning values to some of the variables. As discussed in Section 2, for the inspection and maintenance work at the naval shipyards, the breathing rate, BR, is 1.2 m^3/hr and the resuspension factors topside, K_{TS}, and below decks, K_{BD}, are $10^{-6}\ m^{-1}$ and $10^{-5}\ m^{-1}$, respectively. The fraction of time topside, f_{TS}, is 0.25 and the fraction of time below decks, f_{BD}, is 0.75. Based on Figures 3 through 6 (Section 3), the average below decks radiation intensity, I_{BD}, is 10 percent of the average topside radiation intensity, I_{TS}.

Using the above values, Equations 15 and 16 are simplified to:

$$D_j = (1.2 \times 10^{-6})\, I_{TS} \cdot T \cdot BIF_j \qquad (17)$$

$$D_{FB} = (0.2275)\, I_{TS} \cdot T \qquad (18)$$

Using Equation 18 to eliminate I_{TS} and T in Equation 18 gives:

$$D_j = (5.27 \times 10^{-6})\, D_{FB} \cdot BIF_j \qquad (19)$$

During the interval of about one year (for while film badge data are reported), the radionuclide inventory, and hence BIF_j, changes considerably. Therefore, film badge doses are partitioned into quarterly intervals. For each ship, the topside intensity is integrated for each quarter. The ratio of the quarterly integrated intensity to the total annual integrated intensity is used (assuming constant daily exposure periods) to partition the film badge dose quarterly.

Table 21 gives the average topside radiation intensity of each of the eight target ships as of 1 January 1947, 160 days after Shot BAKER (Reference 2). From these values, the radiation intensity of a target ship on a given day is calculated. Fallout decay is known to accelerate after six months (Reference 29); therefore, the standard CROSSROADS decay proportional to $t^{-1.3}$ is no longer applicable. Decay determined by the FIIDOS code (Reference 7) is used through 1948, approximately $t^{-2.3}$ for the period. Based on the arrival and departure information given in Table 20, the target ships present at a naval shipyard on a given day are identified. During the two-year inspection and maintenance period, the radiation intensities of those target ships present at the shipyard on each day are summed and then divided by the number of ships present to give the average radiation intensity. Figure 11 shows the average radiation intensity of target ships at each of the three naval shipyards for the 1947-1948 period.

Table 22 shows the fraction of the film badge dose received per quarter as calculated for each of the naval shipyards. For San Francisco, the film badge doses allocated are annual doses for the years 1947 and 1948. For Puget Sound, the doses allocated are for a 10-month period preceding 1 March 1948 and for a 9-month period following 1 March 1948; to simplify quarterly calculations for the two-year period, the doses are treated as though they were accumulated over the first five quarters and the last three quarters of the period, respectively. Note that for a quarter when no target ships were present at a given shipyard, the film badge dose fraction is not specified.

For Pearl Harbor, the doses are determined from the ratio of film badge dose to integrated intensities at the other shipyards. Because the ratio of film badge dose for both years to the integrated intensity is greater for Puget Sound than for San Francisco, the organ dose commitments for Pearl Harbor are high-sided by using the Puget Sound ratio. The two-year Pearl Harbor film badge dose thus obtained is partitioned annually and then quarterly as previously described. The annual calculated film badge dose for Pearl Harbor (shown in Table 23) is less than that for Puget Sound. This is consistent with the intensities shown in Figure 11.

The calculated organ dose commitments for the inspection and maintenance work at the naval shipyards in 1947 and 1948 are given in Tables 24, 25, and 26, for Pearl Harbor, Puget Sound, and San Francisco Naval Shipyards, respectively. For situations in which individual film badge data are available, organ doses can be determined from the ratio of the actual to the average film badge dose.

