ANALYSIS OF RADIATION EXPOSURE FOR NAVAL UNITS OF OPERATION CROSSROADS
Volume I-Basic Report

Science Applications, Inc.
P.O. Box 1303
McLean, VA 22101-1303

3 March 1982

Technical Report

CONTRACT No. DNA 001-82-C-0012

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**Title:** Analysis of Radiation Exposure for Naval Units of Operation Crossroads

**Volume:** I - Basic Report

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**Organization:** Science Applications, Inc.

**Address:** P.O. Box 1303
McLean, VA 22101-1303

**Report Date:** 3 March 1982

**Number of Pages:** 168

**Security Class.:** UNCLASSIFIED

**DISTRIBUTION STATEMENT (of this report):**
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**SUPPLEMENTARY NOTES:**
This work was sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B384082466 V99QAXNA00011 H2590D.

**KEY WORDS:**
- Operation CROSSROADS
- Nuclear Test Personnel Review (NTPR)
- Joint Task Force One
- Ship Contamination
- Oceanic Nuclear Test
- Radiation Exposure Assessment

**ABSTRACT:**
External radiation doses are reconstructed for crews of support and target ships of Joint Task Force One at Operation CROSSROADS, 1946. Volume I describes the reconstruction methodology, which consists of modeling the radiation environment, to include the radioactivity of lagoon water, target ships, and support ship contamination; retracing ship paths through this environment; and calculating the doses to shipboard personnel. The USS RECLAIMER, a support ship, is selected as a representative ship to demonstrate...
20. ABSTRACT (Continued)

this methodology. Doses for all other ships are summarized. Volume II (Appendix A) details the results for target ship personnel. Volume III (Appendix B) details the results for support ship personnel. Calculated doses for more than 36,000 personnel aboard support ships while at Bikini range from zero to 1.7 rem. Of those, approximately 34,000 are less than 0.5 rem. From the models provided, doses due to target ship reboarding and doses accrued after departure from Bikini can be calculated, based on the individual circumstances of exposure.
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Section 1
INTRODUCTION

This report provides a description of the methodology and the results of the reconstruction of radiation doses received by test participants aboard the various support and target ships of Joint Task Force One at Operation CROSSROADS from 1 July 1946 until departure from Bikini Lagoon. The report consists of three volumes. Volume I, Methodology, contains the description of the dose reconstruction methodology, with supporting calculations. The methodology consists of modeling the radiation environment, determining the ship paths through this environment, and calculating the doses to personnel. The support ship USS RECLAIMER is selected to demonstrate the application of this methodology for a representative ship. This vessel is chosen because her movements were extensively documented, and because she was the flagship of the Director of Ship Material and therefore participated in nearly every maneuver and operation of radiological significance. The doses calculated for RECLAIMER personnel are compared with existing film badge data to gauge the accuracy of the results. Volume II (Appendix A, Target Ships) contains the results of target ship analyses. The data in this volume allow the calculation of doses received while aboard the target vessels. Volume III (Appendix B, Support Ships) contains the results of dose reconstructions for personnel aboard support ships during Operation CROSSROADS.

1.1 Joint Task Force One Organization

Joint Task Force One was established by the Joint Chiefs of Staff to conduct Operation CROSSROADS, the first nuclear test series following the World War II bombings of Hiroshima and Nagasaki. The task force staff organization is shown in Figure 1-1. Much of the documentation on which these dose reconstructions are based emanated from the offices of the Technical Director and Director of Ship Material. Joint Task Force One was dissolved 1 November 1946 and was succeeded by the Joint CROSSROADS Committee. This committee was disbanded 10 June 1947 after publication of the final CROSSROADS reports.
Figure 1-1 Joint Task Force One Staff Organization
1.2 Shot Data

Operation CROSSROADS consisted of two nuclear detonations, Shots ABLE and BAKER, at Bikini Atoll in July 1946. The details of these shots are given in Table 1-1. Both nuclear devices were similar to that detonated over Nagasaki the previous year. Shot ABLE was a low air-burst, Shot BAKER a shallow underwater detonation.

1.3 Target Ship Arrays

Since Operation CROSSROADS was primarily a Navy test, a large assortment of naval vessels was present in the lagoon during the operation. These various types of target and support vessels are listed for reference in Table 1-2.

Extensive arrays of target vessels were positioned in the lagoon of Bikini Atoll for both shots. Figures 1-2 and 1-3 outline the number and types of target vessels utilized for Shots ABLE and BAKER, respectively, while Figures 1-4 and 1-5 display the approximate target ship locations for each shot. The exact locations and orientations of most target vessels relative to surface zero are provided in Reference 1 (Chapters 10 and 20). While References 2 and 3 contain fairly complete listings of target vessels for Operation CROSSROADS, no single source has been found that contains a complete listing. Reconstructions of the target arrays reveal that there were 88 target vessels for each shot, of which 70 were anchored and 18 were beached. Between Shots ABLE and BAKER, some ships were removed from the target array and new ones added. In all, 95 naval units have been identified as target vessels during Operation CROSSROADS. A number of these were small non-commissioned or unmanned craft, some of which served as beached targets. The final count of target vessels for purposes of this analysis is 84; radiological data for these vessels are included in Appendix A, Target Ships. The remaining 11 vessels were either too small to be tracked or were sunk as a result of the tests.

1.4 Support Ships

A large number of support vessels were required to conduct the operation. The number and types of such vessels are summarized in Table 1-3 from data taken primarily from Reference 3. Of the 154 non-target support ships, it was possible to extract positional data from the deck logs of 121 ships in order to reconstruct their movements.
Table 1-I
Operation CROSSROADS Detonations

- **SHOT ABLE**
  Time: 0900 hrs, 1 July 1946  
  Place: Bikini Lagoon  
  Type Weapon: Plutonium Implosion  
  Yield: 23 KT  
  Type Burst: Airburst (520 ft) over water

- **SHOT BAKER**
  Time: 0835 hrs, 25 July 1946  
  Place: Bikini Lagoon  
  Type Weapon: Plutonium Implosion  
  Yield: 23 KT  
  Type Burst: Shallow Underwater (90 ft depth)
Table 1-2
Naval Vessel Types at Operation CROSSROADS

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD</td>
<td>Destroyer Tender</td>
</tr>
<tr>
<td>AG</td>
<td>Auxiliary Miscellaneous</td>
</tr>
<tr>
<td>AGC</td>
<td>Communication</td>
</tr>
<tr>
<td>AGS</td>
<td>Surveying</td>
</tr>
<tr>
<td>AH</td>
<td>Hospital</td>
</tr>
<tr>
<td>AKA</td>
<td>Attack Cargo Transport</td>
</tr>
<tr>
<td>AKS</td>
<td>Cargo Transport, General Stores</td>
</tr>
<tr>
<td>AN</td>
<td>Net Laying</td>
</tr>
<tr>
<td>AO</td>
<td>Oiler</td>
</tr>
<tr>
<td>AOG</td>
<td>Gasoline Tanker</td>
</tr>
<tr>
<td>AOW</td>
<td>Oiler/Water</td>
</tr>
<tr>
<td>AP</td>
<td>Troop Transport</td>
</tr>
<tr>
<td>APA</td>
<td>Attack Troop Transport</td>
</tr>
<tr>
<td>APB</td>
<td>Barracks Ship</td>
</tr>
<tr>
<td>APD</td>
<td>Troop Transport, High-Speed</td>
</tr>
<tr>
<td>APH</td>
<td>Hospital</td>
</tr>
<tr>
<td>APL</td>
<td>Troop Transport, Labor</td>
</tr>
<tr>
<td>AR</td>
<td>Repair</td>
</tr>
<tr>
<td>ARB</td>
<td>Battle Damage Repair</td>
</tr>
<tr>
<td>ARD</td>
<td>Dry Dock Repair</td>
</tr>
<tr>
<td>ARDC</td>
<td>Dry Dock</td>
</tr>
<tr>
<td>ARG</td>
<td>Engine Repair</td>
</tr>
<tr>
<td>ARL</td>
<td>Landing Craft Repair</td>
</tr>
<tr>
<td>ARS</td>
<td>Salvage</td>
</tr>
<tr>
<td>ARSD</td>
<td>Salvage Lifting Ship</td>
</tr>
<tr>
<td>ARST</td>
<td>Salvage Craft Tender</td>
</tr>
<tr>
<td>AS</td>
<td>Submarine Tender</td>
</tr>
<tr>
<td>ASR</td>
<td>Submarine Rescue</td>
</tr>
<tr>
<td>ATA</td>
<td>Auxiliary Ocean Tug</td>
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<td>ATF</td>
<td>Fleet Ocean Tug</td>
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<td>Battleship</td>
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<tr>
<td>CA</td>
<td>Heavy Cruiser</td>
</tr>
<tr>
<td>CL</td>
<td>Light Cruiser</td>
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<td>CV</td>
<td>Aircraft Carrier</td>
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<td>CVL</td>
<td>Aircraft Carrier, Light</td>
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<td>Destroyer</td>
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<tr>
<td>IX</td>
<td>Unclassified Miscellaneous</td>
</tr>
<tr>
<td>LCI</td>
<td>Landing Craft, Infantry</td>
</tr>
<tr>
<td>LCM</td>
<td>Landing Craft, Mechanized</td>
</tr>
<tr>
<td>LCPL</td>
<td>Landing Craft, Personnel, Large</td>
</tr>
<tr>
<td>LCT</td>
<td>Landing Craft, Tank</td>
</tr>
<tr>
<td>LCVP</td>
<td>Landing Craft, Vehicle/Personnel</td>
</tr>
<tr>
<td>LSD</td>
<td>Landing Ship, Dock</td>
</tr>
<tr>
<td>LSM</td>
<td>Landing Ship</td>
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<td>PGM</td>
<td>Motor Gunboat</td>
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<tr>
<td>SS</td>
<td>Submarine</td>
</tr>
<tr>
<td>WAGL</td>
<td>Coast Guard Auxiliary</td>
</tr>
<tr>
<td>YF</td>
<td>Covered Lighter</td>
</tr>
<tr>
<td>YMS</td>
<td>Mine Sweeper</td>
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<tr>
<td>YO</td>
<td>Fleet Oil Barge</td>
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<tr>
<td>YOG</td>
<td>Gasoline Barge</td>
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<tr>
<td>YOW</td>
<td>Oil/Water Barge</td>
</tr>
<tr>
<td>YP</td>
<td>Yard Patrol</td>
</tr>
<tr>
<td>YW</td>
<td>Water Barge</td>
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Figure 1-2 Summary of Shot ABLE Target Array
Figure 1-3 Summary of Shot BAKER Target Array

FLOATING TARGETS

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<td>APA</td>
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<tr>
<td>LST</td>
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<tr>
<td>LCI</td>
<td>4</td>
</tr>
<tr>
<td>LCT</td>
<td>10</td>
</tr>
<tr>
<td>LCM</td>
<td>1</td>
</tr>
<tr>
<td>BARGES</td>
<td>3</td>
</tr>
<tr>
<td>LSM</td>
<td>1</td>
</tr>
</tbody>
</table>

70

SUNK (9)

ARKANSAS LSM-60
PILOTFISH YO-160
SARATOGA LCT-1114
NAGATO ARDC-13
APOGON

BEACHED TARGETS

| LST       | 1 |
| LCI       | 2 |
| LCT       | 4 |
| LCM       | 5 |
| LCVP      | 6 |

18

SUNK

LST-125
LCI-620
Figure 1-4  Shot ABLE Target Ship Locations
Figure 1-5 Shot BAKER Target Ship Locations
### Table 1-3

#### Summary of Support Ships

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<td>(AC, AGC, AH, AP, APA, APD, AV, CA, LCT)</td>
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<td><strong>Transportation Group</strong></td>
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<td><strong>Naval Air Group</strong></td>
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<tr>
<td><strong>Surface Patrol Group</strong></td>
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<td>(DD)</td>
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<tr>
<td><strong>Salvage Group</strong></td>
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</tr>
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<td>(AN, ARS, ARSD, ARST, ASR, ATA, ATF, ATR, LCT,)</td>
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<td><strong>Service Group</strong></td>
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<td>(AD, AG, AKS, AO, AOG, AR, ARR, AKD, ARG, ARL, AS, AI-A, ATF, AW, IX, LST, YC, YF, YO, YOC, YW)</td>
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<tr>
<td><strong>Dispatch and Roat Pool Unit</strong></td>
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<td>(APB, LCI, LCT, LSD, PGM)</td>
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<tr>
<td><strong>Medical Unit</strong></td>
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<td>(AH)</td>
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<td><strong>Survey Unit</strong></td>
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</tbody>
</table>
The results of the dose calculations for these ships are contained in Appendix B. The other 34 were determined to be either small units with no permanently assigned crew, or non-commissioned vessels. No deck logs could be located for reconstruction of the movements of these vessels (types LCT, YO, YOG, YP, YF). The 34 naval units listed by the official historian as being support ships and participants of Operation CROSSROADS for which no deck logs have been located are:

| LCT-531 | LCT-1377 | YF-753 |
| LCT-746 | LCT-1415 | YF-754 |
| LCT-1116 | LCT-1420 | YF-990 |
| LCT-1130 | LCT-1461 | YF-991 |
| LCT-1132 | LIMESTONE (IX-158) | YF-992 |
| LCT-1155 | YC-1009 | YO-132 |
| LCT-1184 | YF-385 | YO-199 |
| LCT-1268 | YF-733 | YOG-63 |
| LCT-1341 | YF-734 | YOG-70 |
| LCT-1359 | YF-735 | YP-636 |
| LCT-1361 | YF-752 | YW-92 |

1.5 Navy Personnel Summary

Over 39,000 Navy personnel participated in Operation CROSSROADS. The distribution of personnel among the various types of support and target vessels is given in Table 1-4.

1.6 Dose Reconstruction Methodology

The methodology developed for dose reconstruction of Operation CROSSROADS personnel is shown schematically in Figure 1-6. The modeling of the radiation environment is described in detail in Section 2, the identification of relevant ship operations in Section 3, and the total dose reconstruction in Section 4. The basic approach used in dose reconstruction is to describe mathematically the radiation environment that existed in the Bikini Lagoon as a function of time and location, and then to overlay the physical movement of the naval units. The time integral of the radiation intensity at a vessel's location as it moves within the radiation environment determines the dose attributed to the crew of that vessel. Three major sources of radioactivity are considered: lagoon water, target ships, and support ship hull and internal (e.g., piping)
Table 1-4
Summary of Naval Personnel

Support Ships:

<table>
<thead>
<tr>
<th>Group</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flag and Technical Group</td>
<td>5140</td>
</tr>
<tr>
<td>Transportation Group</td>
<td>5238</td>
</tr>
<tr>
<td>Naval Air Group</td>
<td>4177</td>
</tr>
<tr>
<td>Surface Patrol Group</td>
<td>2376</td>
</tr>
<tr>
<td>Service Group</td>
<td>5344</td>
</tr>
<tr>
<td>Salvage Group</td>
<td>1698</td>
</tr>
<tr>
<td>Dispatch and Boat Pool</td>
<td>1539</td>
</tr>
<tr>
<td>Medical Unit</td>
<td>1258</td>
</tr>
<tr>
<td>Survey Unit</td>
<td>809</td>
</tr>
<tr>
<td>Evacuation and Miscellaneous</td>
<td>23</td>
</tr>
<tr>
<td>JTF Staff and Air Units</td>
<td>2762</td>
</tr>
</tbody>
</table>

| Non-remanned                               | 7912 |
| Remanned                                   | 1092 |

Total: 39,418

* Doses for these personnel are derived from the support ships to which they were assigned.

** On transportation ships at time of shot and until radiologically safe to return to target ship.
* Comparisons made for USS RECLAIMER to validate methodology

**Figure 1-6 Dose Reconstruction Methodology**
contamination. Suspended and dissolved fission products concentrated in the marine growth and rust on the hull at and below the waterline and in the internal salt water piping of support ships which sailed through contaminated water. Ship contamination is therefore considered for Shot BAKER only, since no fission products were detected in the lagoon water after Shot ABLE.
Section 2
RADIATION ENVIRONMENT

The radiation environments created at Bikini Atoll by Shots ABLE and BAKER were quite different—virtually all localized activity from Shot ABLE resulted from neutron activation, while Shot BAKER activity was predominantly from weapon debris. The magnitude of the radiation hazard after BAKER was much more significant than that of ABLE, and consequently the BAKER activity was measured and documented in more detail than was done for Shot ABLE. The measurements made to characterize the radiation environments were of two types: those taken by scientific personnel under the Technical Director, usually from samples (e.g., water, rust) collected in the lagoon and removed to a laboratory for analysis; and those made by radiation monitors for use by the Director of Ship Material in controlling operations in and around the radioactive areas. While the documentation on many of these measurements has not been located, sufficient information has been recovered to allow reconstructions of the environments for both shots. The approach taken here is to develop radiation intensity models from the best available data, and to use all other relevant documentation to check these models for consistency.

2.1 Shot ABLE Water Intensity

It is well-documented (References 1 (Chapter 17), 4 (Enclosure J), and 5) that virtually all the radioactivity observed in the lagoon after Shot ABLE was due to neutron activation, and that little fallout (fission products and unfissioned plutonium) was deposited locally. A theoretical analysis of neutron-activated seawater was performed with computer codes ORIGEN (Reference 6) and ANISN (Reference 7), using the salt concentrations of typical seawater given in Reference 8. The results indicate that the gamma radiation emitted in sodium-24 (Na-24) decay was the major contributor to the intensity above the seawater from shortly after detonation until approximately one week later. This is the period during which all significant operations took place in the vicinity of the target array following Shot ABLE. These conclusions are confirmed by analysis of water sample data found in the archives at Los Alamos National Laboratory. The water samples were taken on 1 July 1946 (ABLE day), and activities were measured at various intervals through 8 July. The decay curves, shown in Figure 2-1, clearly demonstrate that the early radioactivity (through
Figure 2-1 Decay of Shot ABLE Water Samples
the first 100 hours after detonation) was dominated by an isotope with a half life of approximately 15 hours; this isotope is Na-24. The change in slope evident in these curves indicates that another isotope (probably bromine-82) became significant after approximately five days. However, Na-24 would have continued providing the major contribution to the intensity above the water surface for another few days, due to the high energy of the Na-24 gamma rays (average energy greater than 2 MeV, compared to approximately 0.8 MeV for bromine-82). Therefore it is necessary to consider only one isotope, Na-24, in developing a water intensity model.

In determining the intensity from Na-24 in the lagoon water, it is necessary to specify the initial source distribution, model the time-dependent concentration of this isotope in the seawater, and develop a relation between waterborne activity and intensity in air. The initial distribution of radioactive sodium was closely related to the distribution of thermal neutrons at the water surface in the vicinity of surface zero (SZ). The approximate nature of the latter distribution is determined with computer code ATR4 (Reference 9); it appears that this distribution was so sharply peaked around SZ that, when considering subsequent diffusion, the initial distribution of Na-24 in the water can be taken as a point source at SZ for computational purposes. The concentration of Na-24 in the seawater changed with time due to horizontal diffusion, vertical diffusion, and radiological decay. Horizontal diffusion caused the radioactive area to spread, with the concentration at radius r and time t after detonation being approximately proportional to (Reference 8)

\[ t^{-1} \exp \left( -\frac{r^2}{4D_h t} \right), \]

where \( D_h \) = horizontal diffusion coefficient (assumed to be constant in this simplified model). Due to vertical diffusion, the concentration of Na-24 in the upper layer of seawater decreased approximately as \( t^{-\frac{1}{2}} \) (Reference 10), quickly becoming nearly uniform with depth. Radioactive decay caused a decrease in Na-24 concentration proportional to \( e^{\lambda t} \), where \( \lambda \approx 0.0462 \text{ hr}^{-1} \) (decay constant for Na-24).

The intensity (measured, for example, in roentgen (R)/hour) above such seawater is proportional to the activity density of Na-24 in the seawater (e.g., in curies/cm\(^3\)) which, in turn, is proportional to the concentration of Na-24. In each decay, a Na-24 nucleus emits two gamma rays with energies of 1.37 and 2.75 MeV, respectively.
Calculations performed with the radiation transport code ANISN (Reference 7) indicate that this decay results in an intensity of 3.51 R/hr at one meter above the water surface when the activity density of the water is one microcurie of Na-24 per cm$^3$. This value decreases only slightly to 3.44 at 2.7 meters and 3.23 at 9.1 meters above the water surface. Therefore, within at least ten meters of the water surface, the distance above the surface is not a significant parameter in determining intensity. Within this region above the surface, where personnel aboard ships are likely to be located, the intensity may be expressed as

$$I(r, t) = t^{-3/2} \exp \left[ -A \left( \frac{r^2}{t} \right) - \lambda t + B \right].$$

where parameter $A$ depends on the horizontal diffusion coefficient, and $B$ depends on the horizontal and vertical diffusion coefficients and the total number of neutrons captured in the water. The values of the diffusion coefficients and number of neutrons absorbed are largely uncertain; therefore $A$ and $B$ are empirically determined by fitting this expression to the existing measurements of intensity at specific times and locations.