Table 20. Schedule of Target Ship Arrivals and Departures at Naval Shipyards

Naval Shipyard	Target Ship	Date Arrived	Date Departed[1]
Pearl Harbor	USS NEVADA (BB-36)	15 May 47	31 Jul 48
	USS NEW YORK (BB-34)	15 Mar 47	8 Jul 48
Puget Sound	USS HUGHES (DD-410)	31 May 4,	16 Oct 48
	USS PENSACOLA (CA-24)	21 Apr 47	10 Nov 48
	USS SALT LAKE CITY (CA-25)	28 Jul 47	25 May 48
San Francisco[2]	USS CRITTENDEN (APA-77)	1 Jan 47	5 Oct 48
	USS GASCONADE (APA-85)	27 Jan 47	21 Jul 48
	USS INDEPENDENCE (CVL-22)	16 Jun 47	26 Jan 51[3]

(1) The departure date is taken as the date the ship was sunk.

(2) Two other target ships, USS SKATE (SS-305) and USS SKIPJACK (SS-184), were also sent to the San Francisco Naval Shipyard. They are not included in this analysis because, in comparison with the other target ships at the San Francisco Naval Shipyard, they are much smaller and much less contaminated.

(3) This analysis addresses the naval shipyards for the years 1947 and 1948. Calculations for USS INDEPENDENCE (CVL-22) are terminated at the end of 1948.

Table 21. Radiation Intensity of Target Ships at Naval Shipyards

Naval Shipyard	Target Ship	Average Topside Intensity* 1 Jan 47 (D+160) (R/day)
Pearl Harbor	USS NEVADA (BB-36)	0.099
	USS NEW YORK (BB-34)	0.046
Puget Sound	USS HUGHES (DD-410)	0.049
	USS PENSACOLA (CA-24)	0.251
	USS SALT LAKE CITY (CA-25)	0.050
San Francisco	USS CRITTENDEN (APA-77)	0.134
	USS GASCONADE (APA-85)	0.099
	USS INDEPENDENCE (CVL-22)	0.134

*Based on $t^{-1.3}$ decay from D+25 (Table 15).

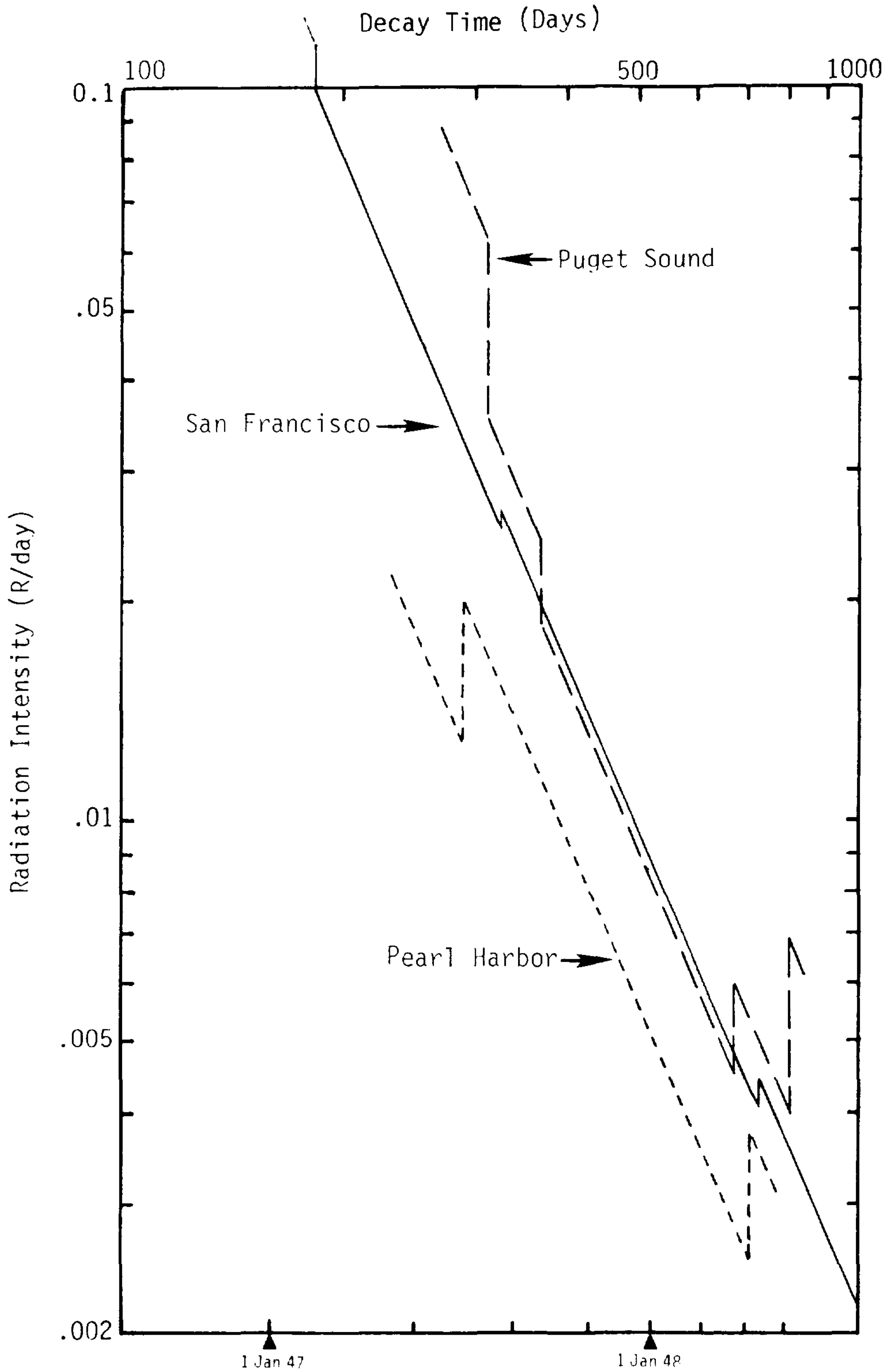

Figure 11. Average Radiation Intensity of Target Ships at Naval Shipyards

Table 22. Fraction of Annual Film Badge Dose Received Per Quarter at Naval Shipyards

Period	Pearl Harbor	Puget Sound*	San Francisco
Jan - Mar 1947	0.12	—	0.56
Apr - Jun 1947	0.42	0.54	0.21
Jul - Sep 1947	0.29	0.23	0.14
Oct - Dec 1947	0.18	0.14	0.08
Jan - Mar 1948	0.52	0.09	0.37
Apr - Jun 1948	0.36	0.42	0.26
Jul - Sep 1948	0.12	0.38	0.21
Oct - Dec 1948	—	0.20	0.16

*The film badge data available for the Puget Sound Naval Shipyard cover the period 27 Apr 47 - 1 Mar 48 and 1 Mar 48 - 30 Nov 48. Film badge doses are allocated to five quarterly periods prior to 1 April 1948 and three quarterly periods subsequent thereto.

Table 23. Average Film Badge Doses at Naval Shipyards

Naval Shipyard	Period	Average Film Badge Dose (rem)
Pearl Harbor*	1 Jan 47 - 31 Dec 47	0.074
	1 Jan 48 - 31 Dec 48	0.017
Puget Sound	1 Jan 47 - 31 Mar 48	0.126
	1 Apr 48 - 31 Dec 48	0.057
San Francisco	1 Jan 47 - 31 Dec 47	0.039
	1 Jan 48 - 31 Dec 48	0.004

*Average film badge doses are estimated from the doses for the Puget Sound Naval Shipyard, as discussed in the text.