Much of the recorded intensity data is contained in the messages from the Radiological Safety Control Center, which specify the coordinates of the 0.1 R/day and 1.0 R/day isointensity contours at frequent time intervals following the ABLE detonation. These contours, referred to as the “blue line” and “red line”, respectively, in CROSSROADS literature, have the following significance. The daily dose tolerance allowed for most personnel during Operation CROSSROADS was 0.1 R/day. Therefore, a ship theoretically could have operated outside the blue line for an indefinite period without exceeding this tolerance. Operation between the blue and red lines was permitted only for certain ships (“red line ships”), and only for durations such that the daily tolerance was not exceeded. The red line was not to be crossed by any vessel. The red and blue line contours, although generally not closed due to insufficient numbers of readings, can be approximated by circles of appropriate radii. These radii are presented in Table 2-1, together with various other data found in the literature. The red line was eliminated early on the morning of ABLE +1 day (A+l), indicating that the maximum water intensity fell below 1 R/day during the previous night. The blue line was eliminated at 1008 hours on A+1. These data ($I \geq 0.1$ R/day = 0.0042 R/hr, $r = 0$, $t = 25$ hours) are used to evaluate the parameter $B$, giving
Table 2-1

Shot ABLE Water Intensity Data

<table>
<thead>
<tr>
<th>Source</th>
<th>Radius (m)</th>
<th>Time After Detonation (hrs)</th>
<th>Reported Intensity (R/hr)</th>
<th>Intensity (R/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>References 5, 11</td>
<td>0</td>
<td>2</td>
<td>1.0</td>
<td>0.53</td>
</tr>
<tr>
<td>RSCC*</td>
<td>900</td>
<td>4</td>
<td>0.042</td>
<td>0.068</td>
</tr>
<tr>
<td>Reference 4</td>
<td>810&quot;&quot;&quot;&quot;</td>
<td>4</td>
<td>0.021</td>
<td>0.081</td>
</tr>
<tr>
<td>RSCC</td>
<td>1800</td>
<td>4</td>
<td>0.0042</td>
<td>0.0043</td>
</tr>
<tr>
<td>RSCC</td>
<td>2600</td>
<td>4.75</td>
<td>0.0042</td>
<td>0.0002</td>
</tr>
<tr>
<td>RSCC</td>
<td>1800</td>
<td>6.75</td>
<td>0.0042</td>
<td>0.0077</td>
</tr>
<tr>
<td>RSCC</td>
<td>1500</td>
<td>22.3</td>
<td>0.0042</td>
<td>0.0035</td>
</tr>
<tr>
<td>RSCC</td>
<td>700</td>
<td>24.7</td>
<td>0.0042</td>
<td>0.0039</td>
</tr>
<tr>
<td>Reference 4, RSCC</td>
<td>0</td>
<td>25</td>
<td>0.0042</td>
<td>0.0042</td>
</tr>
</tbody>
</table>

*Radiological Safety Control Center
**Inferred from reference, which was not specific.
B = 0.503. The remaining data in Table 2-1 are then used to determine a mean value of the parameter A to be $4.56 \times 10^{-6}$. In these calculations, t is in hours, r in meters, and intensity I in R/hr. It may be noted that the associated value of the horizontal diffusion coefficient,

$$D_h \equiv \frac{1}{4A} = 5.5 \times 10^4 \text{ m}^2/\text{hr},$$

is in excellent agreement with a value of $5.4 \times 10^4 \text{ m}^2/\text{hr}$ derived by W.H. Munk, et al. (Reference 12) from a study of the diffusion of radioactive material deposited in the lagoon water by Shot BAKER.

The intensities calculated from this model are displayed in Table 2-1 for times and radii corresponding to the available data. With the exception of two outlying data points, the agreement between the model and observed intensities is generally good. The intensity equation derived above can be used to predict isointensity contours at specific times. The radii of the 0.1 R/day and 1.0 R/day contours are plotted in Figure 2-2 as functions of time, and the predicted red and blue contours are compared with the reported red and blue lines in Figure 2-3 for 1255 hours on ABLE day. It is found that better agreement between model and measurement can be achieved by allowing the radially symmetric intensity pattern to drift northward (azimuth $10^0$) at a speed of approximately 900 meters per day. This correction is included in all Shot ABLE dose calculations.

2.2 Shot ABLE Target Ship Intensity

The radioactivity detected on the target ships after Shot ABLE was due almost entirely to neutron activation of ship materials (Chapter 17 of Reference 1, Enclosure J of Reference 4). However, since the activity levels were rather low, few measurements were documented, thus necessitating the calculations which follow.

Listings of the elemental compositions of seven vessel types, representing most of the ships present in the target array for Shot ABLE, were found in the Operation CROSSROADS files in the archives at Los Alamos National Laboratory. This information is presented in Table 2-2. By analyzing the radioactive isotopes produced by thermal neutron capture in the ship material, and the gamma rays emitted
Figure 2-2 Theoretical Model of Shot ABLE Water Intensity
Red and Blue Lines reported by RSCC at 1255 hours on Able Day (open contours); and corresponding contours predicted by model (circles). The extensions of the red and blue lines to the west were apparently for control purposes, and not an actual representation of the radiological situation.

Figure 2-3 Able Day Red and Blue Lines
Table 2-2
Elemental Compositions of Various Vessel Types
(quantities in this table are elemental weights in pounds)

<table>
<thead>
<tr>
<th>Element</th>
<th>Battleship</th>
<th>Heavy Cruiser</th>
<th>Carrier</th>
<th>Light Carrier</th>
<th>Destroyer</th>
<th>Submarine</th>
<th>Attack Troop Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>4.8+7 *</td>
<td>1.9+7</td>
<td>6.2+7</td>
<td>2.1+7</td>
<td>2.3+6</td>
<td>2.5+6</td>
<td>9.6+6</td>
</tr>
<tr>
<td>Aluminum</td>
<td>4.2+5</td>
<td>2.4+5</td>
<td>1.6+6</td>
<td>6.2+5</td>
<td>1.5+5</td>
<td>1.6+4</td>
<td>2.6+4</td>
</tr>
<tr>
<td>Magnesium</td>
<td>6.2+3</td>
<td>3.6+3</td>
<td>2.3+4</td>
<td>9.4+3</td>
<td>2.3+3</td>
<td>2.3+2</td>
<td>3.9+2</td>
</tr>
<tr>
<td>Copper</td>
<td>2.0+6</td>
<td>1.3+6</td>
<td>2.8+6</td>
<td>1.3+6</td>
<td>3.4+5</td>
<td>3.0+5</td>
<td>2.5+5</td>
</tr>
<tr>
<td>Nickel</td>
<td>9.7+5</td>
<td>3.8+5</td>
<td>1.1+6</td>
<td>4.5+5</td>
<td>4.7+4</td>
<td>4.0+4</td>
<td>5.4+4</td>
</tr>
<tr>
<td>Chromium</td>
<td>5.9+5</td>
<td>2.0+5</td>
<td>9.0+5</td>
<td>2.2+5</td>
<td>2.6+4</td>
<td>2.3+4</td>
<td>2.3+4</td>
</tr>
<tr>
<td>Tungsten</td>
<td>6.2+2</td>
<td>5.1+2</td>
<td>7.0+2</td>
<td>5.0+2</td>
<td>1.5+2</td>
<td>8.0+1</td>
<td>3.9+2</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>2.4+4</td>
<td>9.6+3</td>
<td>2.1+4</td>
<td>9.7+3</td>
<td>1.8+3</td>
<td>1.3+3</td>
<td>5.2+3</td>
</tr>
<tr>
<td>Vanadium</td>
<td>6.4+3</td>
<td>2.6+3</td>
<td>6.3+3</td>
<td>2.6+3</td>
<td>4.8+2</td>
<td>3.6+2</td>
<td>1.4+3</td>
</tr>
<tr>
<td>Zinc</td>
<td>1.5+5</td>
<td>5.0+4</td>
<td>2.0+5</td>
<td>6.3+4</td>
<td>2.2+4</td>
<td>2.6+4</td>
<td>2.0+4</td>
</tr>
<tr>
<td>Lead</td>
<td>1.2+5</td>
<td>6.9+4</td>
<td>1.2+5</td>
<td>6.3+4</td>
<td>1.4+4</td>
<td>4.3+5</td>
<td>1.3+4</td>
</tr>
<tr>
<td>Tin</td>
<td>7.0+4</td>
<td>4.6+4</td>
<td>9.8+4</td>
<td>4.6+4</td>
<td>1.3+4</td>
<td>1.1+4</td>
<td>8.8+3</td>
</tr>
<tr>
<td>Antimony</td>
<td>7.0+3</td>
<td>4.6+3</td>
<td>9.8+3</td>
<td>4.6+3</td>
<td>1.3+3</td>
<td>1.1+3</td>
<td>8.8+2</td>
</tr>
<tr>
<td>Manganese</td>
<td>3.3+5</td>
<td>1.3+5</td>
<td>4.1+5</td>
<td>1.3+5</td>
<td>1.8+4</td>
<td>9.0+3</td>
<td>5.8+4</td>
</tr>
<tr>
<td>Cadmium</td>
<td>4.9+3</td>
<td>2.0+3</td>
<td>4.9+3</td>
<td>2.0+3</td>
<td>3.7+2</td>
<td>2.7+2</td>
<td>1.1+3</td>
</tr>
<tr>
<td>Sulfur</td>
<td>2.2+4</td>
<td>9.0+3</td>
<td>2.9+4</td>
<td>9.0+3</td>
<td>1.1+3</td>
<td>1.1+3</td>
<td>4.5+3</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>2.2+4</td>
<td>9.0+3</td>
<td>2.9+4</td>
<td>9.0+3</td>
<td>1.1+3</td>
<td>1.1+3</td>
<td>4.5+3</td>
</tr>
<tr>
<td>Silicon</td>
<td>2.2+5</td>
<td>8.8+4</td>
<td>2.8+5</td>
<td>9.4+4</td>
<td>1.0+4</td>
<td>1.0+4</td>
<td>3.6+4</td>
</tr>
<tr>
<td>Carbon</td>
<td>1.5+5</td>
<td>5.8+4</td>
<td>1.9+5</td>
<td>6.5+4</td>
<td>6.7+3</td>
<td>7.0+3</td>
<td>2.9+4</td>
</tr>
<tr>
<td>Beryllium</td>
<td>6</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>.2</td>
</tr>
<tr>
<td>Cobalt</td>
<td>7.5+2</td>
<td>7.1+2</td>
<td>7.0+2</td>
<td>5.7+2</td>
<td>2.0+2</td>
<td>8</td>
<td>7.4+1</td>
</tr>
<tr>
<td>Titanium</td>
<td>5.6+3</td>
<td>3.0+3</td>
<td>5.5+3</td>
<td>2.7+3</td>
<td>4.2+2</td>
<td>4.8+2</td>
<td>4.8+2</td>
</tr>
<tr>
<td>Mercury</td>
<td>4.9+2</td>
<td>3.9+2</td>
<td>5.2+2</td>
<td>3.7+2</td>
<td>2.5+2</td>
<td>4.7+1</td>
<td>2.3+2</td>
</tr>
</tbody>
</table>

*Read as \(4.8 \times 10^7\)

Source: Los Alamos National Laboratory archives.
Therefore, it is possible to calculate the relative levels of intensity induced by a fixed neutron fluence in the various types of vessels as a function of time after detonation. In these calculations, it is assumed that the ships were homogeneous mixtures of the materials given in Table 2-2, that all vessels had similar average densities, and that the contribution to the intensity from the activation of extraneous materials placed on or in the target ships (e.g., various types of military equipment placed on deck for effects testing) was negligible. The relative intensities at 24 hours after detonation, normalized to the intensity on a destroyer, are presented below.

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Relative intensity at t = 24 hours*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destroyer (DD)</td>
<td>1.000</td>
</tr>
<tr>
<td>Submarine (SS)</td>
<td>0.737</td>
</tr>
<tr>
<td>Heavy Cruiser (CA)</td>
<td>0.539</td>
</tr>
<tr>
<td>Light Carrier (CVL)</td>
<td>0.495</td>
</tr>
<tr>
<td>Carrier (CV)</td>
<td>0.379</td>
</tr>
<tr>
<td>Battleship (BB)</td>
<td>0.363</td>
</tr>
<tr>
<td>Attack troop transport (APA)</td>
<td>0.256</td>
</tr>
</tbody>
</table>

*For fixed neutron fluence. These values are later designated $M_i$.

These values are most strongly affected by the fraction of copper present in the ship material. The time dependence of the intensities for the seven vessel types is shown in Figure 2-4, where the curves have been normalized to the intensity at 24 hours. The initial slope of these curves is due to the decay of copper-64 with a 12.8 hour half-life.

Vessel types LST, LCI, and LCT, for which elemental composition data are lacking, were determined to be similar in material composition to a destroyer, submarine, and heavy cruiser, respectively, and hence should display similar intensity and decay characteristics. These relationships are assumed for calculations involving these three types of ships.

The results of the neutron activation calculation allow an estimate of relative intensity levels at arbitrary times for various types of vessels exposed to identical neutron fluences, i.e., at a fixed range from SZ. It is necessary to develop a method of estimating intensity level as a function of range. Ideally this range dependence would
A Attack Troop Transport (use for YQ, YOG, ARDC)
B Battleship, Carrier
C Light Carrier, Heavy Cruiser (use for LCT)
D Submarine (use for LCI)
E Destroyer (use for LST)

Figure 2-4 Shot ABLE Ship Intensities Relative to Intensity at 24 Hours
be estimated from thermal neutron fluence data, since the absorption of thermal neutrons is responsible for most activation interactions. Thermal neutron measurements were made during Shot ABLE, using activation of phosphate pills to determine the fluences at numerous locations on various target ships. The results are presented in Appendix XIII of Reference 15, a technical report compiled shortly after the ABLE detonation. Unfortunately, the experimental technique and analysis of the data appear to have serious shortcomings (e.g., most activation samples were placed in shielded locations which were not well documented); consequently, the data are considered unreliable. A much more sophisticated effort was undertaken by Dr. G. A. Linenberger of Los Alamos to measure fast neutron fluence by activation of sulfur samples placed on the target ships. These data, contained in Reference 16, are fit with the expression:

$$\phi = R^{-2} \exp \left[ -\frac{R}{\lambda_f} t \right]$$

where

- $\phi$ = fast neutron fluence,
- $R$ = slant range,
- $\lambda_f$ = fast neutron relaxation length $\approx 209.1$ yards,
- $B$ = constant.

To develop the Shot ABLE ship activation model, it is assumed that the range dependence of ship activation was approximately the same as that of the fast neutron fluence. This assumption is valid, since the relaxation length for thermal neutrons is comparable to that of fast neutrons for typical neutron fission spectra transported in an air-over-seawater geometry (References 13, 14).

The ship activation model is given by the expression

$$I_i(t) = C M_i f_i(t) R_i^{-2} \exp \left[ -\frac{R_i}{\lambda_f} \right],$$

where

- $I_i(t)$ = activation intensity on target ship $i$ at time $t$,
- $M_i$ = intensity of ship $i$ at $t = 24$ hours relative to that of a destroyer,
- $f_i(t)$ = intensity of ship $i$ at time $t$ relative to that at $t = 24$ hours (given in Figure 2-4),
- $R_i$ = slant range of ship $i$. 
Here C is a constant which, ideally, is independent of target ship. A numerical value for C is determined by fitting the model to exterior ship intensity readings, a summary of which is given in Table 2-3(a). Data from the YO 160 and ARDC 13 cannot be used here, since elemental compositions of these vessels are not available. With intensity I in R/day and range R in yards, a good fit to the remaining data is achieved with $C = 1.1 \times 10^7$. With this, absolute intensities in R/day at 24 hours after detonation are calculated for all target vessels except the YO 160, YOC 83, and ARDC 13. All such intensities greater than 1 mR/day are listed in Table 2-4.

The vessels YO 160, YOG 83, and ARDC 13 were not similar in composition to other ships in the target array. However, intensity readings on the YO 160 and the ARDC 13 are available, as given in Table 2-3, so that these vessels may be normalized separately. It is assumed that the YOG 83 was similar in composition to the YO 160, and that the time-dependence of the intensity for these three vessels is similar to that of the attack troop transport. The 24-hour intensities thus derived are included in Table 2-4.

In summary, the intensity on a ship at time t is estimated by obtaining the 24-hour intensity from Table 2-4 and using the appropriate curve in Figure 2-4 to determine the factor which adjusts the 24-hour value to the value at time t. Ships not listed in Table 2-4 are considered to have had negligible induced intensity (<1 mR/day at 24 hours after Shot ABLE).

The consistency of these results is tested by comparing them with relevant statements on ship intensities contained in References 1, 4, 18, 19, and 20, and by analyzing the radiological reports and boarding times of target vessels documented in References 21 and 22. Reference 1 states that 13 vessels had intensities greater than 0.1 R/day on ABLE + 1 day; 14 such vessels are predicted by this model, as shown in Table 2-4. The most radioactive ships after Shot ABLE, as listed in the cited references, agree well with those predicted by the model. The maximum intensity of 8 R/day reported on the ARKANSAS (A+1 day reading) by Reference 1 was apparently a local \textit{“hot spot”}, composed mostly of radioactive sodium in a pool of water on deck. The reports of the radiological and reboarding status of the target ships, as given in References 21 and 22, generally agree with model predictions. An apparent exception is that six vessels (CATRON, SARATOGA, PENNSYLVANIA, LCT 874, LST 661, and
### Table 2-3
Shot ABLE Target Ship Intensities

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Slant Range (yds)</th>
<th>Time of Reading (hrs)</th>
<th>Intensity Average</th>
<th>Measurement Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(a) Exterior Readings</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRITTENDEN (APA)</td>
<td>619-753</td>
<td>28</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>INDEPENDENCE (CVL)</td>
<td>586-720</td>
<td>30</td>
<td>0.24</td>
<td>0.34</td>
</tr>
<tr>
<td>SKATE (SS)</td>
<td>436-513</td>
<td>54</td>
<td>0.4-0.8</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-75</td>
<td>0.4</td>
<td>--</td>
</tr>
<tr>
<td>NEVADA (BB)</td>
<td>639-811</td>
<td>28</td>
<td>--</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32</td>
<td>--</td>
<td>0.43</td>
</tr>
<tr>
<td>ARDC 13</td>
<td>852-973</td>
<td>5.5</td>
<td>0.2</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25.5</td>
<td>0.2</td>
<td>--</td>
</tr>
<tr>
<td>YO 160</td>
<td>550-660</td>
<td>30</td>
<td>0.7</td>
<td>--</td>
</tr>
<tr>
<td><strong>(b) Interior Readings</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKATE (SS)</td>
<td>436-513</td>
<td>-96</td>
<td>0.03</td>
<td>0.06</td>
</tr>
<tr>
<td>APOGON (SS)</td>
<td>951-1051</td>
<td>26.5</td>
<td>0.003</td>
<td>0.006*</td>
</tr>
<tr>
<td>PARCHE (SS)</td>
<td>1377</td>
<td>24.5</td>
<td>0.3**</td>
<td>0.3**</td>
</tr>
<tr>
<td>DENTUDA (SS)</td>
<td>1938-1956</td>
<td>24</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TUNA (SS)</td>
<td>2200-2234</td>
<td>48</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Maximum reading of 0.072 R/day taken around clock and depth gauges in control room probably due to radium dials.

**Questionable data; see text.

Sources: Exterior data for days At1 and At2 taken from radio messages; SKATE 75-hour data from Reference 17. Interior data taken from Commanding Officer letter reports.
Table 2-4

Calculated Average Exterior Ship Intensities at 24 Hours after Shot ABLE

(Vessels not listed have calculated intensities less than 0.001 R/day)

<table>
<thead>
<tr>
<th>Ship</th>
<th>Intensity (R/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARKANSAS (BB)</td>
<td>0.44</td>
</tr>
<tr>
<td>NEW YORK (BB)</td>
<td>0.001</td>
</tr>
<tr>
<td>NEVADA (BB)</td>
<td>0.43</td>
</tr>
<tr>
<td>PENNSYLVANIA (BB)</td>
<td>0.001</td>
</tr>
<tr>
<td>NAG AT0 (Japanese battleship)</td>
<td>0.11</td>
</tr>
<tr>
<td>PENSACOLA (CA)</td>
<td>0.31</td>
</tr>
<tr>
<td>SALT LAKE CITY (CA)</td>
<td>0.11</td>
</tr>
<tr>
<td>SAKAWA (Japanese cruiser)</td>
<td>2.7</td>
</tr>
<tr>
<td>PRINZ EUGEN (German cruiser)</td>
<td>0.011</td>
</tr>
<tr>
<td>INDEPENDENCE (CVL)</td>
<td>1.0</td>
</tr>
<tr>
<td>TALBOT (DD)</td>
<td>0.04</td>
</tr>
<tr>
<td>RHIND (DD)</td>
<td>0.11</td>
</tr>
<tr>
<td>STACK (DD)</td>
<td>0.013</td>
</tr>
<tr>
<td>WILSON (DD)</td>
<td>0.005</td>
</tr>
<tr>
<td>HUGHES (DD)</td>
<td>0.18</td>
</tr>
<tr>
<td>SKIP JACK (SS)</td>
<td>0.04</td>
</tr>
<tr>
<td>SKATE (SS)</td>
<td>6.7</td>
</tr>
<tr>
<td>APOGON (SS)</td>
<td>0.01</td>
</tr>
<tr>
<td>PARCHÉ (SS)</td>
<td></td>
</tr>
<tr>
<td>LST 52</td>
<td>0.005</td>
</tr>
<tr>
<td>LCT 816</td>
<td>0.009</td>
</tr>
<tr>
<td>LCT 818</td>
<td>0.004</td>
</tr>
<tr>
<td>BANNER (APA)</td>
<td>0.008</td>
</tr>
<tr>
<td>BARROW (APA)</td>
<td>0.003</td>
</tr>
<tr>
<td>BRULE (APA)</td>
<td>0.027</td>
</tr>
<tr>
<td>CRITTENDEN (APA)</td>
<td>0.40</td>
</tr>
<tr>
<td>DAWSON (APA)</td>
<td>0.073</td>
</tr>
<tr>
<td>FALLON (APA)</td>
<td>0.004</td>
</tr>
<tr>
<td>YO 160</td>
<td>3.9</td>
</tr>
<tr>
<td>YOG 83</td>
<td>0.10</td>
</tr>
<tr>
<td>ARDC 13</td>
<td>0.91</td>
</tr>
</tbody>
</table>
TUNA) were reported “Geiger Sour” (i.e., having intensities greater than 0.1 R/day) on ABLE day, whereas the calculated intensities on vessels at these ranges are much lower. At the times these reports were made, the six vessels were located on or within the radiological blue line, indicating that the surrounding radioactive water, and not the ships themselves, was the major source of the intensity. Subsequent reports on these vessels indicate that they soon became “Geiger Sweet” (having average intensities less than 0.1 R/day) when the blue line had receded past their positions.

In addition to the exterior ship intensity readings on which this model is based, interior submarine intensity readings found in Commanding Officers’ reports are included in Table 2-3(b). The measured interior intensities on the SKATE and APOGON are significantly smaller than the exterior intensities predicted by the model; this is consistent, since the interiors of the surfaced submarines were strongly shielded from the neutron fluence by the surrounding seawater. Both the data and model give negligible intensities for the DENTUDA and TUNA. The reported 0.3 R/day intensity on the interior of the PARCHE, however, is anomalous. Although the PARCHE was approximately 300 yards farther from surface zero than the APOGON, this intensity is two orders of magnitude larger than that measured for the APOGON. The A+1 PARCHE intensity data consist of sixteen reported readings for various interior locations, each recorded as "0.3". Such uniformity is inconsistent with readings on other submarines. Further, the PARCHE was declared “Geiger Sweet” at 0935 hours on 2 July (Reference 21), indicating that the intensity levels at that time were below 0.1 R/day. Thus, these reported A+1 intensity readings on the PARCHE appear to be in error.

2.3 Shot BAKER Water Intensity

The radiological environment after Shot BAKER was dominated by fission products deposited in the water and on the target ships. Extensive measurements of water activity (e.g., in Curies/liter) were made by scientific personnel under the Technical Director. Unfortunately, only fragments of this information have been located. Concurrently, radiological patrols were reporting intensities (in R/day) above the water to the Radiological Safety Control Center; this information exists in the form of red (1.0 R/day) and blue (0.1 R/day) line coordinates, used by the Director of Ship Material to control ship movement in the lagoon. Both sets of data are utilized in the development of the Shot BAKER water intensity model.
Perhaps the best source of post-BAKER water activity data is Reference 12, which gives activity contours for one, two, and three days after the BAKER detonation. These contours, reproduced in Figure 2-5, are labeled in “arbitrary radiation units”, or aru, which were normalized to a fixed time to correct for decay. This time normalization was performed so that the effects of diffusion could be examined. The normalization procedure is not described in the article, so the precise definition of aru is uncertain. Another valuable source of information is a set of tables authored by Dr. Kenneth G. Scott, which appeared in an unpublished manuscript (Reference 23) assembled by Dr. J. O. Hirschfelder and found in the archives at the Los Alamos National Laboratory. These tables include information on maximum radiation intensities and contaminated areas, total radioactivity in lagoon water, and simultaneous measurements of water activity and intensity. A third significant source of water activity data is Appendix V of Reference 24, a technical report submitted in September 1946 covering the BAKER detonation. This document contains tables giving total radioactivity in lagoon waters and variations in activity with depth for five days following the BAKER shot, with more detailed information presented on the water activity distribution on the fifth day after detonation (B+5). Other sources of water activity data include References 1 (Chapter 27), 4 (Enclosure J), and 21.

The red and blue line coordinates are contained in the transcripts of radio messages found at the Federal Records Center in Suitland, MD. Red line data are given for BAKER day through B+2; the red line was eliminated at 1455 hours on B+3. Blue line data are given through B+4; the blue line was eliminated at 0959 hours on B+5. Examples of red and blue lines for days B+1, B+2, and B+3 are presented in Figure 2-6.

The radiological condition of the lagoon water after B+5 is largely unknown. There is evidence that the water intensity decreased significantly between B+5 and B+8. Enclosure F of Reference 4 discusses the natural flushing of the lagoon water between five and eight days after BAKER day, thereby reducing water activity to very low levels by B+8. This is supported by data appearing in Reference 24, indicating a rapid decrease in the activity concentration in the lagoon water between these dates. The only quantitative data available on the water environment beyond B+8 is contained in a message from the Radiological Safety Officer (COL S.L. Warren) to CJTF-1 on 15 August 1946, in which he states “Lagoon water average 0.02 to 0.03 R per day.”
Figure 2-5 Shot BAKER Water Activity

Source Reference 12
Figure 2-6 Red and Blue Lines after Shot BAKER
Water of such intensity must have been contained within a relatively small region of the lagoon, since it is easily demonstrated that the initial inventory of fission products available from a 23 kt detonation was much too small for intensities of this level to have existed throughout the lagoon three weeks after the shot. Unfortunately, the location of the contaminated pool is unspecified in the message.

The BAKER water intensity model is developed to estimate the intensity at any location in the lagoon at any time after the BAKER detonation. A summary of the data base utilized in the construction of this model is given in Table 2-5. A general computer-based calculational methodology based on this model estimates doses for specific ship paths through BAKER-contaminated water from B+1 until final lagoon departure. Due to the lack of data available for BAKER day, this day is not included in the generalized methodology. Doses accrued on BAKER day are analyzed separately, using primarily red/blue line information and data from ship logs. The development of this model is subsequently discussed.

To develop the model, the intensity distribution throughout the lagoon at a reference time on each of days B+1 through B+5 is approximated from available data. The graphical activity contours (in units of a;u) provided in Reference 12 for days B+1 through B+3, and the areas within various activity density contours (in microcuries/liter) given in Reference 24 for B+5, form the basis of the intensity distribution modeling for this period. It is first necessary to convert these contours to intensity contours. The most direct method to achieve this conversion is the use of red/blue line data to calibrate the contours for each of these four days. The advantage of utilizing the red/blue lines, which were employed at CROSSROADS to control ship movements, is that those portions of the intensity contours most important in calculating personnel doses are modeled most accurately. The B+4 intensity contours are developed by using the area-integrated surface activity (in units of square miles-millicuries per liter, as given in Reference 24) and red/blue line data to interpolate between the B+3 and B+5 contours. It is assumed that, except for a contaminated pool that persisted in the vicinity of the target array (and apparently formed the basis of Warren’s observation), the intensity distribution on B+5 decreased linearly to zero by 200 hours after the detonation (B+8). The intensity in the vicinity of a ship is estimated by linearly interpolating in time between the intensities at the ship location derived from the two reference intensity distributions bracketing the time of interest.
<table>
<thead>
<tr>
<th>Day:</th>
<th>B</th>
<th>B+1</th>
<th>B+2</th>
<th>B+3</th>
<th>B+4</th>
<th>B+5</th>
<th>B+5-</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Activity contours (graphical)</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Reference 12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity contours (areas)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>(Reference 24)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated surface activity</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>(Reference 24)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red/blue lines</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>(RSCC messages)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total contaminated area/max</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(References 5, 23)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.L. Warren message</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>(dated 15 August 1946)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The intensity level reported in the Warren message forms the basis for characterizing the contaminated water environment for the month of August 1946. It is reasoned that the lagoon intensity levels observed by Warren (0.02-0.03 R/day on 14 August, B+20) were limited in spatial extent by the total activity deposited in the lagoon, which is calculated to have been $5 \times 10^9$ Curies at $H+1$ hour (Reference 24). Assuming a $t^{-1.3}$ decay (Reference 4) coupled with a 3.2 percent per day depletion by flushing (Enclosure F of Reference 4), the total activity available in the lagoon is calculated for each day. This activity is assumed to have been confined to a cylindrical slug of water 150 feet deep (the average depth of the lagoon), having a vertical distribution such that the surface concentration is about one order of magnitude higher than the concentration near the lagoon bottom. This distribution is consistent with the vertical profile data reported in Reference 24 for several days after detonation. Maintaining this vertical activity gradient throughout the period of interest, despite its likely dissipation through mixing, high-sides the intensity at the surface and thus the dose to shipboard personnel.

The radius of the cylinder is determined in the following manner. The intensity above the surface of the contaminated water, which is assumed uniform throughout the contaminated region, is modeled as a function of time by fitting a logarithmic function to the intensity readings of 0.1 R/day on B+5 (when the blue line was eliminated) and 0.025 R/day on B+20 (Warren’s data). The activity concentration of the water corresponding to an intensity level as measured above the surface is then determined from measurements reported by Scott (Table 20.15 of Reference 23), which indicate that an activity concentration of one microcurie per liter of lagoon water (in situ) resulted in an intensity of approximately 0.024 R/day above the surface. This is in general agreement with a measurement taken by USS BURLESON personnel on B+5 (Reference 21, 0.029 R/day/liter) and the results of calculations with the radiation transport code ANISN (Reference 7, 0.013 R/day/µCi/l). The required radius of the contaminated pool follows from the activity available in the lagoon on the day of interest, the assumed vertical profile, and the surface concentration on that day. The radius is approximately 5000 yards from B+8 through B+40. It is assumed that the decaying pool remained centered on surface zero, encompassing most of the target array and thereby maximizing potential exposure to this radioactivity. Ship movement data are then used to determine the periods when each ship was in contaminated water of the specified intensity.
2.4 Shot BAKER Target Ship Intensity

The contamination of target vessels from the BAKER detonation was quite extensive, due primarily to the base surge (a cloud of contaminated water droplets formed by the underwater detonation) and early rainout of fission products. The base surge extended approximately 1800 yards upwind, 2700 yards crosswind, and 4000 yards downwind, to the northwest (Reference 25). Target ships within the base surge generally received significant contamination, while many ships on the outer portions of the array experienced only light contamination. Detailed documentation of intensity levels exists for most of the target vessels. Appendix VII of Reference 24 lists maximum topside, average topside, and average interior readings for virtually every target vessel for numerous days following the BAKER shot. While these data are often inconsistent, and individual readings may be questionable, they nevertheless provide the best available estimates of target ship intensities. Also included in Reference 24 are readings taken alongside many of the target vessels during the period when they were too radioactive to board. Daily target ship status reports and transcripts of radio messages (found at the Federal Records Center) also contain detailed target ship radiological data. In addition, References I (Chapter 27), 4 (Enclosure J), 20, 21, and 22 quote numerous intensity readings for the target ships. Dr. W. E. Strope, in Reference 25, has evaluated much of this topside intensity data for many target ships.

The target ship intensity model for Shot BAKER is developed by accumulating all available data on ship intensities and organizing them in graphical form. It had been observed that the intensities on target ships generally followed a $t^{-1.3}$ decay law, exclusive of decontamination (Reference 4). Therefore, the ship intensity data are fit with such curves except during documented periods of decontamination. When decontamination is known to have taken place, intensity-time curves based on $t^{-1.3}$ decay are fit separately to the data taken before and after decontamination, while the data taken during decontamination are used to empirically construct a curve connecting these segments. When data are available, separate curves are constructed for average topside, amidships (alongside), and below deck readings. An example is shown in Figure 2-7 for the USS PENSACOLA. For each event involving a target ship (moored alongside, boarding, etc.), the appropriate ship intensity curve is used to estimate the radiation environment. Target ship intensity curves so derived are presented in Appendix A.
Figure 2-7 USS PENSACOLA (CA-24) Post-BAKER Ship Contamination
2.5 Shot BAKER Support Ship Contamination

During post-BAKER operations it quickly became apparent that support ships, when operating in contaminated water, accumulated radioactive materials on their underwater hulls and in salt water lines and evaporators. The resulting interior intensities were sufficiently large on some early re-entry ships, notably the PGMs, to require overnight crew evacuation (Reference 33). The intensities in other support ships were reduced to or maintained at a tolerable level through such decontamination processes as “hogging” (scraping the ship hull with rope or chain) or steaming in open seas. The physical processes responsible for this radioactive accumulation appear to include assimilation of radionuclides by aquatic organisms (e.g., algae and barnacles) that were or became attached to the ship, and ion-exchange absorption of the polyvalent fission products by inert material (e.g., paint or rust) on the ship hull or in the piping (References 24 and 34). A ship contamination model based on the microscopic details of these mechanisms is not feasible, due to the complexity of these processes and the uncertainties in the initial conditions of the hulls/piping and lagoon water contamination composition. The approach taken here is to develop a mathematical model that describes the macroscopic features of the support ship contamination process in a manner consistent with the observed data and underlying physics.

Two basic assumptions are made in developing this model. The first is that the mixture of fission products present in the accumulated radioactive material on the hull and in the piping of a support ship decayed radiologically as $t^{-1.3}$. This decay rate was verified experimentally for fission products deposited in seawater and on the decks of target ships (Reference 4). It is possible that selective absorption of fission products took place on the hull and in the piping of the support ships, such that a decay rate different than $t^{-1.3}$ could be applied; however, since specific data on this point are lacking, the referenced decay rate is used. The second assumption is that the rate of contamination buildup on the hull and interior piping is initially proportional to the radiation intensity of the water surrounding the ship, but, as buildup progresses, a limiting or saturation value of contamination is approached asymptotically. Such a saturation effect has been observed in the accumulation of radioactive isotopes in various aquatic organisms (References 34 and 40). Saturation is indicated by hull intensity readings taken on various ships after their departure from the lagoon.

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Specifically, the amount of foreign matter (i.e., fission products) accumulating on the hull and piping is assumed to approach saturation, therefore, the radiation intensity of the saturation level of this material decays as $t^{-1.3}$. The exterior intensity of the saturated hull at time $t$ after detonation is therefore assumed to have the mathematical form

$$I_{\text{sat}}(t) = S t^{-1.3},$$

where $S$ is a constant.

With these assumptions, the intensity $I_o$ of the contaminated hull of a support ship at time $t$ may be written

$$I_o(t) = I_o(t - \Delta t) \left[ \frac{t - \Delta t}{t} \right]^{1.3} + C \left[ 1 - \frac{I_o(t)}{S t^{-1.3}} \right] I_w(t) \Delta t,$$

where $I_w(t)$ = intensity of surrounding water at time $t$,
$\Delta t$ = small interval of time,
$C$ = constant.

The first term of the right represents the contribution from previously accumulated contamination, while the second term is the contribution from the contamination accumulated between $t - \Delta t$ and $t$. The factor

$$\left| \frac{I_o(t)}{S t^{-1.3}} \right|$$

insures that this contribution vanishes as saturation is approached, that is, as $I_o(t) \rightarrow S t^{-1.3}$.

By rearranging this equation, taking the limit as $\Delta t$ becomes very small, and solving the resulting differential equation, one obtains

$$I_o(t) = S t^{-1.3} \left[ 1 - \exp \left\{ - \frac{C}{S} D_w(t) \right\} \right],$$

where

$$D_w(t) = \int_0^t \tau^{1.3} I_w(\tau) \, d\tau.$$
Note that $I_w(t)$ is determined from the BAKER water intensity model and the ship path through the contaminated water. It is evident that saturation is approached as the integral $D_r(t)$ becomes large; this occurs as a ship spends sufficient time in contaminated water.

The constants $S$ and $C$ in the contamination model are evaluated from support ship intensity data found primarily in messages sent to CJTF-1 by radiological safety officers at various shipyards. Combined beta-plus-gamma intensities were measured at points external to the hulls of numerous support ships during post-CROSSROADS decontamination operations, and were generally reported as port and starboard average and maximum intensities. Much of these data cannot be used in this analysis, because readings were taken after the hulls were partially decontaminated (by scraping) in the shipyard, or because the hulls were wet when readings were taken (the emission of beta particles from the contaminant material is inhibited when the material is wet; the intensity appears to be sensitive to the amount of moisture present). Intensity readings taken on dry, unscraped hulls were reported for nine support ships. This limited data set was selected for use in evaluation of $S$ and $C$, since inclusion of the scraped and/or wet data would introduce a bias toward lower dose estimates. In addition, various reported intensity readings for three other ships are considered of similar quality. Reference 27 contains wet unscraped hull readings for the USS ROCKBRIDGE, with the notations that “readings on hull will be 3-6 times higher when dry.” A factor of six is thus used to determine an equivalent average dry hull intensity. Reference 35 gives an exterior hull reading on the USS SAIDOR, while Reference 36 gives an interior hull reading for the USS MOUNT McKinley. The intensity readings for these twelve ships constitute the data base for determining best estimates of constants $S$ and $C$. These intensity data are included in Table 2-6.

In performing the evaluation of $S$ and $C$, the various hull readings are first converted to exterior hull gamma intensities. Since the beta particles (electrons) were almost completely attenuated by the hull material, while the gamma intensities experienced a much smaller attenuation (Reference 26), it is the gamma radiation that contributes to dose on the interior of the ship. Consequently, the exterior hull gamma reading is used as an indicator of the level of ship contamination. Contained in the reported hull intensity data are five sets of gamma and beta-plus-gamma readings, each set taken concurrently during decontamination operations. These data indicate
Table 2-6

Contamination Model Data Base

<table>
<thead>
<tr>
<th>Ship</th>
<th>Type Reading</th>
<th>Date of Reading</th>
<th>Reported Intensity (mR/day)</th>
<th>$S$ (mR·day$^{0.3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUARTZ (IX)</td>
<td>Dry hull,$\beta$+$\gamma$</td>
<td>22 Oct 46</td>
<td>22**</td>
<td>1172</td>
</tr>
<tr>
<td>HESPERIA (AKS)</td>
<td>Dry hull,$\beta$+$\gamma$</td>
<td>6 Nov 46</td>
<td>21*</td>
<td>1355</td>
</tr>
<tr>
<td>BRAMBLE (WAGL)</td>
<td>Dry hull, $\beta$+$\gamma$</td>
<td>2 Nov 46</td>
<td>23*</td>
<td>1410</td>
</tr>
<tr>
<td>SAIDOR (CVE)</td>
<td>Gamma</td>
<td>30 Aug 46</td>
<td>7.2</td>
<td>1515</td>
</tr>
<tr>
<td>MOUNT MCKINLEY (AGC)</td>
<td>Interior</td>
<td>19 Aug 46</td>
<td>10</td>
<td>1573</td>
</tr>
<tr>
<td>ROCKBRIDGE (APA)</td>
<td>Wet hull,$\beta$+$\gamma$</td>
<td>3 Oct 46</td>
<td>12***</td>
<td>2820</td>
</tr>
<tr>
<td>HUNTINGTON (DD)</td>
<td>Dry hull,$\beta$+$\gamma$</td>
<td>4 Nov 46</td>
<td>20</td>
<td>1257</td>
</tr>
<tr>
<td>SUMNER (DD)</td>
<td>Dry hull,$\beta$+$\gamma$</td>
<td>4 Nov 46</td>
<td>27</td>
<td>1699</td>
</tr>
<tr>
<td>INGRAHAM (DD)</td>
<td>Dry hull,$\beta$+$\gamma$</td>
<td>4 Nov 46</td>
<td>29</td>
<td>1524</td>
</tr>
<tr>
<td>MOALE (DD)</td>
<td>Dry hull,$\beta$+$\gamma$</td>
<td>4 Nov 46</td>
<td>43</td>
<td>2683</td>
</tr>
<tr>
<td>PGM-23</td>
<td>Dry hull, $\beta$+$\gamma$</td>
<td>2 Nov 46</td>
<td>51</td>
<td>3092</td>
</tr>
<tr>
<td>PGM-24</td>
<td>Dry hull, $\beta$+$\gamma$</td>
<td>2 Nov 46</td>
<td>27</td>
<td>1624</td>
</tr>
</tbody>
</table>

* Arithmetic average of reported port and starboard average intensities.

** Average of 7 hull readings.

*** Average of 22 hull readings.
that the approximate gamma intensity can be derived from a beta-plus-gamma reading by multiplying the latter quantity by 0.078. The value is consistent with various beta-gamma ratios measured during the CROSSROADS operation (Reference 38 and 39).

The resulting set of 12 exterior hull gamma intensities indicates that a form of saturation may have been acting to limit the accumulation of contaminant materials on the support ships. When these intensities are adjusted (via $t^{-1.3}$) to equivalent readings taken on the same day, the adjusted intensities are similar in magnitude, even though the ships’ exposure histories were quite different. Thus, it appears probable that all ships that spent sufficient time in contaminated water approached a limiting value of the amount of accumulated contaminant material and that at some later date these ships all exhibited similar contamination intensities, independent of the details of their individual exposures to contaminated water.

To evaluate $S$ and $C$, the exterior hull gamma intensity derived for each of the 12 ships is adjusted to the value that would have existed on the day the support ship departed Bikini Lagoon. According to statements presented in Reference 2, steaming in uncontaminated water at full speed for 24 hours reduced the accumulated activity by 50 percent, but continued steaming did not result in further reduction. Reference 37 reports that the USS HENRICO experienced a period of leaching the first night at sea, bringing her hull down to 0.4 (of departure intensity) and the auxiliary condenser down 0.6, but effecting the evaporators but little.” In the present analysis, it is assumed that both hull and pipe intensities were reduced to half of their departure values during the first day after departure from the lagoon. An assumption concerning the subsequent radiological and physical decay of the remaining radioactive material must be made. Data presented in Reference 37 indicates that the decay during the first few days following departure may have been greater than $t^{-1.3}$ (due to continued leaching), but that at later times the decay rate decreased significantly. Due to lack of definitive data on which to construct reliable post-departure intensity-time curves, the standard $t^{-1.3}$ decay rate established for deposited BAKER fission products is used. The calculated intensity at lagoon departure, $I_o(t_f)$, for each of the twelve ships in the data base is determined by increasing the reported intensity by a factor $(t_r/t_f)^{1.3}$, where $t_r$ is the time of the intensity reading, and $t_f$ is the time of final lagoon departure; this adjusted value is then multiplied by two (to account for initial leaching of radioactive material in clear water) to arrive at $I_o(t_f)$. Substituting into the previously equation, one arrives at a relation between the constants $S$ and $C$:
Thus, for each of the twelve ships, curves of $S$ versus $C$ are constructed. These curves have the general form shown in Figure 2-8 for representative ships. While unique values of $S$ and $C$ cannot be determined from these curves directly, they may be evaluated with one additional curve constructed from data given in Reference 2:

$$I_0(t_f) = S t_f^{-1.3} \left[ 1 - \exp \left\{ -\frac{C}{S} D_w(t_f) \right\} \right].$$

After re-entry of the non-target vessels to the lagoon, the same tendency of radioactive materials to adhere to the outer shell below the waterline was observed. The conditions here were ideal for ion-exchange and although the water itself showed intensity of radioactivity at and near the surface of only about $0.1$ R/day, the active material was absorbed so efficiently from the lagoon waters that within a period of three days several of the non-target vessels began to show Geiger counter readings of greater than $0.1$ R/day of gamma radiation inside the hull in the vicinity of the waterline.

This statement appears to refer to support ships that re-entered the lagoon on BAKER day, and therefore applies to the first three days after detonation. It is assumed that the maximum hull reading was $0.12$ R/day after three days; the $S$-versus-$C$ curve described from these values is shown schematically in Figure 2.8. As shown in the diagram, the latter curve crosses those derived from the support ship intensity data base in such a manner that unique values of $S$ and $C$ can be assigned to each of the twelve ships. The values of $S$ thus determined are given in Table 2-6. It is seen that the individual values of $S$ vary within each group. Part of this variation is undoubtedly due to the simplicity of the basic model, uncertainties in the calculated water intensities $I_w(t)$, and uncertainties in the exterior hull readings due to instrument inaccuracies and nonstandard measurement techniques. However, much of this spread may be physical, representing variations in the amount of accumulated contaminant material on ship hulls due to differences in type and condition of paint (Reference 2), cleanliness of the hull while at Bikini, and decontamination actions taken while in the lagoon.

The values of $S$ used in this analysis are the geometric mean values of $S$ appearing in the table, grouped by ship type. Specifically, $S = 2240$, $1800$, and $1570$ mR-day$^{-0.3}$ for PCMs, destroyers, and all other ships, respectively. The range in the derived values of $C$ is small, and the dose calculations are relatively insensitive to the exact value chosen. An average value of $C = 11.0$ day$^{-1}$ is used for all support ships.
Figure 2-8 Ship Contamination Model Parametric Curves
A method is now developed whereby the exterior hull gamma intensity (the \( I_0 \) calculated as described above) is used to determine interior ship intensities resulting from exterior hull contamination and contamination in salt water piping. A contaminated ship is modeled as a three-level structure with vertical sides (hull), as shown in Figure 2-9. The relevant geometric parameters are indicated in the figure. The hull contamination is modeled as a number (ten was found to be sufficient) of infinite line sources on each side of the lower exterior of the structure. The interior piping consists of two water mains (also taken as line sources) above level 2 in the structure. The structure is assumed to be symmetric about the centerline. Eight parameters \(( W, H, h_1, v_1, v_2, t_1, t_2, t_3 )\) are determined for each ship type from analyses of ship diagrams. The value of \( Z \) (height above deck) is taken as 4.5 feet, the approximate height of a chest-worn badge. It is necessary to relate intensities measured in the salt water mains \(( I_p )\) to the exterior hull gamma intensities \(( I_0 )\), which are assumed to have been read with the detector held at the nominal water line of the ship and with the hull exposed (i.e., in dry dock or listed to the other side). Readings available for the USS SAIDOR (Reference 35) and the USS ROCKBRIDGE (Reference 27) indicate that \( I_p \approx 1.5 I_0 \). This relationship is assumed to hold for all ships.