Table 24. Organ Dose Commitments at Pearl Harbor Naval Shipyard

Organ	Jan-Mar 1947 (1)	Apr-Jun 1947	Jul-Sep 1947	Oct-Dec 1947	Total 1947 (2)	Jan-Mar 1948	Apr-Jun 1948	Jul-Sep 1948 (3)	Oct-Dec 1948	Total 1948 (2)
	Organ Dose Commitment (rem)									
Lung	0.014	0.098	0.13	0.13	0.37	0.12	0.096	0.036	0.000	0.25
LLI Wall	<.001	0.003	0.003	0.002	0.008	0.002	0.001	<.001	0.000	0.004
Bone	0.003	0.027	0.040	0.042	0.11	0.042	0.038	0.015	0.000	0.095
R Marrow	0.003	0.022	0.033	0.035	0.093	0.036	0.031	0.012	0.000	0.079
Endosteum	0.037	0.30	0.45	0.48	1.3	0.47	0.43	0.20	0.000	1.1
Kidneys	0.001	0.008	0.011	0.012	0.032	0.012	0.011	0.004	0.000	0.027
Liver	0.007	0.058	0.086	0.092	0.24	0.092	0.082	0.033	0.000	0.21
Testes	<.001	0.003	0.004	0.005	0.012	0.005	0.004	0.002	0.000	0.011
Thyroid	<.001	0.001	0.001	0.001	0.002	0.001	0.001	<.001	0.000	0.002
Total Body	0.001	0.006	0.008	0.009	0.024	0.008	0.008	0.003	0.000	0.019
	Film Badge Dose (rem)									
Film Badge	0.009	0.031	0.021	0.013	0.074	0.009	0.006	0.002	0.000	0.017

(1) First target ship arrived at Pearl Harbor Naval Shipyard on 15 March 1947.
(2) Total is for the calendar year. Doses for total period may not equal sum of quarterly doses due to rounding.
(3) Last target ship departed Pearl Harbor Naval Shipyard on 31 July 1948.

Table 25. Organ Dose Commitments at Puget Sound Naval Shipyard

Organ	Jan-Mar 1947	Apr-Jun 1947 (1)	Jul-Sep 1947	Oct-Dec 1947	Total 1947 (2)	Jan-Mar 1948	Apr-Jun 1948	Jul-Sep 1948	Oct-Dec 1948 (3)	Total 1948 (2)
	Organ Dose Commitment (rem)									
Lung	0.000	0.22	0.18	0.17	0.56	0.15	0.38	0.39	0.22	1.1
LLI Wall	0.000	0.005	0.004	0.003	0.012	0.003	0.006	0.005	0.003	0.016
Bone	0.000	0.059	0.055	0.059	0.17	0.052	0.15	0.17	0.096	0.46
R Marrow	0.000	0.049	0.045	0.049	0.14	0.044	0.12	0.14	0.079	0.38
Endosteum	0.000	0.66	0.61	0.66	1.9	0.59	1.7	2.1	1.2	5.6
Kidneys	0.000	0.017	0.016	0.017	0.050	0.015	0.042	0.047	0.027	0.13
Liver	0.000	0.13	0.12	0.13	0.37	0.11	0.32	0.36	0.21	1.00
Testes	0.000	0.007	0.006	0.007	0.019	0.006	0.016	0.018	0.010	0.051
Thyroid	0.000	0.001	0.001	0.001	0.003	0.001	0.003	0.003	0.002	0.009
Total Body	0.000	0.013	0.012	0.012	0.027	0.010	0.030	0.033	0.019	0.091
	Film Badge Dose (rem)									
Film Badge	0.000	0.068	0.029	0.018	0.115	0.011	0.024	0.022	0.011	0.068

(1) First target ship arrived at Puget Sound Naval Shipyard on 21 April 1947.
(2) Total is for the calendar year. Doses for total period may not equal sum of quarterly doses due to rounding.
(3) Last target ship departed Puget Sound Naval Shipyard on 10 November 1948.