With the sources now fixed, the interior ship intensities are calculated. This step requires the computation of the attenuation and buildup of gamma radiation through the material interposed between each element of source radiation and the point of interest, and the summation (integration) of contributions from all source elements. This is accomplished by means of the kernel technique with the Taylor form of the buildup factor (Section 3.8 of Reference 25). A gamma energy of 0.8 MeV (representative of gamma radiation from fallout material) is assumed. The resulting relative intensity (i.e., relative to exterior hull gamma intensity, \( I_0 \)) distribution for each of the three levels of a destroyer is displayed in Figure 2-10. The relative intensity averaged over all three levels is used for contamination dose calculations in this report. These averaged relative intensities, referred to as apportionment factors, \( F_a \), are listed in Table 2-7 for all ship types of interest.

Finally, an estimate is made of the intensity in the engine room of a ship. From the intensity data referenced above for the SAIDOR and ROCKBRIDGE, and from values given for the A.M. SUMNER in a radio message transmitted on 28 July 1946, it
Figure 2-9 Support Ship Contamination Model
Destroyer Parameters

- \( w = 41 \text{ ft} \)
- \( h_l = 14 \text{ ft} \)
- \( t_2 = 0.50^{\circ} \)
- \( H = 8 \text{ ft} \)
- \( z = 4.5 \text{ ft} \)
- \( t_3 = 0.20^{\circ} \)
- \( V_1 = 0 \)
- \( t_1 = 0.28^{\circ} \)
- \( N_5 = 10 \)
- \( V_2 = 0.5 \text{ ft} \)

Figure 2-10 Interior Intensity Distribution for a Destroyer
Table 2-7  
Ship Apportionment Factors

<table>
<thead>
<tr>
<th>TYPE</th>
<th>SHIP Description</th>
<th>DESIGNATION</th>
<th>$F_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Destroyer</td>
<td>DD</td>
<td>.39</td>
</tr>
<tr>
<td>II</td>
<td>Cruisers</td>
<td>CA-131</td>
<td>.05</td>
</tr>
<tr>
<td>III</td>
<td>Carrier, Light</td>
<td>CVE</td>
<td>.10</td>
</tr>
<tr>
<td>IV</td>
<td>Mine Sweepers</td>
<td>YMS</td>
<td>.55</td>
</tr>
<tr>
<td>VA</td>
<td>Salvage &amp; Rescue</td>
<td>AN, ARS, ARSD-1, ASR-1, ASR-8</td>
<td>.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ATA, ATF, ATR, WAGL-392</td>
<td></td>
</tr>
<tr>
<td>VB</td>
<td>Small Survey</td>
<td>AGS (8, 10, 13) (not AGS-4)</td>
<td>.55</td>
</tr>
<tr>
<td>v c</td>
<td>Patrol Boats</td>
<td>PCM</td>
<td>.67</td>
</tr>
<tr>
<td>VIA</td>
<td>300’ Merchant</td>
<td>APD-27, AVP-49</td>
<td>.29</td>
</tr>
<tr>
<td>VIC</td>
<td>465-508' Merchant</td>
<td>AH-4, 12, 13, AV-5, 14, 17 APA-27, APA-33, APA-45 LSD-5, LSD-25</td>
<td>.15</td>
</tr>
<tr>
<td>VIIA</td>
<td>Tankers 300’</td>
<td>AOG(W)-11</td>
<td>.33</td>
</tr>
<tr>
<td>VIIB</td>
<td>Tankers 400’</td>
<td>AW-2</td>
<td>.28</td>
</tr>
<tr>
<td>VIIC</td>
<td>Tankers 500’</td>
<td>AOW-6 1, AO-54, AO-69</td>
<td>.24</td>
</tr>
<tr>
<td>VIII</td>
<td>Tenders &amp; Repair</td>
<td>AD-1%, AS-1 1, AR-6</td>
<td>.15</td>
</tr>
<tr>
<td>IXA</td>
<td>Landing Craft</td>
<td>LCI</td>
<td>.57</td>
</tr>
<tr>
<td>IXB</td>
<td>Landing Craft</td>
<td>LCT</td>
<td>.43</td>
</tr>
<tr>
<td>IXC</td>
<td>Landing Craft</td>
<td>LST, ARL-24</td>
<td>.33</td>
</tr>
<tr>
<td>X</td>
<td>Barges</td>
<td>YO, YOG, YW</td>
<td>.57</td>
</tr>
</tbody>
</table>

*The apportionment factor $F_a$ is the average interior ship intensity relative to the exterior hull gamma intensity. It is calculated by averaging the interior intensity distribution over the three levels of the ship model.*
appears that evaporators and associated equipment have average intensities \( I_e \) similar to those of pipes, i.e.,

\[ I_e \approx 1.5 \, I_o. \]

Therefore, the engine room is estimated to have an average intensity no greater than this value.
Section 3
NAVAL OPERATIONS

Only those portions of the CROSSROADS ship activities before and after tests ABLE and BAKER that are pertinent to radiological examination are discussed. Elaborate fleet operation plans were established by CJTF-1 for safety and operational control purposes. These plans are recorded in Reference 29. The ocean in and around Bikini Lagoon was sectioned into specific geographic regions. Centered on the Delta Beacon on Bikini Island, designated Point Auto, concentric circles and radials were drawn. The resulting annular sectors were assigned various automobile names. The sector chart, defining the operating areas for the task groups of the Joint Task Force, is shown in Figure 3-1. A sector axis was drawn through sections Benz and Graham. Radiological axes based on the local surface wind directions for ABLE and BAKER were established at azimuths $050^\circ$ and $120^\circ$, respectively. The sector axis was then aligned with the radiological axis and the sectors were rotated accordingly. Each ship was assigned an operating area based on these sectors.

3.1 Pre-Shot Evacuation

On the day before each test, 30 June and 24 July, the crews manning the target ships, approximately 9,000 personnel, were transferred to various units of the transportation group. Other transportation units visited the neighboring islands and took native personnel aboard in case a permanent evacuation might become necessary as a result of radioactive fallout. The various operating groups took positions as specified by the CJTF-1 Operation Order 1-46 and the sector chart of Figure 3-1 to await the test. Figure 3-2 shows the locations of the operating groups prior to the BAKER detonation; the radiological axis for this shot was at $120^\circ$, as indicated.

3.2 Post-Shot Maneuvers

Immediately after Shots ABLE and BAKER, the PGMs, salvage units and technical group reentered the lagoon in that order. The 20 LCPL craft, each normally manned by a boat officer and a crew of four, were lowered into the lagoon to accompany the PGMs into the target array to define the radiological environment. The Director of Ship Material, located on the USS RECLAIMER (ARS-42), supervised
the initial damage survey of the target array and also reported radiological readings of
the water and target ships. The remaining salvage units and the technical group
remained near the lagoon entrance, well outside radioactive waters. Their general
location upon reentry are shown in Figure 3-3.

Little detailed information is available on the actual movements of the PGMs and LCPLs. Figure 3-4 shows the sector assignments of the PGMs for a hypothetical
wind of $070^\circ$, nearly the actual condition for Shot ABLE. One hour before Shot ABLE, the sector assignments were shifted one segment clockwise for each PCM patrol and
their attached LCPLs. The assignments of LCPLs and patrol areas for both shots are
given in Table 3-1.

Table 3-1
PG M Patrol Assignments

<table>
<thead>
<tr>
<th>Metal/ PCM</th>
<th>Assigned LCPLs*</th>
<th>Assigned</th>
<th>Sector:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steel 32</td>
<td>A4</td>
<td>ABLE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B18</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nickel 31</td>
<td>B15</td>
<td>ABLE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B16</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Iron 29</td>
<td>B12</td>
<td>BAKER</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B13</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gold 25</td>
<td>B9</td>
<td>ABLE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cobalt 24</td>
<td>B6</td>
<td>BAKER</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brass 23</td>
<td>A1</td>
<td>ABLE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>A3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B19</td>
<td></td>
</tr>
</tbody>
</table>

*As specified in Operation Plan
Note: Plan shown is for Shot ABLE.
For Shot BAKER, Sector Holland was deleted and all sectors were rotated 50° clockwise.

Figure 3-4 PCN Operation Plan
On ABLE day, the PGMs and attached LCPLs proceeded into the lagoon and to their assigned sectors. Beginning at the outside of the target array, the patrols proceeded toward the center of the array, reporting radiological intensities as they converged. In this manner, the red (1.0 R/day) and blue (0.1 R/day) lines were specified. The LCPLs then began to circle the target ships in their assigned sectors and report the radiological status of the water around the ships. On ABLE day plus one (A+1), the lagoon patrol followed straight grid lines and made east-to-west sweeps through the target array, allowing early clearance to be given to the center portion of the array. In the late morning on A+1, the blue line was discontinued. Later that day, the lagoon patrols searched for and identified remaining radiologically hazardous areas. By A+2, most of the target ships had been cleared, and the LCPLs of the lagoon patrol had become a water taxi service, performing various jobs not specified in the Operation Plan.

The PGMs and assigned LCPLs followed similar radiological reconnaissance procedures in the lagoon after Shot BAKER. Because of the intensity and size of the contaminated area, only seven target ships were cleared on BAKER day. During these patrols, some crews on the PGMs and LCPLs entered radiological "hot" spots and reached or exceeded their daily tolerance of radiation (0.1 R/day) in a period of several hours. Patrols were continued on subsequent days and by B+2, the water around approximately half of the target ships had been cleared. By B+5, the blue line and boating restrictions had been eliminated.

As previously stated, incomplete information exists on the actual movements of the PGMs and LCPLs while they were performing their assigned tasks. The PGM deck logs typically note "... various courses and various speeds while on radiological patrol...". While not every position and maneuver is recorded, sufficient information is available on the PGMs to reconstruct major movements, from which dose calculations can be made. There is insufficient information, however, to accurately determine the movements of the LCPLs, and thus to reliably reconstruct doses for the crews. Fortunately, most of the crew members were issued film badges at the beginning of each day, and records exist on the dose levels for each crew for the periods 1-3 July 1946, and 25-31 July 1946. Dosimetry for the LCPLs is shown in Table 3-2. These dose levels represent the radiological data base that exists for the LCPL crews and can be used for dose determination of crews engaged in lagoon surveys.
Table 3-2 Dosimetry Summary for LCPL Crews

<table>
<thead>
<tr>
<th>LCPL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>25</th>
<th>26</th>
<th>27</th>
<th>28</th>
<th>29</th>
<th>30</th>
<th>31</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>20(70)</td>
<td>0</td>
<td>-</td>
<td>85(100)</td>
<td>0</td>
<td>62(80)</td>
<td>-</td>
<td>110(110)</td>
<td>113(130)</td>
<td>0</td>
<td>200(200) (7/31-8/26)</td>
</tr>
<tr>
<td>A 2</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>72(80)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>A 3</td>
<td>0</td>
<td>0</td>
<td>70(70)</td>
<td>0</td>
<td>100(100)</td>
<td>-</td>
<td>-</td>
<td>188(270)</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>A 4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8(40)</td>
<td>-</td>
<td>34(50)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>A 5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>28(40)</td>
<td>28(30)</td>
<td>0</td>
<td>50(50)</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>A 6</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>110(120)</td>
<td>152(180)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
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<td>A 7</td>
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<td>-</td>
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<td>100(100)</td>
<td>-</td>
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</tr>
<tr>
<td>A 8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>B 6</td>
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<td>0</td>
<td>52(60)</td>
<td>84(90)</td>
<td>124(150)</td>
<td>100(100)</td>
<td>-</td>
<td>-</td>
<td>90(100)</td>
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<td>B 9</td>
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<th>NO. OF BADGES</th>
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<th>92</th>
<th>20</th>
<th>97</th>
<th>96</th>
<th>97</th>
<th>35</th>
<th>27</th>
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<td>NO. OF ZERO</td>
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<td>82</td>
<td>18</td>
<td>65</td>
<td>56</td>
<td>33</td>
<td>4</td>
<td>2</td>
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Table gives average dose in [Tc], maximum dose in parentheses.
Dash indicates no data available.
The 10 salvage units led by the RECLAIMER were the first ships to follow the PGM radiological patrol. Each ARS except the RECLAIMER was accompanied by a rescue tug carrying a fire fighting officer and team. The movements of the RECLAIMER are well documented and are discussed at length in Section 5. Following Shot BAKER, most other units remained outside the lagoon and did not enter until after B+4, by which time the water intensity had greatly diminished. Units operating within the lagoon generally anchored for the night in the southeastern corner of the lagoon. However, on B+3 some ships were forced to shift their anchorages 4-5 miles to the west to avoid the advancing radioactive waters.

3.3 Boarding Party Operations

Boarding parties were established to board target ships for purposes of inspection, damage control, instrument retrieval, and reactivation of target ships. The organization and mission of the major boarding parties are discussed below.

1) Initial Boarding Teams

There were ten such teams, each composed of seven to eleven people. Key elements of each team included:

Representative, Director of Ship Material - In charge of team.

Assistant to Representative, Director of Ship Material - Deputy team leader.

Radiological Safety Monitor - Determined radiological conditions of all topside structures. Advised length of time personnel could remain onboard under existing conditions. Located and marked all unsafe spots.

Medical Safety Officer - Determined possible personnel hazards regarding air contamination; noted conditions of animals on topside structures, and served as Damage Control Safety Officer.

Bomb and Ammunition Safety Officer - Determined over-all condition of exposed ammunition and safety of ammunition in magazines as indicated by results of previous and existing fires.

Photographer - Obtained photographs of gross damage conditions as directed by DSM representative.
Six of the ten Initial Boarding Teams were located aboard salvage ships; four were aboard LCPLs and later transferred to other salvage units. The function of these teams was damage control, radiological monitoring and initial inspection and disposition of the target vessels. Boarding teams were kept together during the inspection of each ship insofar as practicable. The assignment of individuals to the various Initial Boarding Teams was made in accordance with the Initial Boarding Plan, Reference 30. However, the compositions of the teams were tailored to the nature of each day’s operations.

In addition, salvage and firefighting teams from Task Unit 1.2.7 were embarked in vessels carrying Initial Boarding Teams.

2) Target Ship Crew Inspection Parties

The crew of each target ship was divided into four teams. Teams A, B, and C were headed by the commanding officer, engineering officer, and executive officer, respectively. Team A was to make a complete survey of the ship’s superstructure. Team B would open the interior of the ship and make it habitable if possible. Team C would reactivate the administration functions, and team D, the remaining ship’s personnel, would remain the ship. These parties included any Army personnel attached to the target ships.

3) Boarding Inspection Parties from the DSM Staff

These boarding parties were comprised of technical personnel on the DSM staff, many of whom were located on the USS WHARTON. These included Army, BuAir, BuShips, BuOrd, BuMed and BuShips electronics personnel.
Section 4
DOSE RECONSTRUCTION

Operations within Bikini Lagoon after the ABLE and BAKER shots were complicated not only by a complex radiological environment, but also because the unexpectedly high radiation levels from Shot BAKER necessitated revisions of the operation plans. The planned ship movements were revised on an ad hoc basis, and detailed reports are subsequently fragmentary. Central to the reconstruction of the dose to a crew is the knowledge of the vessel’s path. This path must then be correlated with the radiological environment, which itself was changing with time due to radioactive decay and physical transport in the water.

Three sources of radiation are considered significant in this analysis. Each was present to various degrees after the ABLE and BAKER shots. Sources considered are:

1) Radioactivity in the lagoon water. Analysis of the radioactivity of neutron-activated seawater after Shot ABLE is described in Section 2.1. Estimation of the radiation intensities from water contaminated by weapon debris after Shot BAKER is described in detail in Section 2.3. Occasionally it was reported that various support ships passed through radioactive “hot” spots. Most of these hot spots were oil slicks encountered by destroyers on patrol north of the lagoon, and therefore not included in the water activity model. Doses from these sources are estimated from measured or assumed intensities and durations in these locations. In calculating shipboard doses, the water is treated as an infinite plane, and shielding by the ship structure is assumed negligible for topside exposures.

2) Radioactivity on target ships. Separate models are constructed for Shots ABLE and BAKER. Since there was essentially no local fallout for ABLE, only the neutron activation of the target ships is considered for this shot. The analysis of this radiation source is developed in Section 2.2. The residual activity of target ships is more complex for Shot BAKER, because of the radioactive weapon debris that was deposited on many of the target ships. Since there is an abundance of radiological data available for the BAKER target vessels, an empirical, vice
theoretical approach is taken. From reported readings, time-dependent gamma intensity curves for target ships of interest are developed, as explained in Section 2.4. Three curves for each target vessel cover most operational situations regarding close encounters of non-target support ships and crews with target vessels. When available, the effects of target ship decontamination are shown on the gamma intensity curves. These curves apply to the following locations:

a) Topside on the target vessel. This curve describes the average topside intensity that was present on the upper exposed decks of a target vessel. This curve is applicable to boarding parties working topside on target ships.

b) Below decks on a target vessel. This curve is applicable whenever personnel were below decks. Its use requires a determination of the time spent below decks for parties operating aboard.

c) Moored alongside a target vessel while conducting reboarding, damage control or scientific operations. The amidships curve for the target ship describes the radiation intensity that existed near (6 feet) the side of a target vessel.

In addition to these encounters with target ships, there were occasional reports of various support ships passing near (within approximately 100 feet) radioactive target ships and measuring intensities. Doses accrued during such maneuvers are estimated from the reported intensities and an assumed exposure duration of three minutes.

3) Contamination buildup on ships operating in contaminated water. For target and non-target ships operating in the lagoon, radioactivity began to accumulate on those surfaces in contact with the contaminated water. The areas of greatest concern were the exterior hull at or below the water line, salt water piping, and the condensers/evaporators of the ships. The method developed to estimate dose contributions from these sources is described in Section 2.5.

The radiation environments described in Section 2 are free-field intensities. A conversion factor from free-field dose to film badge dose, 0.7 for a properly worn film

66
badge (Reference 26), is applied to all free-field doses. It is also necessary to consider personnel activity aboard a ship. A typical sailor will not be fully exposed to all radiation sources at the same time. Specifically, the water intensity contributed to the dose of a sailor topside, but the self-shielding of the water and shielding by ship structural material greatly reduced this contribution below decks. Similarly, the ship contamination dose contributed significantly to doses accrued below decks, but probably contributed negligibly topside. In computing total doses, it is assumed that the average sailor spent 8 hours daily topside, and 16 hours below decks. Therefore, 24-hour water doses are multiplied by $1/3$, and 24-hour ship contamination doses by $2/3$, to determine the total dose for a typical sailor.

4.1 Computerized Methodology

The radiation environments described in Section 2 essentially define the gamma intensity in the lagoon as a function of position and time. The calculation of a ship’s free-field dose can be obtained by correlating the unit’s maneuver history with the radiation environment. A computerized methodology has been developed which allows input of ship path data and calculates the doses accrued by shipboard personnel from the previously described radiation sources. Figure 4-1 shows the reconstruction of a hypothetical ship’s movement and the manner in which it is represented in this computer model. The lagoon is divided into 1000-yard grid squares, each assigned a unique number. Each grid square is subdivided into 200-yard squares. This coordinate system, used during the operation, allows the positioning of a unit to within 200 yards through the use of a five-digit alpha-numeric code. For example, the surface zeroes for Shots ARLE and BAKER were 2101L and 2201K, respectively. Figure 4-1 shows the input positions and four intermediate positions interpolated by computer on a three-minute basis. Straight-line interpolation between known position points is used, and incremental doses are calculated from the local radiation intensity and the size of the time step. The values of gamma intensity in the post-BAKER environment are stored for each grid square in the lagoon for each of six days (B+1 through B+5, and B+8) following the detonation. Linear interpolation in time between these data sets is employed. The post-ABLE water environment is described in the computer code by the mathematical expression developed in Section 2. A computer program calculates
Figure 4-1  Ship Position Calculation
water doses through ABLE plus 3 days and BAKER plus 8 days. Doses from target ships and ship contamination are calculated on a daily basis until departure from the lagoon.

4.2 Program Descriptions/Listings

A series of programs has been developed to perform these calculations and to provide various bookkeeping functions. A description of each program and its listing are included in this section. The following programs are included:

- INPUT PATH
- INPUT PASSING SHIP DOSE
- WATER INTENSITY
- LATE WATER
- TARGET INTENSITY
- SHIP CONTAMINATION
- RADIATION REPORT
- UPDATE
- UPDATE TARGET SHIPS
- UPDATE PASSING SHIP DOSE
- PATH REPORT
- UPDATE SHIP CONTAMINATION
Program: INPUT PATH

Program objective: To create files that define a ship’s location in Rikiri Lagoon as a function of time.

Description: The path is input as a set of discrete data points. Each data point includes a time, a place, and an indicator of the ship’s proximity to any target ships. The time is input in days, hours, and minutes, e.g., 031650 is the 3rd of July at 1650. The place is input using the coordinate system described in Figure 4-1. The target ship proximity is indicated by the letters P, A, L, or N, where P = passing, A = alongside, L = leaving, and N = not near a target ship. All codes except N are then followed by the name of the target ship. This information is stored in a file created for each ship.

After this information is input, there is the option of supplying the doses received when passing radioactive target ships. This option need not be selected - a separate program can be used to input the passing numbers at a later time. See INPUT PASSING SHIP DOSE.

Input: Terminal input of a sequence of values for time, place and target ship proximity.