Table 26. Organ Dose Commitments at San Francisco Naval Shipyard

Organ	Jan-Mar[1] 1947	Apr-Jun 1947	Jul-Sep 1947	Oct-Dec 1947	Total[2] 1947	Jan-Mar 1948	Apr-Jun 1948	Jul-Sep 1948	Oct-Dec[3] 1948	Total[2] 1948
	Organ Dose Commitment (rem)									
Lung	0.034	0.026	0.034	0.031	0.125	0.019	0.016	0.015	0.012	0.062
LLI Wall	0.001	0.001	0.001	0.001	0.003	<.001	<.001	<.001	<.001	0.001
Bone	0.008	0.007	0.010	0.011	0.036	0.007	0.006	0.006	0.006	0.025
R Marrow	0.007	0.006	0.008	0.009	0.030	0.006	0.005	0.005	0.005	0.016
Endosteum	0.091	0.079	0.12	0.12	0.40	0.077	0.072	0.081	0.070	0.30
Kidneys	0.002	0.002	0.003	0.003	0.010	0.002	0.002	0.002	0.002	0.007
Liver	0.018	0.015	0.022	0.023	0.078	0.015	0.014	0.014	0.012	0.055
Testes	0.001	0.001	0.001	0.001	0.004	0.001	0.001	0.001	0.001	0.003
Thyroid	<.001	<.001	<.001	<.001	0.001	<.001	<.001	<.001	<.001	<.001
Total Body	0.002	0.002	0.002	0.002	0.008	0.001	0.001	0.001	0.001	0.005
	Film Badge Dose (rem)									
Film Badge	0.022	0.008	0.005	0.003	0.039	0.001	0.001	0.001	0.001	0.004

(1) First target ship arrived at San Francisco Naval Shipyard on 1 January 1947.
(2) Total is for the calendar year. Doses for total period may not equal sum of quarterly doses due to rounding.
(3) Last target ship departed San Francisco Naval Shipyard in 1951. Dose analysis is cut-off at 31 December 1948 to be consistent with analyses for other naval shipyards.

SECTION 7
CONCLUSIONS

Organ dose commitments for ten selected organs are calculated for personnel associated with specific activities relating to Operation CROSSROADS. These activities all involve post-Shot BAKER reboarding of target ships at Bikini, ammunition unloading of target ships at Kwajalein, maintenance and security of target ships at Kwajalein, and inspection and maintenance of target ships at three naval shipyards. These activities were performed by different organizations and units over the period of August 1946 through December 1948.

Table 27 presents a synopsis of the calculated organ dose commitments and film badge doses. The full set of results that provides the basis for Table 27 is given in Tables 11 and 12 in Section 3, Tables 14 and 16 in Section 4, Table 19 in Section 5, and Tables 24, 25, and 26 in Section 6. Fifty-year bone dose commitments for each year of exposure are less than 0.15 rem for all activities except at the Puget Sound Naval Shipyard (0.17 rem in 1947, 0.46 rem in 1948). The endosteal doses were typically up to a factor of 10 higher than corresponding bone doses. Uncertainties are dominated by those in the resuspension factor. The high-sided values chosen tend to upper-limit the internal doses derived. Actual doses could be much smaller.