Output: File “ship” PATH containing path information
File “ship” PASSES with passing dose information
Table 4-1 Input Path

10 HOME
20 DIM PLACE$(300); TIME$(300); SHIP$(300)
30 PRINT:
40 PRINT "THIS PROGRAM CREATES A FILE WHICH"
50 PRINT "CONTAINS THE HISTORY OF THE PATH"
60 PRINT "OF A SHIP"
70 PRINT
80 INPUT "NAME OF SHIP ?": Y$  
90 Z$ = Y$ + " PATH"
100 PRINT
110 PRINT "EACH DATA POINT CONSISTS OF A TIME"
120 PRINT "IN THE FORM DHHMM AND THEN A"
130 PRINT "POSITION LIKE 2581K"
140 PRINT "AND THEN A SHIP CODE BEGINNING"
150 PRINT "WITH M, L, A, OR P, WITH ALL BUT M A SHIP NAME FOLLOWS"
160 PRINT:
170 PRINT "HIT RETURN WHEN DONE"
180 PRINT
190 FOR I = 1 TO 300
200 GOSUB 3500
210 IF A1$ = CHR$(13) THEN 290
220 GOSUB 4500
230 GOSUB 4500
240 IF SHIP$(I) = CHR$(13) THEN  
250 SHIP$(I) = "M"
260 NEXT I
270 PRINT "ONLY FIRST 300 POINTS USED"
280 PRINT CHR$(7); CHR$(7); CHR$(7)
290 M = I - 1
300 D$ = CHR$(4)
310 PRINT D$; "OPEN \"Z\"; D2"  
320 PRINT D$; "DELETE \"Z\""  
330 PRINT D$; "OPEN \"Z\""  
340 PRINT D$; "WRITE \"Z\""  
350 PRINT N + 1
360 FOR I = 0 TO N
370 PRINT TIME$(I)
380 PRINT PLACE$(I)
390 PRINT SHIP$(I)
400 NEXT I  
410 PRINT D$; "CLOSE \"Z\""
420 PRINT "CREATE PASSING SHIP DOSE FILE NOW?"
430 :GET #1:
440 PRINT #1:
450 IF # > "Y" THEN 570
460 DIM FM#(#), FN#(#), P#(#)
470 FOR I = 0 TO NTIMES - 1
480 IF T# = "A" THEN
490 GOTO 560
500 IF T# = "B" THEN
510 L = INT(SH#(I)
520 SH#(I) = SH#(I) + L
530 IF T# = "P" THEN
540 GOSUB 730
550 IF TEST = 0 THEN
560 GOSUB 220
570 TEST = 0
580 NEXT I
590 Z# = X# + \ "PASSES"
600 PRINT D#; OPEN "Z\#", 02
610 PRINT D#; DELETE#1
620 PRINT D#; OPEN "Z#"
630 PRINT D#; WRITE "Z#"
640 PRINT PASSES
650 IF PASSES = 0 THEN 680
660 FOR I = 1 TO PASSES
670 PRINT PTIME#(I)
680 PRINT FN#(I)
690 PRINT P#(I)
700 NEXT I
710 PRINT D#; CLOSE "Z#"
720 PRINT D#; "PASSES = "
730 PRINT D#; "P#(I)"
740 PRINT D#; "P#(I)"
750 PRINT D#; "P#(I)"
760 PRINT D#; "P#(I)"
770 PRINT D#; "P#(I)"
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218 PRINT D#; "P#(I)"
870 IF LEFT$(A#1) = "Y" THEN
    PRINT D$:"RUN MENU.D1"
880 PRINT "ERROR TERMINATION: RETURNING TO BASIC"
900 PRINT "TYPE CONT TO RESTART PROGRAM"
920 END
910 POKE 51;128:
    GOTO 450
3500 PRINT "TIME "";
    GET A1$:
    PRINT A1$;
3600 IF A1$ = CHR$(13) THEN
    RETURN
3710 GET A2$:
    PRINT A2$;
    IF A2$ = CHR$(13) THEN
        GET A1$:
        PRINT A1$:
        GOTO 3600
3720 GET A3$:
    PRINT A3$:
    IF A3$ = CHR$(13) THEN 3710
3730 GET A4$:
    PRINT A4$:
    IF A4$ = CHR$(13) THEN 3720
3740 GET A5$:
    PRINT A5$:
    IF A5$ = CHR$(13) THEN 3730
3750 GET A6$:
    PRINT A6$:
    IF A6$ = CHR$(13) THEN 3740
3800 TIME$(I) = A1$ + A2$ + A3$ + A4$ + A5$ + A6$ + A7$
3500 RETURN
4000 PRINT "PLACE "";
    GET A1$:
    PRINT A1$:
4010 GET A2$:
    PRINT A2$:
    IF A2$ = CHR$(13) THEN
        GET A1$:
        PRINT A1$:
        GOTO 4010
4020 GET A3$:
    PRINT A3$:
    IF A3$ = CHR$(13) THEN 4010
4030 GET A4$:
    PRINT A4$:
    IF A4$ = CHR$(13) THEN 4020
4040 GET A5$:
    PRINT A5$:
    IF A5$ = CHR$(13) THEN 4030
4100 PLACE$(I) = A1$ + A2$ + A3$ + A4$ + A5$
4200 RETURN
4500 PRINT " SHIP "";

73
4501  GET T1$:
        PRINT T1$:
4502  IF T1$ = CHR$(13) THEN
        T1$ = "M"
        GOTO 4504
4503  INPUT "";T2$
        T2$ = T1$ + T2$
4510  L = LEN (T2$)
4515  T1$ = LEFT$(T2$,1)
4520  IF T1$ = "M" THEN 4600
        IF L > 1 THEN 4560
4550  FLASH :
        PRINT "BAD INPUT; TRY AGAIN"
        NORMAL :
        GOTO 4500
4560  IF T1$ = "L" THEN 4600
4570  IF T1$ = "P" THEN 4600
4580  IF T1$ = "A" THEN 4600
4590  GOTO 4550
4600  SHIP$ (I) = T2$
4700  RETURN
Program: INPUT PASSING SHIP DOSE

Program Objective: To create a file containing information on the radiation dose received while “passing” radioactive ships.

Description: Program cycles through the PATH file to locate passing code "P". For each occurrence as noted below, the dose received from passing a target ship is calculated. This dose, along with the time of occurrence and the name of the radioactive ship, is then inputed and saved in a new data file. This file is subsequently used as input for the Radiation Report.

Input: File “ship” PATH from INPUT PATH.
Terminal input for dose received from passing ships (in mR).

Output: File “ship” PASSES containing passing ship dose information.

Note: This program is used only to create a new file. It need not be used if a file was created while running INPUT PATH. UPDATE should be used to modify an existing file. This file is created for every situation where a time and intensity are reported for a ship passing a radiation source.
<table>
<thead>
<tr>
<th>Line</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>D1 = CHR$(44)</td>
</tr>
<tr>
<td>20</td>
<td>PRINT D1:CHR$(34)</td>
</tr>
<tr>
<td>30</td>
<td>DIM RIDE$(300),PHRMS$(300),PTIME$(300)</td>
</tr>
<tr>
<td>40</td>
<td>DIM PLACE$(300),TIME$(300),SHIP$(300)</td>
</tr>
<tr>
<td>50</td>
<td>INPUT &quot;NAME OF SHIP &quot;:X$</td>
</tr>
<tr>
<td>60</td>
<td>X$ = &quot;PATH&quot;</td>
</tr>
<tr>
<td>70</td>
<td>PRINT DEF:OPEN &quot;+D1&quot;:D2</td>
</tr>
<tr>
<td>80</td>
<td>PRINT D1:READ &quot;+D1</td>
</tr>
<tr>
<td>90</td>
<td>INPUT NTIME$</td>
</tr>
<tr>
<td>100</td>
<td>FOR I = 0 TO NTIME$ - 1</td>
</tr>
<tr>
<td>110</td>
<td>L = TIME$(I),PLACE$(I),SHIP$(I)</td>
</tr>
<tr>
<td>120</td>
<td>NEXT I</td>
</tr>
<tr>
<td>130</td>
<td>PRINT D1:CLOSE &quot;+D1</td>
</tr>
<tr>
<td>140</td>
<td>IF NTIME$ &lt; 2 THEN 9000</td>
</tr>
<tr>
<td>150</td>
<td>FOR I = 0 TO NTIME$ - 1</td>
</tr>
<tr>
<td>160</td>
<td>TS = LEFT$(SHIP$(I),1)</td>
</tr>
<tr>
<td>170</td>
<td>IF TS = &quot;A&quot; THEN</td>
</tr>
<tr>
<td>180</td>
<td>GOTO 200</td>
</tr>
<tr>
<td>190</td>
<td>IF TS = &quot;M&quot; THEN</td>
</tr>
<tr>
<td>200</td>
<td>GOTO 240</td>
</tr>
<tr>
<td>210</td>
<td>IF TS = &quot;L&quot; THEN</td>
</tr>
<tr>
<td>220</td>
<td>GOTO 240</td>
</tr>
<tr>
<td>230</td>
<td>L = LEN(SHIP$(I)) - 1</td>
</tr>
<tr>
<td>240</td>
<td>SHIP$(I) = RIGHT$(SHIP$(I),L)</td>
</tr>
<tr>
<td>250</td>
<td>IF TS = &quot;P&quot; THEN</td>
</tr>
<tr>
<td>260</td>
<td>GOSUB 410</td>
</tr>
<tr>
<td>270</td>
<td>IF TEST = 0 THEN</td>
</tr>
<tr>
<td>280</td>
<td>GOSUB 900</td>
</tr>
<tr>
<td>290</td>
<td>TEST = 0</td>
</tr>
<tr>
<td>300</td>
<td>NEXT I</td>
</tr>
<tr>
<td>310</td>
<td>Z$ = X$ + &quot; PASSES&quot;</td>
</tr>
<tr>
<td>320</td>
<td>PRINT D1:OPEN &quot;+Z1&quot;:D2</td>
</tr>
<tr>
<td>330</td>
<td>PRINT D1:DELETE&quot;Z1</td>
</tr>
<tr>
<td>340</td>
<td>PRINT D1:OPEN &quot;+Z1</td>
</tr>
<tr>
<td>350</td>
<td>PRINT D1:WRITE &quot;+Z1</td>
</tr>
<tr>
<td>360</td>
<td>PRINT PASSES</td>
</tr>
<tr>
<td>370</td>
<td>IF PASSES = 0 THEN 120</td>
</tr>
<tr>
<td>380</td>
<td>FOR I = 1 TO PASSES</td>
</tr>
<tr>
<td>390</td>
<td>PRINT TIME$(I)</td>
</tr>
<tr>
<td>400</td>
<td>PRINT PHRMS$(I)</td>
</tr>
<tr>
<td>410</td>
<td>PRINT PASSES</td>
</tr>
<tr>
<td>420</td>
<td>NEXT I</td>
</tr>
<tr>
<td>430</td>
<td>PRINT D1:CLOSE &quot;+Z1</td>
</tr>
</tbody>
</table>

---

Table 4-2: Input Passing Ship Dose
380    PRINT D$;"NOMON,C"
390    PRINT D$;"PRI0"
400    PRINT D$;"RUN MENU;D1"
410    PRINT TIME$(I);" PASSING ";SHIP$(I)
420    INPUT * DOSE = ? *;D
430    PRINT
440    PASSES = PASSES + 1
450    TIME$(PASSES) = TIME$(I)
460    NAME$(PASSES) = SHIP$(I)
470    POSE$(PASSES) = D
480    TEST = 1:
        RETURN
490    RETURN
500    PRINT "ERROR IN PATH FILE(HOT N,L,P,A)"
510    PRINT TIME$(I),PLACE$(I),SHIP$(I)
520    PRINT "DO YOU WANT TO CONTINUE? ":
530    GET A$:
        PRINT A$:
        IF A$ = "Y" THEN
            RETURN
540    PRINT "WANT TO GO TO MENU ?";A$:
550    IF LEFT$(A$,1) = "Y" THEN
            PRINT D$;"RUN MENU;D1"
560    PRINT "ERROR TERMINATION, RETURNING TO BASIC"
570    PRINT "TYPE CONT TO RESTART PROGRAM"
580    END
590    POKE 51,120:
600    GOTO 59
6000   PRINT "NOT ENOUGH DATA, ONLY ";NTIMES;" POINTS"
6010   GET A$:
        PRINT :
        PRINT D$;"RUN MENU;D1"
Program: WATER INTENSITY

Program Objective: To estimate the doses accrued by support ship personnel from radioactive water sources during post-ABLE and post-BAKER operations.

Description: The program first calculates doses from the Shot ABLE water environment, and then from the BAYER environment.

Shot ABLE

The intensity at time t after detonation and distance r from surface zero is determined from the equation

\[ I(r,t) = t^{3/2} \exp\left[-4.56 \times 10^{-6} \left( \frac{r^2}{t}\right) - 0.0462 t + 0.503\right], \]

where t is in hours, r in meters, and I in R/hr. This pattern drifts 900 meters per 24 hours on an azimuth of 10° east of north. The derivation of this model is discussed in Section 2-1.

Dose increments are calculated every 3 minutes while the vessel was in water with intensity greater than 0.01 R/day, as predicted by the water intensity model. The 3-minute time step can be changed by a single line program change (change value of \( S1T \) in first line of program). To decrease the execution time, the radius at which the intensity mathematically becomes less than 0.01 R/day was calculated for each hour, and is input via data statements. If the ship’s radius is greater than this radius, no calculation is required.

As the program executes, any time interval for which the intensity exceeds 0.1 R/day is printed out. The accumulated dose for each hour is calculated and the first 72 hourly doses stored in the file "ship" WATER.
Shot BAKER

For Shot BAYER, the water intensity data base consists of the intensities at six different times (28, 50, 78, 100, 129, and 200 hours after detonation) for each of the thousand-yard grid squares in the lagoon. The values of intensity in the data base are in arbitrary units. To convert to R/hr, these values are divided by the following scale factors, which were derived from the contours in Reference 12 and the red-blue line data (see Section 2.3).

<table>
<thead>
<tr>
<th>Time</th>
<th>Scale factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 hrs</td>
<td>10</td>
</tr>
<tr>
<td>50</td>
<td>15</td>
</tr>
<tr>
<td>78</td>
<td>100</td>
</tr>
<tr>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>120</td>
<td>100</td>
</tr>
</tbody>
</table>

Linear interpolation in time is used to estimate intensities at other times.

Spatial and time interpolation along a ship path is performed in three-minute time steps (this can be changed by changing the value of SBT in the second line of the program). First, the position of the ship is determined by linear interpolation between two data points in the ship's PATH file. Then the intensity at the ship's position is determined by linear interpolation in time of the intensities of the appropriate grid square appearing in the RAKER data base.

Any calculated intensities above 0.1 R/day are printed out. The dose increments are added to determine hourly totals, and the hourly dose for each of the first 290 hours is written to the file "ship" WATER.

Note that this program does not include water dose contributions from BAKER day operations. These must be calculated and input separately.
Input: File “ship” PATH

Output: File “ship” WATER

Intensities greater than 0.1 R/day, and the dose for each hour for both ABLE and BAKER (excluding BAKER day).
Table 4-3 Water Intensity

60 SLT = 3
70 SBT = 3
80 HOME: VTAB 8
100 PRINT "DO YOU WANT TO USE THE PRINTER?";
110 GET A$: PRINT A$
111 IF A$ = "Y" THEN PRINT "WHAT SLOT IS THE PRINTER IN?";
: GET P$: PRINT P$
112 IF A$ = "Y" AND P$ > "3" OR A$ = "Y" AND P$ < "1" THEN
80
120 PR = 0: IF A$ = "Y" THEN PR = 1
130 D$ = CHR$(13) + CHR$(4): REM CTRL-M + CTRL-D
400 DIM X2(24), Y2(24), RO(72)
410 DIM PLACE$(300), TIME$(300)
415 DIM SHIP$(300)
420 DIM DOSE$(300)
450 INFUT "NAME OF SHIP "; X$: Z$ = X$ + "FATH"
460 PRINT D$; "OPEN "; Z$; D2"
470 PRINT D$; "READ "; Z$
480 INFUT NTIMES
490 FOR I = 0 TO NTIMES - 1
500 INFUT TIME$(I), PLACE$(I), SHIP$(I)
510 NEXT
520 PRINT D$; "CLOSE "; Z$
530 IF NTIMES < 2 THEN PRINT "NOT ENOUGH DATA, ONLY "; NTIMES; "FONTS": END
1000 REM ****************************
1005 REM *
1010 REM * ABLE ACTIVATION *
1015 REM *
1020 REM ****************************
1025 CS = .98481
1026 SI = .17365
1027 DRFT = 1000 / 24
1030 TZERO = .51
1040 A1 = -4.56 * 10^-6
1050 A2 = -3.0462
1060 A3 = 0.503
1070 DEF FN ACT(T) = EXF(A1 * T + A2 * T + A3) / (T * SQRT(T))
1080 S = SLT
1085 REM READ IN GROUND ZERO. & TIME FOR ABLE
1090 READ XO, YO, TO
1100 DATA 21200, 0400, 33
1105 REM READ IN CODES FOR GRID SQUARES
1110 REM READ IN WHAT CODES STAND FOR IN RECTANGLES
1120 FOR I = 0 TO 24: READ X2(I), Y2(I): NEXT
1130 DATA 0.0, 200, 0, 400, 0, 600, 0, 800, 0
1140 DATA 0, 200, 200, 200, 400, 200, 600, 200, 800, 200
1150 DATA 0,400,200,400,400,400,600,400,800,400
1160 DATA 0,600,200,600,400,600,400,600,600,800,600
1170 DATA 0,800,200,800,400,800,600,800,600,800,800
1175 REM READ IN DISTANCE TO ZERO RADIATION
1180 FOR I = 0 TO TZERO: READ H(I): NEXT I
1190 DATA 1344,1771,2067,2298,2487,2646
1200 DATA 2783,2901,3004,3095,3176,3246
1210 DATA 3308,3362,3408,3448,3481,3509
1220 DATA 3531,3547,3558,3564,3565,3565
1230 DATA 3553,3540,3522,3499,3472,3440
1240 DATA 3403,3360,3313,3261,3202,3139
1250 DATA 3069,2992,2908,2817,2718,2610
1260 DATA 2491,2360,2215,2054,1871,1660
1270 DATA 1409,1089,601,409,1409,1089,601
1290 GOTO 1530
1295 REM SUBROUTINE TO GET TIME
1300 DAY = VAL (LEFT$(TIME$(I),2))
1310 HOUR = VAL (MID$(TIME$(I),3,2))
1320 MINUTE = VAL (RIGHT$(TIME$(I),2))
1330 MINUTE = ST * INT ((MINUTE + ST / 2) / ST)
1340 T = (24 * DAY + HOUR + MINUTE / 60) * TO
1350 RETURN
1355 REM SUBROUTINE TO GET POSITION FOR ABLE
1360 CODE = ASC (RIGHT$(PLACE$(I),1)) - 65
1370 IF CODE > 24 THEN PRINT CODE
1380 X = 1000 * VAL (LEFT$(PLACE$(I),2)) + X2(CODE) - XO
1390 Y = VAL (MID$(PLACE$(I),3,2)) + Y2(CODE) - YO
1400 IF Y > 50 THEN Y = Y - 100
1410 Y = 1000 * Y - Y2(CODE) - YO
1412 REM INCORPORATE DRIFT
1415 X9 = X - SI * DRFT * T
1416 Y9 = Y - CS * DRFT * T
1420 R = SQRT (X9 * X9 + Y9 * Y9)
1430 R = R *.9144
1440 RETURN
1530 IF PR = 1 THEN PRINT D$;"PR#";P$
1535 PRINT : PRINT
1540 IF PR < > 1 THEN HOME
1550 PRINT "RUNNING ABLE WATER ACTIVATION"
1560 PRINT "FOR"
1570 PRINT "FLASH : F'PRINT X$; NORMAL"
1580 PRINT : POKE 34,4
1590 I = 0
1600 GOSUB 1300
1605 IF T < O THEN I = I + 1: GOTO 1600
1610 IF T > TZERO THEN GOTO 1980
1614 PRINT "TIME", "PLACE"
1615 PRINT "HOURS AFTER", "X-GRID(YD)", "Y-GRID(YD)", "RADIUS (M)", "DOSE RATE (R/HR)"
1620 GOSUB 1360
1630 XI = X:YI = Y:R1 = R:T1 = T
1640 I = I + 1
1650 GOSUB 1300: GOSUB 1360
1660 PRINT TIME$(I - 1), PLACE$(I - 1)
1665 REM INTERPOLATE BETWEEN DATA POINTS
1670 N = (T - T1) / (ST / 60): IF N < 1 THEN N = 1
1690 I1 = INT(T1); I2 = INT(T)
1740 TX = (X - X1) / N; TY = (Y - Y1) / N
1770 FOR J = 1 TO N
1780 X = X1 + J * TX
1790 Y = Y1 + J * TY
1800 T = T1 + J * ST / 60
1875 REM INCORPORATE DRIFT
1876 X9 = X - SI * DRFT * T
1877 Y9 = Y - CS * DRFT * T
1878 R = SRR (X9 * X9 + Y9 * Y9)
1879 REM CONVERT TO YARDS
1880 R = R * 9144
1975 IF TI > TZERO THEN 1980
1980 IF R > RO(TI) THEN 1860
1980 D = FN ACT(T)
1980 DOSE(TI) = DOSE(TI) + D
1980 IF D > 0.004 THEN PRINT T, X, Y, R, D
1980 NEXT
1975 IF I = 72 OR I = NTIMES - 1 OR T > TZERO THEN 1980
1980 GOT0 1630
1980 PRINT TIME$(I), PLACE$(I)
1987 IF I = 0 THEN 2020
1989 REM ABLE 0-72 ALWAYS
1990 FOR L = 0 TO 72
1995 DOSE(L) = DOSE(L) / (60 / ST)
2000 IF PR < 0 THEN PRINT L, DOSE(L)
2010 NEXT
2020 PRINT "DONE WITH ABLE ACTIVATION"
4900 REM *******************
4910 REM *
4920 REM * BAKER CONTAMINATION *
4930 REM *
4940 REM *******************
5000 ST = SBT
5020 REM BAKER AT 830 JULY 25
5025 REM TSTART IS MIDNIGHT, THE BEGINNING OF THE 26TH OF JULY
5030 TO = 608.5
5040 TSTART = 624 - TO
5070 TLAST = 208
5075 REM H IS HOURS TO DATA FOR BAKER
5076 REM F IS SCALE FACTOR FOR DATA SET AT TIME H
5080 H(0) = 28; F(0) = 10
5090 H(1) = 50: F(1) = 15
5100 H(2) = 78: F(2) = 100
5110 H(3) = 100: F(3) = 50
5120 H(4) = 120: F(4) = 100
5130 H(5) = 216: F(5) = 0
5140 H(6) = H(0): H(1) = H(2): H(3) = H(4)
5150 PRINT D$: "OPEN BAKER, L3, D1"
5155 REM READ IN SURFACE ZERO
5160 READ X0, Y0
5170 DATA 22, 1
5180 GOTO 5300
5240 REM SUBROUTINE TO GET FLACE FOR BAKER
5250 x = VAL(LEFT$(FLACE$(I), 2))
5260 IF X > 50 THEN X = X - 100
5270 Y = VAL(MID$(FLACE$(I), 3, 2))
5280 IF Y > 50 THEN Y = Y - 100
5281 CODE = ASC(RIGHTS(FLACE$(I), 1)) - 65
5282 X = X + X2(CODE)/1000.
5283 Y = Y + Y2(CODE)/1000.
5290 RETURN
5300 IF FR = 0 THEN HOME
5310 VTAB 1
5320 PRINT "RUNNING BAKER WATER CONTAMINATION"
5321 PRINT " FOR"
5322 PRINT " ; FLASH : PRINT X9: NORMAL"
5330 VTAB 5
5333 PRINT "TIME", "FLACE"
5335 PRINT "HOURS AFTER", "X-GRID", "Y-GRID", "DOSE RATE (R/DAY)"
5340 IF I > NTIMES - 1 THEN 5910
5350 GOSUB 1300
5360 IF T > TLAST THEN GOTO 5910
5370 IF T < TSTART THEN I = I + 1: GOTO 5350
5380 GOSUB 5250
5390 X1 = X: Y1 = Y: T1 = T
5400 I = I + 1
5410 IF I > NTIMES - 1 THEN 5910
5420 GOSUB 1300: GOSUB 5250
5430 PRINT TIME$(I - 1), PLACE$(I - 1)
5440 N = (T - T1) / (ST / 60): IF N < 1 THEN N = 1
5470 IF PLACE$(I) = PLACE$(I - 1) THEN 5580
5480 TX = (X - X1) / N: TY = (Y - Y1) / N
5490 FOR J = 1 TO N
5500 X = X1 + J * TX
5510 Y = Y1 + J * TY
5520 T = T1 + J * ST / 60
5530 IF T > TLAST THEN 5910
5550 GOSUB 5650
5560 NEXT
5570 GOTO 5390
FOR J = 1 TO N
T = TI + J * ST / 60
IF T > TLAST THEN 5910
NEXT
GOSUB 5650