Table 27. Operation CROSSROADS Internal Dose Synopsis

Activity	Element	Film Badge Dose (rem)	Organ Dose Commitment (rem): Lung	LLI Wall	Bone	R. Marrow	Endos	Kidneys	Liver	Testes	Thyroid	Total Body
Post-BAKER Reboarding at Bikini	USS INDEPENDENCE (CVL-22)											
	Inspection Team	0.19*	0.025	0.003	0.004	0.003	0.040	0.001	0.008	<.001	0.011	0.001
	Anchor Team	0.087*	0.007	0.001	0.001	0.001	0.012	<.001	0.002	<.001	0.003	<.001
	USS NEW YORK (BB-34)											
	Survey Team	0.001*	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
	Decontamination Team	0.34*	0.012	0.003	0.002	0.001	0.016	0.001	0.003	<.001	0.013	0.001
	Engineers	0.93*	0.067	0.013	0.010	0.008	0.096	0.003	0.020	0.001	0.067	0.003
	Inspection Team	0.051*	0.005	0.001	0.001	0.001	0.008	<.001	0.002	<.001	0.003	<.001
	Pump Detail Team	0.072*	0.009	0.001	0.002	0.001	0.015	<.001	0.003	<.001	0.004	<.001
	Ordnance Team	0.020*	0.003	<.001	<.001	<.001	0.005	<.001	0.001	<.001	0.001	<.001
	Anchor Team	0.13*	0.011	0.001	0.002	0.001	0.018	0.001	0.004	<.001	0.004	<.001
	USS PENSACOLA (CA-24)											
	Advance-1 Team	0.28*	0.015	0.004	0.002	0.002	0.020	0.001	0.004	<.001	0.019	0.001
	Advance-2 Team	0.17*	0.006	0.003	0.001	0.001	0.007	<.001	0.001	<.001	0.010	<.001
	Decontamination-1 Team	0.10*	0.004	0.001	0.001	0.001	0.006	<.001	0.001	<.001	0.004	<.001
	Decontamination-2 Team	0.22*	0.019	0.003	0.003	0.002	0.030	0.001	0.006	<.001	0.011	0.001
	Inspection Team	0.15*	0.018	0.002	0.003	0.002	0.028	0.001	0.006	<.001	0.009	0.001
	Anchor Team	0.14*	0.013	0.001	0.002	0.002	0.023	0.001	0.005	<.001	0.004	0.001
	USS SALT LAKE CITY (CA-25)											
	Advance Team	0.090*	0.003	0.001	<.001	<.001	0.003	<.001	0.001	<.001	0.005	<.001
	Decontamination-1 Team	0.52*	0.015	0.004	0.002	0.002	0.018	0.001	0.004	<.001	0.019	0.001
	Decontamination-2 Team	0.43*	0.013	0.003	0.002	0.001	0.017	0.001	0.004	<.001	0.016	0.001
	Inspection Team	0.037*	0.005	0.001	0.001	0.001	0.008	<.001	0.002	<.001	0.002	<.001
	Anchor Team	0.061*	0.005	0.001	0.001	0.001	0.008	<.001	0.002	<.001	0.002	<.001
Ammunition Unloading at Kwajalein												
	Initial Boarding Team	0.340	0.53	0.03	0.10	0.08	1.0	0.03	0.21	0.011	0.04	0.03
	Team No. 1	0.312	0.56	0.03	0.11	0.09	1.1	0.03	0.22	0.012	0.03	0.03
	Team No. 2	0.378	0.66	0.04	0.13	0.10	1.3	0.04	0.26	0.014	0.04	0.03
	Team No. 3	0.468	0.71	0.05	0.13	0.11	1.4	0.04	0.27	0.015	0.06	0.03
	Team No. 4	0.315	0.58	0.03	0.11	0.09	1.2	0.03	0.23	0.013	0.03	0.03
	Team No. 5	0.281	0.44	0.03	0.09	0.07	0.85	0.03	0.17	0.010	0.03	0.02
	Unassigned Personnel	0.173	0.29	0.02	0.06	0.05	0.57	0.02	0.11	0.006	0.02	0.01
Maintenance and Security at Kwajalein												
	August 1946-July 1947	0.66*	0.31	0.013	0.072	0.059	0.79	0.023	0.16	0.009	0.009	0.018
	August 1947-July 1948	0.041*	0.28	0.005	0.10	0.084	1.1	0.028	0.22	0.011	0.001	0.020
Inspection and Maintenance at Naval Shipyards												
	Pearl Harbor-1947	0.074*	0.37	0.008	0.11	0.093	1.3	0.032	0.24	0.012	0.002	0.024
	Pearl Harbor-1948	0.017*	0.25	0.004	0.095	0.079	1.1	0.027	0.21	0.011	0.002	0.019
	Puget Sound-1947	0.115	0.56	0.012	0.17	0.14	1.9	0.050	0.37	0.019	0.003	0.027
	Puget Sound-1947	0.068	1.1	0.016	0.46	0.38	5.6	0.13	1.0	0.051	0.009	0.091
	San Francisco-1947	0.039	0.13	0.003	0.036	0.030	0.40	0.010	0.078	0.004	0.001	0.008
	San Francisco-1948	0.004	0.062	0.001	0.025	0.016	0.30	0.007	0.055	0.003	<.001	0.005

*Calculated.

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