REM SUBROUTINE TO GET DATA BETWEEN POINTS
X9 = 29 - INT (X)
Y9 = INT (Y + 10)
R = 45 * Y9 + X9
IF T > H8 THEN 5720
IF R = R1 AND K = K1 THEN 5820
GOSUB 5880
D8 = D9
GOTO 5820
IF T < H9 THEN 5720
H1 = H9: K = K + 1: H9 = H(K + 1)
R = R + K * 1125
IF T = H8 + ST / 60 THEN R1 = 0
IF R = R1 AND K = K1 THEN 5810
GOSUB 5880
D1 = D9
D8 = D9
RETURN
REM SUBROUTINE TO READ DOSE FOR POSITION FROM RANDOM ACCESS FILES
IF F(K) < > 0 THEN 5885
IF SQR ((X - XO) ^ 2 + (Y - YO) ^ 2) > 5.58 THEN D9 = 0: RETURN
D9 = .069
RETURN
PRINT D$: "READ BAKER,R"; R
INPUT D9
D9 = D9 / F(K)
RETURN
PRINT D$: "CLOSE BAKER"
PRINT TIME$(I); PLACE$(I)
Z$ = X$ + "WATER"
FOR I = 73 TO TLAST + 73
5940 DOSE(I) = DOSE(I) / (60 / ST)
5950 NEXT
5960 PRINT D$; "OPEN "; Z$; ",D2"
5970 PRINT D$; "DELETE "; Z$
5980 PRINT D$; "OPEN "; Z$
5990 PRINT D$; "WRITE "; Z$
6000 PRINT TLAST + 72
6005 REM O-72 ARE FOR BAKER
6006 REM 73 TO TLAST ARE FOR BAKER
6010 FOR I = 0 TO TLAST + 72
6020 PRINT DOSE(I)
6030 NEXT
6040 PRINT D$; "CLOSE "; Z$
6050 POKE 34,0
6060 IF PR = 0 THEN 6110
6070 FOR I = 73 TO TLAST + 72
6080 PRINT I - 73, DOSE(I)
6090 NEXT
6100 PRINT D$; "PR#0"
6110 PRINT D$; "RUN MENU,D1"
Program: LATE WATER

Program Objective: To allow input of manually obtained ship’s late lagoon water dose; late water dose is that dose received after BAKER + 8.

Description: This program accepts inputs from the keyboard to daily lagoon water dose received after BAKER + 8. The daily doses, having been determined in a separate analysis, are input and edited by this program. The “late water” file created is a continuation of the “water” file created by program WATER INTENSITY. Both the WATER and LATE WATER files are read by program SHIP CONTAMINATION.

Input: From keyboard, daily doses

Output: File "ship" LATE WATER
REM THIS PROGRAM CREATES OR EDITS
REM THE LATE WATER DOSE FILE
D$ = CHR$ (4)
DIM H30 (100)
HOME
INPUT "EDIT(E) OR CREATE(C) WATER DOSE FILE?"; A$
IF A$ = "E" THEN GOTO 400
IF A$ = "C" THEN GOTO 190
PRINT "ENTER "E" FOR EDIT OR "C" FOR CREATE"
PRINT
GOTO 140
REM BEGIN CREATE SECTION
HOME : INPUT "NAME OF SHIP? "; X$
INPUT "HOW MANY DAYS TO INPUT? "; NDAYS
FOR I = 1 TO NDAYS
PRINT "ENTRY #"; I; "B+"; I + 8; " = "
HTAB 13
INPUT H30 (I)
NEXT
HOME : VTAB 5: HTAB 5
INPUT "DO YOU WANT TO CHANGE ANY VALUES? (Y/N) "; A$
IF A% = "Y" THEN GOTO 600
GOTO 800: REM WRITE OUTPUT FILE
REM INPUT DATA FOR EDITING
INPUT "NAME OF SHIP?"; X$
PRINT D8; "PR#O" 2% = X8 + "LATE WATER"
PRINT D9; "OPEN "; Z$; D2"
PRINT D$; "READ "; Z$
INPUT NDAYS
FOR I = 1 TO NDAYS
INPUT H30 (I)
NEXT
PRINT D$; "CLOSE "; Z$
REM EDIT PORTION OF PROGRAM
HOME : PRINT "CHANGE OR ADD VALUES?"; A$
IF A$ = "A" THEN GOTO 1400
IF A$ = "C" THEN GOTO 620
PRINT "ENTER C OR A": GOTO 611
HOME : REM FIRST LIST THE VALUES
PRINT "ENTRY"; TAB (12); "VALUE (MREM/DAY)"
FOR I = 1 TO NDAYS
PRINT I; TAB (5); "B+"; I + 8; TAB (12); " = "; H30 (I)
NEXT
PRINT : PRINT "ENTER 0 TO QUIT"
INPUT "WHICH ENTRY TO CHANGE? "; E1
675 IF El = 0 THEN GOT0 1400
680 PRINT "OLD VALUE FOR ENTRY ";E1;" = ";H30(E1)
690 PRINT
700 INPUT "INPUT NEW VALUE ";H30(E1)
710 HOME: INPUT "ANOTHER CHANGE? (Y/N) ";A$
720 IF A$ = "N" THEN GOT0 1400
730 IF A$ = "Y" THEN GOT0 620
740 PRINT: PRINT "ANSWER Y OR N": GOT0 710
800 REM WRITING THE OUTPUT FILE TO DISK
810 Z$ = X8 + " LATE WATER"
820 PRINT D$; "PR#0"
830 PRINT D$; "OPEN "; Z$; ",D2"
840 PRINT D$; "DELETE"; Z$
850 PRINT D$; "OPEN "; Z$
860 PRINT D$; "WRITE"; Z$
870 PRINT NDAYS
880 FOR I = 1 TO NDAYS
890 PRINT H30(I)
900 NEXT
910 PRINT D$; "CLOSE "; Z$
915 PRINT D$; "RUN MENU,D1"
920 END
1000 REM ROUTINE TO ADD ADDITIONAL DATA ENTRIES I.E. MORE DAYS
1010 HOME: INPUT "HOW MANY ADDITIONAL DAYS TO BE ENTERED? ";N2
1030 N3 = NDAYS + N2
1080 FOR I = NDAYS + 1 TO N3
1090 PRINT "ENTRY "; I; "; B+”; I + 8;” = ";
1100 INPUT H30(I)
1110 NEXT
1120 REM LIST THE INPUTED DATA
1130 HOME
1140 VTAB 3: HTAB 10
1150 PRINT "THE NEW VALUES ARE"
1160 PRINT
1200 PRINT "ENTRY”; TAB (12); "VALUE (MR/DAY) ”
1210 FOR I = NDAYS + 1 TO N3
1220 PRINT I; TAB(5); "B+"; I + 8;” = "; TAB(12); H30(I)
1225 PRINT
1230 NEXT: PRINT "ENTER 0 TO QUIT"
1240 INPUT "WHICH ENTRY TO CHANGE? ";E1
1250 IF E1 = 0 THEN GOT0 800
1260 PRINT "OLD VALUE FOR ENTRY ";E1;" = ";H30(E1)
1270 PRINT
1280 INPUT "INPUT NEW VALUE ";H30(E1)
1290 HOME: INPUT "ANOTHER CHANGE? (Y/N) ";A$
1294 IF A$ = "Y" THEN GOT0 1120
1295 NDAYS = N3

89
1300 IF A$ = "N" THEN GOTO 800
1320 PRINT : PRINT "ANSWER Y OR N" : GOTO 1290
1400 HOME
1410 INPLOIFT "WANT TO ADD ANY ENTRIES? (Y/N)" ; A$
1420 IF A$ = "Y" THEN GOTO 1000
1430 IF A$ = "N" THEN GOTO 800
1440 PRINT "ENTER Y OR N" : GOTO 1410
Program: TARGET INTENSITY

Program Objective: To estimate the radiation dose received by support ship personnel while alongside or passing radioactive target ships--Shot RAKER only.

Description: As this program progresses through a ship path, two things are accomplished:

1. If the file indicates the support ship is alongside a target ship, the program calculates the radiation dose based upon the length of time alongside, the time after detonation, and the intensity of the particular target ship. The alongside target ship intensity $I$ at one hour after the shot is obtained from the file TARGET SHIPS. The dose is calculated from:

$$D = \frac{1}{3} \left( \frac{1}{t_1^3} - \frac{1}{t_2^3} \right),$$

where $t_1$ is the time the ship came alongside, and $t_2$ the time it departed; both times are measured in hours after detonation.

2. If the file indicates the support ship is passing a target ship, the dose for this pass from “ship” PASSES is added to the dose received in that hour.

The output is a file indicating dose for each hour attributable to contact with radioactive target ships.

Input: File TARGET SHIPS with alongside one-hour intensity for each target ship.
File “ship” PASSES with dose from passing target ships.
File “ship” PATY with the path of the ship.

Output: File “ship” TARGETS with hourly dose from all target ships.
Table 4-5  Target Intensity

1. REM ADOSE = ABLE TARGET INTENSITY
2. REM BDOSSE = BAKER TARGET INTENSITY
3. REM PDOSE = PASSING SHIP DOSE
4. REM NTIMES = LENGTH OF PATH
5. REM F'TIME = TIME PASSED TARGET SHIF
6. REM FNAME = TARGET SHIP F'ASSED AT F'TIME
7. REM NAME = NAME OF A TARGET SHIP FROM TARGET SHIP FILE
8. REM DO = INITIAL RADIATION FROM TARGET SHIF
9. HOME ;
10. VTab 8
11. D$ = CHR$ (4)
12. PRINT D$;'MON;C'
13. c = 0
14. PRINT 'TARGET INTENSITY PROGRAM':
15. PRINT
16. PRINT 'SEND TO PRINTER ';:
17. GET A$
18. PRINT A$
19. IF A$ = 'Y' THEN
20. PRINT 'WHAT SLOT IS THE PRINTER IN?';:
21. GET P$;
22. PRINT P$
23. HOME ;
24. 'JTAE 8:
25. GOTO 50
26. DIM ADOSE(25),BDOSSE(300)
27. DIM PDOSE(300),FNAME$(300)
28. DIM PLACE$(300),TIME$(300),SHIP$(300)
29. DIM NAME$(90),DO(90)
30. INPUT 'NAME OF SHIP ';X$
31. F'PRINT D$;'OPEN TARGET SHIPS,D1'
32. F'PRINT D$;'READ TARGET SHIPS'
33. INPUT NSHIPS
34. FOR I = 1 TO NSHIPS
35. INPUT NAME$(I),DO(I)
36. NEXT I
37. PRINT D$;'CLOSE TARGET SHIPS'
38. Z$ = X$ + T 'PATH'
39. PRINT D$;'OPEN 'z$';D2'
40. F'PRINT D$;'READ 'z$
41. INPUT NTIMES

92
260 FOR I = 0 TO NTIMES - 1
270 INPUT TIMES(I), PLACE$(I), SHIP$(I)
280 NEXT
290 PRINT D$; 'CLOSE ';$Z$
300 IF NTIMES < 2 THEN 9000
310 Z$ = X$ t ' PASSES'
320 PRINT D$; 'OPEN ';$Z$;'D2'
330 PRINT D$; 'READ ';$Z$
340 PRINT PASSES
350 IF PASSES = 0 THEN 390
360 FOR I = 1 TO PASSES
370 INPUT TIME$, PNAME$(I), PDATE(I)
380 NEXT I
390 PRINT D$; 'CLOSE ';$Z$
400 IF A$ = 'Y' THEN
410 PRINT D$; 'P$'
401 REM
402 REM N = NOT NEAR TARGET SHIP
403 REM L = LEAVING PROXIMITY OF TARGET SHIP
404 REM P = PASSING A TARGET SHIP
405 REM A = COMING ALONGSIDE A TARGET SHIP
406 REM
410 FOR I = 0 TO NTIMES - 1
420 T$ = LEFT$(SHIP$(I), 1)
430 IF T$ = 'N' THEN
440 GOTO 520
450 IF T$ = 'L' THEN
460 GOTO 520
470 L = LEN (SHIP$(I)) - 1
480 SHIP$(I) = RIGHT$(SHIP$(I), L)
490 GOSUB 3000
500 IF T$ = 'P' THEN
510 GOSUB 1000
520 IF T$ = 'A' THEN
530 GOSUB 2000
540 IF TEST = 0 THEN
550 GOSUB 4000
560 TEST = 0
570 NEXT I
580 REM
590 REM FIND LAST TIME RECEIVED DOSE FROM A TARGET SHIP
600 REM
610 FOR I = 300 TO 0 STEP - 1
620 IF DOSE(I) < 0 THEN 570
630 NEXT I
640 PRINT 'NO DATA FOUND FOR BAKER'
650 NEXT I
660 PRINT D$; 'OPEN ';$Z$;'D2'
670 PRINT D$; 'DELETE ';$Z$
680 PRINT D$; 'WRITE ';$Z$
690 FOR J = 0 TO 24
700 PRINT ADOS(J)
710 NEXT J
650 PRINT I \ t 1
660 FOR J = 0 TO I
670 PRINT BDOS(J)
680 NEXT J
690 PRINT D$; 'CLOSE ';Z$
700 PRINT D$; 'NOMON, C'
710 PRINT D$; 'PR$0'
720 PRINT D$; 'RUN MENU, D1'
730 REM
740 REM SUBROUTINE TO GET DOSE FROM PASSING TARGET SHIFTS
750 REM
760 PRINT TIME$(I); ' PASSING '; SHIP$(I);
770 C = C + 1
780 REM
790 REM MATCH FATH AND PASSES FILES
800 REM
810 IF PNAME$(C) = SHIP$(I) THEN 1500
820 PRINT 'FILES DO NOT MATCH, NAMES ARE'
830 PRINT C - lyFNAME$(C - l) + FDOSE(C - l)
840 PRINT C + FNAME$(C) + FDOSE(C)
850 PRINT C + lyFNAME$(C - l) + FDOSE(C - l)
860 PRINT 'RUN PROGRAM TO UPDATE SHIFTS PASSED'
870 GET A$:
880 PRINT:
890 PRINT D$; 'RUN MENU, D1'
900 REM
910 REM IS DOSE FROM PASSES FILE
920 REM ADD DOSE TO THE DOSE FOR THE FOLLOWING DAY FOR ABLE OR BAKER
930 REM
940 D = FDOSE(C)
950 F0KE 36, 32:
960 PRINT D
970 IF DAY < 25 THEN
980 ADOSE(DAY - 1) = ADOSE(DAY - 1) + D:
990 GOTO 1550
1000 BDOS(DAY - 25) = BDOS(DAY - 25) + D
1010 TEST = 1:
1020 RETURN
1030 REM
1040 REM SUBROUTINE TO GET DOSE FROM BEING ALONGSIDE TARGET SHIP
1050 REM
1060 IF DAY <= 35 THEN
1070 TEST = 1:
1080 PRINT 'NO ACTIVATION FROM ABLE YET';
1090 RETURN
1100 PRINT TIME$(I); ' ALONGSIDE '; SHIP$(I);
1110 D = 0:
1120 T1 = 0:
1130 T2 = 0
1140 REM MATCH SHIFTS
1150 FOR J = 1 TO NSHIFS
1160 PRINT I \ t 1
1170 FOR J = 0 TO I
1180 PRINT BDOS(J)
1190 NEXT J
1200 PRINT D$; 'CLOSE ';Z$
1210 PRINT D$; 'NOMON, C'
1220 PRINT D$; 'PR$0'
1230 PRINT D$; 'RUN MENU, D1'
1240 REM
1250 REM SUBROUTINE TO GET DOSE FROM PASSING TARGET SHIFTS
1260 REM
1270 PRINT TIME$(I); ' PASSING '; SHIP$(I);
1280 C = C + 1
1290 REM
1300 REM MATCH FATH AND PASSES FILES
1310 REM
1320 IF PNAME$(C) = SHIP$(I) THEN 1500
1330 PRINT 'FILES DO NOT MATCH, NAMES ARE'
1340 PRINT C - lyFNAME$(C - l) + FDOSE(C - l)
1350 PRINT C + FNAME$(C) + FDOSE(C)
1360 PRINT C + lyFNAME$(C - l) + FDOSE(C - l)
1370 PRINT 'RUN PROGRAM TO UPDATE SHIFTS PASSED'
1380 GET A$:
1390 PRINT:
1400 PRINT D$; 'RUN MENU, D1'
1410 REM
1420 REM IS DOSE FROM PASSES FILE
1430 REM ADD DOSE TO THE DOSE FOR THE FOLLOWING DAY FOR ABLE OR BAKER
1440 REM
1450 D = FDOSE(C)
1460 F0KE 36, 32:
1470 PRINT D
1480 IF DAY < 25 THEN
1490 ADOSE(DAY - 1) = ADOSE(DAY - 1) + D:
1500 GOTO 1550
1510 BDOS(DAY - 25) = BDOS(DAY - 25) + D
1520 TEST = 1:
1530 RETURN
1540 REM
1550 REM SUBROUTINE TO GET DOSE FROM BEING ALONGSIDE TARGET SHIP
1560 REM
1570 IF DAY <= 35 THEN
1580 TEST = 1:
1590 PRINT 'NO ACTIVATION FROM ABLE YET';
1600 RETURN
1610 PRINT TIME$(I); ' ALONGSIDE '; SHIP$(I);
1620 D = 0:
1630 T1 = 0:
1640 T2 = 0
1650 REM MATCH SHIFTS
1660 FOR J = 1 TO NSHIFS
IF \texttt{SHIP$(I) < \textgreater \ NAME$(J)} \textbf{THEN}
\texttt{GOTO 2060}
\texttt{D = DO(J);}
\texttt{J = NSHIPS}
\texttt{NEXT J}
\texttt{IF D = 0 \textbf{THEN}}
\texttt{PRINT ;}
\texttt{PRINT SHIP$(I)'; \ NOT \ FOUND ;:}
\texttt{TEST = 1:}
\texttt{RETURN}
\texttt{REM \ FIND \ OUT \ HOW \ LONG \ WAS \ ALONGSIDE}
\texttt{T1 = TIME - 608.5}
\texttt{FOR M = I + 1 \ TO \ NTIMES \ - \ 1}
\texttt{IF LEFT$(\texttt{SHIP$(M)},1) < \textgreater 'L' \ THEN \texttt{2120}}
\texttt{IF \texttt{SHIP$(I) < \textgreater \ RIGHT$(\texttt{SHIP$(M)},L) \ THEN \texttt{2120}}
\texttt{GOSUB 3500:}
\texttt{M = NTIMES - 1}
\texttt{NEXT M}
\texttt{IF \texttt{DAY > D1Y \ THEN}}
\texttt{PRINT \texttt{D1Y;H1R;MIN;:}}
\texttt{GOSUB 4000}
\texttt{REM \ IF \ SPANS \ TWO \ DAYS \ CALCULATE \ PART}
\texttt{IF \texttt{DAY < > D1Y \ THEN}}
\texttt{GOSUB 2500}
\texttt{REM \ GET \ DOSE \ FROM \ THIS \ CONTACT}
\texttt{DOSE = (1 / T1) ^ 3 - (1 / T2) ^ 3}
\texttt{DOSE = DOSE * 1000:}
\texttt{REM \ R \ TO \ MR}
\texttt{DOSE = INT (DOSE)}
\texttt{POKE 36*32:}
\texttt{PRINT DOSE}
\texttt{REM \ ADD \ TO \ DOSE \ FOR \ DAY}
\texttt{BDOS(\texttt{DAY = 251 = BDOS(\texttt{DAY = 25}) \ t \ DOSE}}
\texttt{TEST = 1:}
\texttt{RETURN}
\texttt{REM \ SUBROUTINE \ WHEN \ CONTACT \ OVER \ MULTIPLE \ DAYS}
\texttt{REM}
\texttt{T3 = T2}
\texttt{ND = D1Y - \texttt{DAY}}
\texttt{FOR J = 1 \ TO \ ND}
\texttt{T1 = T2;}
\texttt{DAY = \texttt{DAY} + 1}
\texttt{NEXT J}
\texttt{T2 = T3}
\texttt{IF \texttt{DAY < > D1Y \ THEN}}
\texttt{PRINT \texttt{D1Y;H1R;MIN;:}}
\texttt{GOSUB 4000}
\texttt{RETURN}
\texttt{REM \ SUBROUTINE \ TO \ GET \ TIME \ \texttt{WHEN \ CONTACT \ TARGET \ \texttt{SHIP}}
2920 REH
3000 DAY = VAL (LEFT$ (TIME$(I),2))
3010 HOUR = VAL (MID$ (TIME$(I),3,2))
3020 M INUTE = VAL (RIGHT$ (TIME$(I),2))
3030 THE = 24 * DAY t HOUR t M INUTE / 60
3040 RETURN
3400 REH
3410 REH SUBROUTINE TO GET LEAVING TIME
3420 REM
3500 DIY = VAL (LEFT$ (TIME$(M),2))
3510 HI R = VAL (MID$ (TIME$(M),3,2))
3520 MIN = VAL (RIGHT$ (TIME$(M),2))
3530 T2 = 24 * DIY t HI R t MIN / 60 - 608.5
3540 RETURN
4000 PRINT 'ERROR IN PATH FILE NOT N, L, F, A'
4010 PRINT TIME$(I), PLACE$(I), SHIP$(I)
4020 PRINT 'DO YOU WANT TO CONTINUE';
4030 GET A$:
4040 PRINT A%
4050 IF A$ = 'Y' THEN
4060 RETURN
4070 INPUT 'WANT TO GO TO MENU ?' : A$
4080 IF LEFT$ (A$,1) = 'Y' THEN
4090 PRINT 'RUN MENU D1'
4100 RETURN 'ERROR TERMINATING, RETURNING TO BASIC'
4110 PRINT 'NOT ENOUGH DATA ONLY ' ; NTIMES ; POINTS'
9010 GET A$:
9020 PRINT A%
9030 PRINT D$ ; 'RUN MENU D1'
Program: SHIP CONTAMINATION

Program Objective: To calculate doses to support skip personnel due to ship contamination.

Description: This program provides daily estimates of doses accrued by support ship personnel due to ship contamination for the duration of post-BAKER operations in the lagoon. Contamination intensities are calculated numerically from the integral formulation developed in Section 2.5:

\[ I_c(t_n) = 3.53 \cdot t_n^{-1.3} \sum_{i=0}^{n} t_i^{1.3} I_w(t_i), \]

where \( I_w(t) \) is the lagoon water intensity at time \( t \) after the BAKER detonation. The dose accrued between times \( t_1 \) and \( t_2 \) is then calculated from the equation

\[ D(t_1 \text{ to } t_2) = \frac{1}{3} t_1^{1.3} I_c(t_1) \cdot t_2^{3} - t_1^{3} \]

Output file contains the contamination dose accrued each day the ship was in the lagoon. In addition, the last element in the file is the ship contamination factor at the time the ship departed the lagoon.

Input:
- File "ship" WATER
- File "ship" PATH
- File "ship" LATE WATER

Output:
- File "ship" SELF
REM I = DOSE # WHICH STARTS AT 89 TO GO WITH WHERE CREATED
REM H1 = STARTING HOUR FOR CURRENT DAY
REM H2 = HOUR AFTER BAKER WHEN FIRST TOUCH HOT WATER ON A
   DAY
REM H3 = ENDING HOUR FOR DAY IN HOURS AFTER BAKER
REM H20 = TOTAL DOSE FROM WATER FOR A DAY
REM TD = SUM OF DOSE TIMES TIME TO 1.3 POWER
REM ITEN = INTENSITY
REM SELF = SHIP CONTAMINATION FOR DAY
REM HR = ARRAY STORING VALUES OF H2
HOME : VTAB 8
T$ = " "; T1 = PEEK (-15382): T2 = PEEK (-15380): T3 =
   PEEK (-15378)
IF T1 < > 8 OR T2 < > 4 OR T3 < > 2 THEN 20
PRINT CHR$(4); "IN#3"
PRINT CHR$(4); "PR#3"
PRINT CHR$(23); "C"
INPUT T$
PRINT CHR$(4); "PR#0"
PRINT CHR$(4); "IN#0"
ABLE = 3
BAKER = 100
DIM H30(100)
DIM DOSE(300), H20(300)
DIM HR(300), TD(300)
DIM SELF(300), ITEN(300)
D$ = CHR$(4): REM CTRL-D
INPUT "NAME OF SHIP IS ?"; X$
PRINT
INPUT "SEND OUTPUT TO PRINTER?"; ANSI
PRINT
IF LEFT$(ANS$, 1) < > "Y" THEN 160
INPUT "WHAT SLOT IS THE PRINTER IN?"; P$
IF P$ > "3" OR P$ < "1" THEN HOME : VTAB 6: PRINT X8:
GOTO 100
PRINT
INPUT "ENTER TOTAL DOSE ON BAKER DAY (MR) " ; BDAY
PRINT
INPUT "HOW MANY HOURS AFTER BAKER DID IT FIRST ENTER TH
E LAGOON? " ; HR (0)
PRINT
INPUT "WHAT IS THE BUILDUP FACTOR FOR THIS RUN? " ; B9
REM B9 IS THE BUILDUP FACTOR "C" WHICH APPEARS IN THE
   EQUATIONS IN THE TEXT
REM 19 = SATURATION FACTOR
INPUT " WHAT IS THE SATURATION FACTOR FOR THIS RUN? " ; I
B9 = B9 / 24: REM CONVERT UNITS
190 Z$ = X8 + " WATER"
200 PRINT
201 19 = 19 * 24 ^ . 3: REM CONVERT UNITS
210 PRINT "READING ";Z$
220 PRINT CHR$(7)
230 PRINT D$: "OPEN "; Z$; ", D$
240 PRINT D$: "READ "; Z$
250 INPUT N
260 FOR I = 0 TO N
270 INPUT DOSE(I)
280 DOSE(I) = 1000 * DOSE(I)
290 NEXT
300 PRINT D$: "CLOSE "; Z$
302 REM CALCULATE VALUES FOR BAKER DAY,
305 H20(0) = BDAY
310 TD(0) = H20(0) * HR(0) ^ 1.3
311 REM X7 = EXPONENT IN INTENSITY EQUATION
312 X7 = B9 / 19 * TD(0)
313 REM B9=BUILDUP FACTOR "C"
314 REM 19=SATURATION FACTOR
315 ITEN(0) = 19 * HR(0) ^ (- 1.3) * (1 - EXP(-X7))
320 SELF(I) = 173 + 24 * (J - 1) + 15 + K
325 H3 = 15
330 FOR J = 1 TO 8
335 ZR = 0: S1 = 0: S2 = 0
340 H1 = H3 + 1: H2 = H1: H3 = H3 + 24
345 FOR K = 1 TO 24
350 IF DOSE(I) = 0 THEN 395
355 IF ZR = 1 THEN H20(J) = H20(J) + DOSE(I): GOTO 395
360 IF H2 = H1 THEN 395
370 IF H2 = H1 THEN 395
372 REM CALCULATE FOR PORTION OF DAY PRIOR TO HOT WATER CONTACT
373 IF ZR = 1 THEN 425
374 x7 = B9 / 19 * TD(J - 1)
375 IO = 19 * H1 ^ (- 1.3) * (1 - EXP(-X7))
380 S1 = (1 / .3) * (H1 ^ 1.3) * IO * (H1 ^ (-.3) - (H2 - 1) ^ (-.3))
385 IF I = N THEN 405
400 NEXT K
405 IF ZR = 1 THEN 425
406 REM CASE WHEN HAD NO HOT WATER CONTACT FOR WHOLE DAY
407 TD(J) = TD(J - 1)
409 x7 = B9 / 19 * TD(J - 1)
410 IO = 19 * H1 ^ (- 1.3) * (1 - EXP(-X7))
415 S1 = (1 / .3) * (H1 ^ 1.3) * IO * (H1 ^ (-.3) - H3 ^ (-.3))
417 ITEN(J) = IO
420 GOTO 440
422 REM CALCULATE FOR PORTION OF DAY AFTER CONTACT WITH HOT WATER
425 TD(J) = TD(J-1) + H2O(J) * H2 ^ 1.3
426 X7 = B9 / 19 * TD(J)
430 ITEN(J) = 19 * H2 ^ (-1.3) * (1 - EXP(-X7))
435 s2 = (1 / .3) * (H2 ^ 1.3) * ITEN(J) * (H2 ^ (-.3) - H
3 ^ (-.3))
440 SELF(J) = S1 + S2
445 HR(J) = H2
450 NEXT J
500 B8 = B9 * 24: REM CONVERT BACK TO ORIGINAL UNITS
501 18 = 19 / 24 ^ .3: REM CONVERT BACK TO ORIGINAL UNITS
540 PRINT D$;"PR#";PB
542 PRINT : PRINT T$;
545 PRINT
546 PRINT ",";"SHIP CONTAMINATION FOR THE USS ";X$
547 PRINT : PRINT "C FACTOR = ";B8
550 PRINT : PRINT "SATURATION FACTOR = ";18
555 PRINT
560 PRINT "DAY","HOUR","WATER","RATE","DOSE"
570 PRINT "----","----","----","----","----"
580 FOR J = 0 TO 7
590 PRINT J,HR(J),H2O(J),ITEN(J),SELF(J)
620 NEXT J
625 REM CALCULATIONS WHEN NOT IN HOT WATER
630 Z$ = X$ + " PATH"
640 PRINT D$;"PR#0"
650 PRINT "READING ";Z$
660 PRINT CHR$(7)
670 PRINT D$;"OPEN ";Z$;","D2"
680 PRINT D$;"READ ";Z$
690 INPUT NTIMES
700 FOR I = 0 TO NTIMES - 1
710 INPUT TIMES,PLKE$,SHIP$
720 NEXT
730 PRINT D$; "CLOSE ";Z$
740 PRINT D$; "PR#";P$
750 DAY = VAL (LEFT$(TIME$,2))
760 HOUR = VAL (MID$(TIME$,3,2))
770 MINUTE = VAL (RIGHT$(TIME$,2))
780 T = 24 * DAY + HOUR + MINUTE / 60 - 608.5
790 T = INT ((T + 8.5) / 24)
810 IF T < 8 THEN 990
860 HR(9) = 208
870 J = 8
890 PRINT J,HR(J),H2O(J),ITEN(J),
900 SELF(J) = (1 / .3) * (HR(J) ^ 1.3) * ITEN(J) * (HR(J) ^
(-.3) - HR(J + 1) ^ (-.3))
910 PRINT SELF(J)
915 IF T = 8 THEN 990
916 REM READ LATE WATER DOSES
917 GOSUB 1300
920 FOR J = 9 TO T
940 HR(J + 1) = HR(J) + 24
949 TD(J) = TD(J - 1) + H3O(J) * HR(J) ^ 1.3
950 x7 = B9 / 19 * TD(J)
951 ITEN(J) = I9 * HR(J) ^ (-1.3) * (1 - EXP(-X7))
955 PRINT J, HR(J), H3O(J), ITEN(J),
960 SELF(J) = (1 / .3) * (HR(J) ^ 1.3) * ITEN(J) * (HR(J) ^ (-1.3) - HR(J + 1) ^ (-1.3))
970 PRINT SELF(J)
980 NEXT J
981 T8 = 0
982 FOR I = 0 TO T
983 T8 = T8 + SELF(I)
984 NEXT I
985 PRINT : PRINT "TOTAL SELF DOSE = "; T8
990 Z$ = X3 + "LATE WATER"
1000 PRINT D$; "PR#0"
1010 PRINT "WRITING "; Z$
1020 PRINT CHR$ (7)
1030 PRINT D$; "OPEN "; Z$; ", D2"
1040 PRINT D$; "DELETE "; Z$
1050 PRINT D$; "OPEN "; Z$
1060 PRINT D$; "WRITE "; Z$
1070 PRINT BDAY
1080 PRINT T
1090 FOR I = OTOT
1100 PRINT SELF(I)
1110 NEXT I
1115 PRINT ITEN(T)
1120 PRINT D$; "CLOSE "; Z$
1130 PRINT D$; "PR#0"
1140 HOME
1141 PRINT D$; "RUN MENU,D1"
1150 END
1300 REM SUBROUTINE TO INPUT SHIP'S
1310 REM LATE DAILY WATER DOSE
1320 REM (I.E. GREATER THAN B+8)
1330 REM
1340 Z$ = X3 + "LATE WATER"
1350 PRINT D$; "PR#0"
1360 PRINT D$; "OPEN "; Z$; ", D2"
1370 PRINT D$; "READ "; Z$
1380 INPUT NTIMES
1390 FOR I = 1 TO NTIMES
1400 INPUT H3O(I + 8)
1410 NEXT I
1420 PRINT D$; "CLOSE "; Z$
1430 PRINT D$; "PR#0"; P$
1440 RETURN

1
Program: RADIATION REPORT

Program Objective: To provide a written report of the radiation dose accrued by support ship personnel.

Description: This program reads files “ship” TARGETS, “ship” WATER, and “ship” SELF and prints a radiation summary report. This report contains a tabulation of daily film badge dose contributions from radioactive water and target ship sources for Shots ABLE and BAKER, and from ship contamination during the post-BAKER period. The free-field doses from the WATER, TARGETS and SELF files are converted to film badge doses via a conversion factor of 0.7. The water and ship contamination doses are multiplied by factors $\frac{1}{3}$ and $\frac{2}{3}$, respectively to account for shielding afforded personnel above and below decks, as discussed in Section 4.

Input: File “ship” WATER
File “ship” TARGETS
File “ship” SELF
Date ship leaves lagoon for the last time.
Ship Apportionment Factor (see Table 2-7).

Output: Written report on daily dose contributions.
Table 4-7 Radiation Report

1 REM DOSE = HOURLY WATER ACTIVATION
2 REM H20 = DAILY WATER DOSE
3 REM SHIP = DAILY TARGET SHIP DOSE
4 REM SELF = DAILY SHIP CONTAMINATION DOSE
5 REM ALL = DAILY TOTAL DOSE
6 REM ABLE = NUMBER OF DAYS FOR ABLE
7 REM BAKER = NUMBER OF DAYS AFTER BAKER ALLOWED
8 REM ITEN = DEPARTING LAGOON INTENSITY
9 REM FRAC = APPORTIONMENT FACTOR
10 REM BDAY = BAKER DAY DOSE
11 REM NDAY = NUMBER OF DAYS OF DATA FROM SHIP CONTAMINATION PROGRAM
19 HOME : VTAB 8
20 ABLE = 4
30 BAKER = 150
40 DIM DOSE(300), H2O(300), SHIP(300), ALL(300), SELF(300)
50 D$ = CHR$(4) : REM CTRL-D
60 INPUT "NAME OF SHIP IS ?" ; X$
70 PRINT ; PRINT
79 IF P$ > "3" OR P$ < "1" THEN HOME : VTAB 6 : PRINT X8 : GOTO 70
81 PRINT
82 INPUT "USE PREVIOUSLY CREATED REPORT FILE?" ; PREP$ : IF LEN (PREP$) = 0 THEN PREP$ = "Y"
83 IF LEN (PREP$) > 1 THEN PREP$ = LEFT$ (PREP$, 1)
84 IF PREP$ < > "Y" AND PREP$ < > "N" THEN PRINT CHR$(7) : HOME : GOTO 82
85 IF PREP$ = "N" THEN 109
86 Z$ = X$ + " REPORT"
87 PRINT D$ ; "OPEN "; Z$ ; ", D2"
88 PRINT D$ ; "READ "; Z$
89 INPUT X28 : INPUT ITEN : INPUT N : INPUT FRAC
90 PRINT D$ ; "CLOSE" ; Z$
91 HOME : IF X8 < > X28 THEN PRINT "SHIP NAMES DO NOT MATCH"
92 PRINT "FILE NAME WAS "; X2$
93 PRINT "SHIP NAME IS "; X1 : PRINT "DEPARTING INTENSITY WAS "; ITEN : PRINT "APPORTIONMENT FACTOR WAS "; FRAC
94 IF N < 7 THEN MM9 = "JUL" ; MD = N + 25
95 IF N > 6 AND N < 38 THEN MM$ = "AUG" ; MD = N - 6
96 PRINT "LEFT LAGOON "; MM$ ; " "; MD
97 PRINT : PRINT
98 INPUT "WANT TO USE THESE INPUTS?" ; AN$ : IF LEN (AN$) = 0 THEN AN8 = "N"
99 IF LEN (AN$) > 1 THEN AN$ = LEFT$ (AN$, 1)
100 IF AN9 = "Y" THEN 181
109 PRINT
110 INPUT "MONTH OF LAST DATA POINT?"; MM$
120 PRINT
130 MM$ = LEFT$(MM$, 3)
140 MM8 = MM9 + " 
150 INPUT "DAY OF MONTH OF LAST POINT?"; MD
160 IF MD < 1 OR MD > 31 THEN PRINT : GOTO 150
170 PRINT
180 INPUT "HOW IS THE SHIP CONTAMINATION FOR THIS SHIP TO BE APPORTIONED? (0-1.0)"; FRAC
181 PRINT
185 INPUT "PRINT APPORTIONMENT FACTOR?"; PFRAC$: IF LEN (PF
186 RAC$) = 0 THEN PFRACB = "Y"
187 IF PFRAC$ > 1 THEN PFRAC$ = LEFT$(PFRAC$, 1)
188 PRINT CHR$(7): HOME : GOTO 185
189 PRINT
190 INPUT "PRINT DEPARTING INTENSITY?"; PITE$: IF LEN (PIT
191 E$:) = 0 THEN PITEB = "Y"
192 IF PITE$ > 1 THEN PITE$ = LEFT$(PITE$, 1)
193 PRINT CHR$(7): HOME : GOTO 189
194 PRINT
195 INPUT "WANT TO CREATE A NEW REPORT FILE?"; AN$: IF LEN
196 (AN$) = 0 THEN AN9 = "N"
197 IF LEN (AN$) > 1 THEN AN9 = LEFT$(AN$, 1)
198 REM
200 REM READ IN DAILY SHIP CONTAMINATION
201 REM
209 Z$ = X$ + " SELF"
210 PRINT D$: "OPEN "; Z$; ",D2"
212 PRINT D$: "READ "; Z$
213 INPUT BDAY
214 INPUT NDAY
215 FOR I = 0 TO NDAY
216 INPUT SELF(I + ABLE + 1)
217 NEXT I
218 INPUT ITEN
219 PRINT D$: "CLOSE "; Z$
220 REM
225 REM READ IN DAILY TARGET ACTIVATION
226 REM
229 Z$ = X$ + " TARGETS"
230 PRINT D$: "OPEN "; Z$; ",D2"
232 PRINT D$: "READ "; Z$
233 FOR J = 0 TO ABLE: INPUT SHIP(J): NEXT
234 FOR J = ABLE + 1 TO 24: INPUT DUMMY: NEXT
235 INPUT K: IF K > BAKER THEN K = BAKER
236 FOR J = ABLE + 1 TO ABLE + K: INPUT SHIP(J): NEXT
237 PRINT D$: "CLOSE "; Z$
238 REM
375 REM READ IN HOURLY WATER ACTIVATION
376 REM
380 Z$ = X$ + " WATER"
390 PRINT D$; "OPEN "; Z$
400 PRINT D$; "READ "; Z$
410 INPUT N
420 FOR I = 0 TO N - 1
430 INPUT DOSE(I)
440 NEXT
450 PRINT D$; "CLOSE "; Z$
454 REM
455 REM CALCULATE DAILY WATER ACTIVATION
456 REM
460 PRINT
470 PRINT D$; "PR# "; P$
471 PRINT CHR$ (9); "100N"
480 FOR I = 0 TO 15
490 H20(0) = H20(0) + DOSE(I)
500 NEXT
510 FOR J = 1 TO 3
520 FOR K = 1 TO 24
530 I = 24 * (J - 1) + 15 + K
540 H20(J) = H20(J) + DOSE(I)
550 NEXT
560 NEXT
570 W = ABLE + 1
580 H20(W) = BDAY / 1000
590 FOR J = 1 TO 8
600 FOR K = 1 TO 24
610 I = 73 + 24 * (J - 1) + 15 + K
620 H20(W + J) = H20(W + J) + DOSE(I)
624 F1 = 1
630 IF I = N - 1 THEN 651
640 NEXT
650 NEXT
651 REM READ IN LATE WATER DAILY DOSE
652 Z$ = X8 + " LATE WATER"
653 PRINT D$; "OPEN "; Z$
654 PRINT D$; "READ "; Z$
655 INPUT N9
656 FOR I = 14 TO N9 + 13
657 INPUT H20(I); H20(I) = H20(I) / 1000: NEXT
658 PRINT D$; "CLOSE "; Z$
659 PRINT CHR$ (12)
660 PRINT D$; "OPEN "; Z$
661 PRINT D$; "READ "; Z$
662 INPUT ABLE + BAKER
663 REM *****
664 REM : APPLY FILM BADGE CONVERSION FACTOR = .7
665 REM : APPLY CREW ACTIVITY APPORTIONMENT FACTOR FOR WATER DOSE = .333
666 REM : APPLY CREW ACTIVITY APPORTIONMENT FACTOR FOR SHIP
CONTAMINATION = .667

676 REM ******
680 H2O(I) = H2O(I) * 1000 * .7 * .333
690 H2O(I) = INT(H2O(I))
700 SHIP(I) = INT(.7 * SHIP(I) + .5)
710 SELF(I) = FRAC * SELF(I)
712 SELF(I) = SELF(I) * F1 * .667
726 SELF(I) = INT(.7 * SELF(I) + .5)
727 REM
728 REM SUM FOR TOTAL DAILY DOSE
729 REM
730 ALL(I) = H2O(I) + SHIP(I) + SELF(I)
740 NEXT
750 CUM = 0
755 PRINT CHR$(27);"M"
760 PRINT: PRINT: PRINT: PRINT
770 PRINT "", "uss ";X8; " CALCULATED FILM BADGE DOSE (IN MREM)"
780 PRINT
790 PRINT
791 Z6 = 14
792 Z7 = Z6 + 9
793 Z8 = Z7 + 8
794 Z9 = 11
810 POKE 36,Z6: PRINT "JUL THRU 24";: POKE 36,Z8: PRINT H2O(ABLE);: POKE 36,Z8 + Z9: PRINT SHIP(ABLE);: POKE 36,Z8 + 2 * Z9 + 5: PRINT CUM
820 POKE 36,Z6:

830 M$ = "JUL"
840 J = 0
850 FOR I = 0 TO ABLE - 1
860 J = J + 1
870 CUM = CUM + ALL(I)
890 NEXT I
892 CUM = CUM + SHIP(ABLE)
900 PRINT
910  J = 24
920  FOR I = ABLE + 1 TO 1 + ABLE + BAKER
930  J = J + 1
940  IF J = 32 AND M$ = "JUL" THEN J = 1:M$ = "AUG"
950  IF J = 32 AND MB = "AUG" THEN J = 1:M$ = "SEP"
960  CUM = CUM + ALL(I)
970  POKE 36, Z6: PRINT M$; J: POKE 36, Z7: PRINT "B+"; I - (1 + ABLE);: POKE 36, Z8: PRINT H20(I);: POKE 36, Z8 + Z9
980  IF J = MD AND MM$ = M$ THEN 1000
990  NEXT I
995  REM
996  REM SCALE DEPARTING INTENSITY
997  REM
1000 PRINT
1004 ITEN = ITEN * F R A C *.667
1005 ITEN = INT (24 * ITEN + .5)
1010 IF FITEN$ = "Y" THEN PRINT "SHIP CONTAMINATION DEPARTURE FACTOR = "; ITEN
1015 PRINT
1017 IF TFRACT$ = "Y" THEN PRINT "APPORTIONMENT FACTOR IS "; ITEN
1020 PRINT D$: "PR#0"
1030 IF AN$ < > "Y" AND AN8 < > "N" THEN PRINT CHR$(7)
1040 IF AN9 = "N" THEN 1200
1044 REM
1045 REM PRINT FILE TO SAVE FINAL DOSE CALCULATIONS
1046 REM
1050 Z$ = X$ + "REPORT"
1060 PRINT D$: "OPEN "; Z$; ",D2"
1070 PRINT D$: "DELETE "; Z$
1080 PRINT D$: "OPEN "; Z$
1090 PRINT D$: "WRITE "; Z$
1100 PRINT X8
1110 PRINT ITEN
1120 PRINT I - (1 + ABLE)
1130 PRINT F R A C
1140 PRINT I + 1
1150 FOR J = 0 TO I
1160 PRINT ALL(J)
1170 NEXT J
1180 PRINT D$: "CLOSE "; Z$
1190 PRINT
1200 END
1210 REM LATEST VERSION RAD REPORT 16 NOV 82 WITH MARGIN & POSITION CORRECTIONS
1220 REM MODIFIED 6 FEB 84 FOR THE EPSON PRINTER
Program: UPDATE

Program Objective: To allow the modification of existing "ship" PATH and "ship" PASSES files.

Description: This program performs edit functions on the PATH file and automatically updates the PASSES file if required. Edit functions are of three types: add, delete, or modify lines of data. Four types of modifications to a line of data are supported. The user may choose to modify date-time, location, or remarks data individually or as a group. As a screen of data is presented, the user is queried as to the accuracy of the data. A "yes" response proceeds to the next screen of data. A response of "no" will produce a question for the type of edit function: add (A), delete (D), modify (M). At the program prompt "ARE THESE OKAY?", three additional responses are supported. A return is interpreted as a yes (Y). Control-A is interpreted to mean the data are correct and there is no need to view the remainder of the file. An "R" response allows the starting of the next screen of data at any line desired. At the end of an edit session, the option is given to the user to save the modified file.

Input: Existing files "ship" PATH
"ship" PASSES

output: Updated files "ship" PATH
"ship" PASSES
10 DA = CHS('D')
20 PRINT DA""'MON,C'
30 DIM PROSE(300),SHAME(300),PTIME(300)
40 DIM TIME$(300),PLACE$(300),SHIP$(300)
50 HOME : VTab 6
60 INPUT "NAME OF SHIP ":V$(2) = X$ + ' PATH'
70 PRINT
80 PRINT DA""'OPEN "Z$" :D2'
90 PRINT DA""'READ "Z$"'
100 INPUT NTIMES
110 FOR I = 0 TO NTIMES - 1
120 INPUT TIME$(I),PLACE$(I),SHIP$(I)
130 NEXT I
140 PRINT I#$"CLOSE "Z$"
150 Y$ = X$ + ' PASSES'
160 PRINT I#$"OPEN "Y$'
170 PRINT I#$"READ "Y$'
180 INPUT PASSES
190 IF PASSES = 0 THEN 230
200 FOR I = 1 TO PASSES
210 INPUT TIME$(I),PLACE$(I),PROSE(I)
220 NEXT I
230 PRINT I#$"CLOSE "Y$'
240 I1 = 0:12 = I1 + 19
250 POKE 34,0
260 IF I1 + 1 > NTIMES THEN 460
270 IF I2 + NTIMES - 1 THEN 12 = NTIMES - 1
280 HOME : PRINT "I TIME PLACE SHIP"
290 FOR I = I1 TO I2
300 IF I < 10 THEN PRINT " ";
310 PRINT I#$"TIME$(I)":"PLACE$(I):"SHIP$(I)
320 NEXT I
330 VTab 23: POKE 34,21
340 PRINT "ARE THERE OR SO FAR": GET A$; PRINT A$
350 IF A$ = 'Y' THEN I1 = I2 + 1:12 = I2 + 1:12 = I2 + 1: GOTO 250
360 IF A$ = 'F' THEN 460
370 IF A$ = 'N' THEN PRINT "TYPE OF UPDATE(A:D,M,T,F,S)?": GET
380 A$; PRINT A$
390 IF A$ = 'D' THEN 1000
400 IF A$ = 'A' THEN 1100
410 IF A$ = 'M' THEN 1200
420 IF A$ = 'T' THEN 1300
430 IF A$ = 'P' THEN 1400
440 IF A$ = 'S' THEN 1500
450 IF A$ = 'R' THEN 1600
460 GOSUB 2000: GOTO 250
470 POKE 34,0: HOME : VTab B
480 PRINT "DO YOU WANT TO SAVE THIS AS THE DATA FOR THIS SHIP?": GET A$; PRINT A$
490 IF A$ < > 'Y' THEN 720
500 IF C1 = 0 THEN 500
590 PRINT DA""'OPEN "Z$"" :Z2
500 PRINT D$;"DELETE ";Z$
510 PRINT D$;"OPEN ";Z$
520 PRINT D$;"WRITE ";Z$
530 PRINT NTIMES
540 FOR I = 0 TO NTIMES - 1
550 PRINT TIME$(I)
560 PRINT PLACE$(I)
570 PRINT SHIP$(I)
580 NEXT I
590 PRINT D$;"CLOSE ";Z$
600 IF C2 = 0 THEN 720
610 PRINT D$;"OPEN ";Y$";D2$
620 PRINT D$;"DELETE";Y$
630 PRINT D$;"WRITE ";Y$
640 PRINT PASSES
650 FOR I = 1 TO PASSES
660 PRINT TIME$(I)
670 PRINT PNAME$(I)
680 PRINT "CLOSE"$(I)
690 NEXT I
700 PRINT D$;"CLOSE ";Y$
710 PRINT D$;"NOMON"C$
720 PRINT D$;"RUN HERE!,D1$
1000 HOME ; INPUT "FIRST LINE TO DELETE=";A$;D1 = VAL (A$)
1010 IF D1 < 0 THEN PRINT CHR$(7);"TOO SMALL"; GOTO 1000
1015 IF D1 > NTIMES THEN PRINT CHR$(7);"TOO LARGE"; GOTO 1
1020 IF D1 < I1 THEN I1 = D1 - 1; GOTO 1520
1025 IF D1 < I THEN PRINT "CYCLE UNTIL COMPS ON SCREEN"; GET A$
1030 PRINT ; GOTO 250
1035 INPUT "LAST LINE TO DELETE=";A$;D2 = VAL (A$)
1040 IF D2 < 0 THEN PRINT CHR$(7);"TOO SMALL"; GOTO 1030
1045 IF D2 > NTIMES THEN PRINT CHR$(7);"TOO LARGE"; GOTO 1
1050 IF D1 > D2 THEN PRINT CHR$(7);"FIRST LARGER THAN LAST";
1055 GOTO 370
1060 GOSUB 5000: IF C1 = 2 THEN PRINT "ABORTED"; GET A$: PRINT
1070 ; GOTO 250
1075 GOSUB 2500: C1 = 1
1080 IF D2 = NTIMES - 1 THEN NTIMES = D1; GOTO 250
1085 J = D2 + D1 + 1
1090 FOR I = D2 + 1 TO NTIMES - 1
1095 K = I - J
1100 TIMES$(K) = TIME$(I)
1105 PLACE$(K) = PLACE$(I)
1110 SHIP$(K) = SHIP$(I)
1120 NEXT I
1130 NTIMES = NTIMES - J: D2 = 0; GOTO 250
1140 J = 300 - (NTIMES - 1): J1 = - 1
1145 A$ = "N"
1150 IF I1 = 0 THEN PRINT "ADD TO START OF FILE ?": GET A$: PR
1160 INT A$
1170 IF A$ < > "Y" THEN INPUT "LAST LINE BEFORE NEW DATA=";A$
1170 IF J1 = HTIMES - 1 THEN 1150
1180 FOR SI = HTIMES - 1 TO J1 + 1 STEP 1
1190 TIME$(SI + J1) = TIME$(SI)
1195 NI = 1
1200 IF N1 = CHR$(13) THEN 1190
1205 I = I + NI; A1 = A1 + 1; GOTO 1160
1210 IF J1 = HTIMES - 1 THEN 1190
1215 FOR SI = I + 1 TO J1
1220 TIME$(I) = TIME$(SI)
1225 NI = 1: HEY \$I
1230 NTIMES = NTIMES + 1; S1 = S1 + 1; I1 = I1 + 19: GOTO 250
1240 INPUT "CHANGE ALL OF WHICH POINT? \$I: I = VAL (\$I)"
1250 IF I < I1 OR I > I2 THEN PRINT "OUTSIDE OF CURRENT DISPLAY"
1260 IF I = I1 OR I = I2 THEN PRINT "OUTSIDE OF CURRNT DISPLAY"
1270 GOSUB 4000: GOSUB 4000: GOSUB 4500: C1 = 1
1280 GOTO 250
1290 GOTO 250
1300 INPUT "CHANGE TIME FOR WHICH POINT? \$I: I = VAL (\$I)"
1310 IF I < I1 OR I > I2 THEN PRINT "OUTSIDE OF CURRENT DISPLAY"
1320 GOSUB 4000: C1 = 1: GOTO 250
1330 GOSUB 4000: C1 = 1: GOTO 250
1340 INPUT "CHANGE SHIP FOR WHICH POINT? \$I: I = VAL (\$I)"
1350 IF I < I1 OR I > I2 THEN PRINT "OUTSIDE OF CURRENT DISPLAY"
1360 GOSUB 4000: C1 = 1: GOTO 250
1370 GOSUB 4500: C1 = 1: GOTO 250
1380 FOR \$A = 0 TO HOME; VTAB 8
1390 PRINT "LAST LINE IS \$I: HTIMES = 1"
1400 INPUT "START NEXT SCREEN AT LINE \$I: I1"
1410 II = I1 + 19
1420 GOTO 250
1430 FOR \$A = 0 TO HOME; VTAB 2
1440 PRINT "POSSIBLE UPDATE RESPONSES";
1450 PRINT "PRI";
1455 PRINT "A = ADD POINTS TO PATH"
1460 PRINT "D = DELETE POINTS FROM PATH"
1465 PRINT "M = MODIFY ALL PARTS OF A POINT"
1470 PRINT "C = CHANGE TIME OF A POINT"
1475 PRINT "P = CHANGE PLACE OF A POINT"
1480 PRINT"
2055  PRINT
2060  PRINT  '  S = CHANGE SHIP OF A POINT'
2063  PRINT
2065  PRINT  '  R = RECYCLE UPDATE TO A LINE NUMBER'
2066  PRINT
2067  PRINT  '  F = FINISHED WITH ALL CHANGES'
2070  VTAB 23: INVERSE : PRINT  'HIT ANY KEY TO CONTINUE': NORMAL
2080  GET A#: PRINT
2090  RETURN
2500  TI$ = TIME$(D1):T2$ = TIME$(D2)
2510  FOR S1 = 0 TO PASSES
2520  IF TI$ > PTIME$(S1) THEN NEXT S1: RETURN
2530  IF TI$ < > PTIME$(S1) THEN S1 = S1 + 1: GOTO 2500
2540  D3 = D1
2550  IF LEFT$(SHIP$(D3),1) = 'P' THEN 2590
2560  D3 = D3 + 1: TI$ = TIME$(D3)
2570  IF TI$ < > TI$ THEN S1 = S1 + 1: GOTO 2500
2580  IF LEFT$(SHIP$(D3),1) < > 'P' THEN 2590
2590  IF RIGHT$(SHIP$(D3), LEN(SHIP$(D3)) - 1) < > PNAME$(S1) THEN 2560
2600  IF T2$ < PTIME$(S1) THEN S1 = PASSES: NEXT S1: RETURN
2610  FOR S2 = S1 TO PASSES
2620  IF PTIME$(S2) < T2$ THEN NEXT S2: GOTO 2700
2630  IF PTIME$(S2) > T2$ THEN S2 = S2 - 1: GOTO 2700
2640  D3 = D2
2650  IF PNAME$(S2) = RIGHT$(SHIP$(D3), LEN(SHIP$(D3)) - 1) THEN 2700
2660  D3 = D3 - 1
2670  IF TIME$(D3) = T2$ THEN 2650
2680  S2 = S2 - 1
2700  J = S2 - S1 + 1
2710  FOR K = S2 + 1 TO PASSES
2720  PTIME$(K - J) = PTIME$(K)
2730  PNAME$(K - J) = PNAME$(K)
2740  PDose$(K - J) = PDose$(K)
2750  NEXT K
2760  PASSES = PASSES - J
2770  S2 = 1
2780  RETURN
3000  FOR S1 = S2 TO PASSES
3010  IF PTIME$(S1) < TIME$(I) THEN NEXT S1: S1 = PASSES + 1: GOTO 3060
3020  IF PTIME$(S1) = TIME$(I) AND PNAME$(S1) = T2$ THEN 3080
3030  FOR S3 = PASSES TO S1: STEP - 1
3040  PTIME$(S3 + 1) = PTIME$(S3)
3050  PNAME$(S3 + 1) = PNAME$(S3)
3060  PDose$(S3 + 1) = PDose$(S3)
3070  NEXT S2
3080  PTIME$(S1) = TIME$(I)
3090  PNAME$(S1) = RIGHT$(T2$, LEN(T2$) - 1)
3090  INPUT 'DOSE FROM THIS PAGE': PDose$(S1)
3090  IF S1 < PASSES THEN S1 = PASSES: NEXT S1
3100  PASSES = PASSES + 1
3100  RETURN
3500 PRINT "TIME"; GET A1$; PRINT A1$$;
3600 IF A1$ = CHR$(13) THEN RETURN
3710 GET A2$; PRINT A2$$; IF A2$ = CHR$(8) THEN GET A1$; PRINT A1$$; GOTO 3600
3720 GET A3$; PRINT A3$$; IF A3$ = CHR$(8) THEN 3710
3730 GET A4$; PRINT A4$$; IF A4$ = CHR$(8) THEN 3720
3740 GET A5$; PRINT A5$$; IF A5$ = CHR$(8) THEN 3730
3750 GET A6$; PRINT A6$$; IF A6$ = CHR$(8) THEN 3740
3800 TIME$(I) = A1$ + A2$ + A3$ + A4$ + A5$ + A6$
3900 RETURN
4000 PRINT "PLACE"; GET A1$; PRINT A1$;
4100 GET A2$; PRINT A2$$; IF A2$ = CHR$(8) THEN GET A1$; PRINT A1$$; GOTO 4010
4200 RETURN
4500 INPUT *; SHIP*; T2$
4510 L = LEN (T2$)
4520 T1$ = LEFT$(T2$, L - 1)
4530 IF T1$ = "N" THEN 4600
4540 IF L > 1 THEN 4560
4550 FLASH: PRINT "BAD INPUT, TRY AGAIN"; NORMAL; GOTO 4500
4560 IF T1$ = "L" THEN 4600
4570 IF T1$ = "F" THEN 50S U B 3000:C2 - 1; GOTO 4600
4580 IF T1$ = "A" THEN 4600
4590 GOTO 4550
4600 SHIP$(I) = T2$
4700 RETURN
5000 J1 = D1 - 1: IF J1 < 0 THEN J1 = 0
5010 J2 = D2 + 1: IF J2 = NTIMES THEN J2 = J2 - 1
5020 POKE 34, 0
5030 HOME; PRINT "I TIME PLACE SHIP"
5040 J3 = J1 + 19
5045 IF J1 > NTIMES - 1 THEN 5140
5050 IF J3 > NTIMES - 1 THEN J3 = NTIMES - 1
5060 FOR J = J1 TO J3
5070 IF J > = D1 THEN INVERSE
5075 IF J > D2 THEN NORMAL
5080 IF J < 10 THEN PRINT "*
5090 PRINT J; TIME$(J); PLACE$(J); SHIP$(J)
5110 NEXT J
5120 NORMAL
5130 PRINT
5140 PRINT "OK"; GET A$: PRINT A$
5150 IF A$ < > "Y" THEN C1 = 2; RETURN
5160 IF D2 < J3 THEN HOME; RETURN
5170 J1 = J1 + 20
5180 HOME; PRINT "I TIME PLACE SHIP"
5190 IF D1 = 0 THEN 5040
5200 K = D1 - 1
5210 IF J < 10 THEN PRINT "*
5220 PRINT K; TIME$(K); PLACE$(K); SHIP$(K)
5230 GOTO 5040
5240 END
Program: UPDATE TARGET SHIPS

Program Objective: To modify the file TARGET SHIPS by deletion, addition, or modification.

Description: The file TARGET SHIPS contains the names of most target ships and their one-hour intensities after Shot BAKER. This program allows the intensities to be modified and ships to be added or deleted, as required.

Input: Existing file TARGET SHIPS

Output: Updated file TARGET SHIPS
Table 4-9  Update Target Ships

10    DIM NAME$(90)
15    DIM DOSE1(90)
20    D$ = CHR$ (4)
30    PRINT D$;'OPEN TARGET SHIPS';D1'
40    PRINT D$;'READ TARGET SHIPS'
50    INPUT NSHIPS
60    IF NSHIPS = 0 THEN 100
70    FOR I = 1 TO NSHIPS
80        INPUT NAME$(I); DOSE1(I)
90        DOSE1(I) = DOSE1(I) * 24
99    NEXT I
100   PRINT D$;'CLOSE TARGET SHIPS'
110   ADDED = 0
115   PRINT 'WANT TO ADD TARGET SHIPS?';$;
120   GET A$;
125   PRINT A$;
130   IF A$ < > 'Y' THEN 200
135   PRINT 'NEW TARGET SHIP NAME';
140   GET A$;
145   PRINT A$;
150   IF A$ = CHR$ (13) THEN
155       GOTO 200
160   INPUT 'N$'
165   N$ = A$ + N$
170   IF LEFT$(N$;1) = CHR$ (13) THEN 200
175   CHECK = 0
180   INPUT 'INTENSITY AT 1 HOUR(R/DAY)';D
185   IF D > 0 THEN 190
190   CHECK = CHECK + 1;
195   IF CHECK > 1 THEN 120
200   PRINT 'BAD INPUT; TRY AGAIN';:
205   GOTO 140
210   ADDED = ADDED + 1
215   NAME$(NSHIPS + ADDED) = N$
220   DOSE1(NSHIPS + ADDED) = D
225   GOTO 120
230   PRINT
235   PRINT 'I$';:
240   POKE 36,5;
245   PRINT 'NAME$';:
250   POKE 36,23:
255   PRINT 'DOSE RATE (R/DAY)'

116
202 PRINT "-----------------------------------------------"
205 FOR I = 1 TO NSHIPS + ADDED
220 NEXT I
230 PRINT!
231 PRINT "ARE THESE OKAY?";'
232 GET A$;
240 IF A$ = "Y" THEN
250 GOTO 500
255 INPUT "WHICH IS WRONG(I)?"; J
260 PRINT NAME$(J), DOSE$(J)
270 PRINT "NEW NAME = "; NAME$(J)
272 CV = PEEK (37); VTAB CV;
274 HTAB 12
276 IF LEN (A$) > 0 THEN
278 NAME$(J) = A$
280 PRINT "NEW INTENSITY = "; DOSE$(J)
282 CV = PEEK (37); VTAB CV;
284 HTAB 17
286 IF LEN (A$) > 0 THEN
288 DOSE$(J) = VAL (A$)
290 GOTO 200
295 PRINT "WANT TO DELETE A SHIP?";'
300 GET A$;
310 IF A$ = "N" THEN 1000
320 INPUT "WHICH ONE?"; J
330 FOR K = J TO NSHIPS + ADDED - 1
340 NAME$(K) = NAME$(K + 1)
350 DOSE$(K) = DOSE$(K + 1)
370 NEXT
390 NSHIPS = NSHIPS - 1
400 GOTO 200
410 NSHIPS = NSHIPS + ADDED
430 FOR I = 1 TO NSHIPS
435 DOSE$(I) = DOSE$(I) / 24
450 NEXT I
460 PRINT D$; "OPEN TARGET SHIPS:" D$;
470 PRINT D$; "DELETE TARGET SHIPS"
480 PRINT D$; "OPEN TARGET SHIPS"
490 PRINT D$; "WRITE TARGET SHIPS"
500 PRINT NSHIPS
520 FOR I = 1 TO NSHIPS
530 PRINT NAME$(I)
2070 PRINT DOSE1(I)
2080 NEXT I
2090 PRINT D$;'CLOSE TARGET SHIPS'
2100 PRINT D$;'RUN MENU,D1'
Program: UPDATE PASSING SHIP DOSE

Program Objective: To modify doses in PASSES file, and to modify any entry in the PATH file that relates to a "passing" encounter with a target ship.

Description: This program reads "ship" PASSES file and allows modification of dose. Input and output are displayed on the screen only.

Input: Existing file "ship" PASSES

Output: Updated file "ship" PASSES
Table 4-10  Update Passing Ship Dose

10  D$ = CHR$ (4)
20  DIM PDOSE(300), PNAME$(300), PTIME$(300)
30  INPUT 'NAME OF SHIP '; X$
40  Z$ = X$ + 'PASSES'
50  PRINT D$;'OPEN '; Z$'; D2'
60  PRINT D$;'READ '; Z$
70  INPUT PASSES
80  IF PASSES = 0 THEN 140
90  FOR I = 1 TO PASSES
100  INPUT PTIME$(I)
110  INPUT PNAME$(I)
120  INPUT PDOSE(I)
130  NEXT I
140  PRINT D$;'CLOSE '; Z$
150  IF PASSES > 0 THEN 200
160  PRINT 'USE UPDATE'
170  PRINT 'TO ADD PASSING SHIP MEETINGS'
180  FOR I = 1 TO 3000:
      NEXT I
190  PRINT D$;'RUN MENU'; D1'
200  ISTART = 1
210  NTILL = ISTART + 19
220  IF NTILL > PASSES THEN
      NTILL = PASSES
230  HOME:
      PRINT Z$;' TIME','SHIP','DOSE'
240  FOR I = ISTART TO NTILL
      PRINT I$;'PTIME$(I),PNAME$(I);'
      POKE 36,32;
      PRINT PDOSE(I)
250  NEXT I
260  PRINT
270  PRINT 'WANT TO CHANGE ANY ? '
280  GET A$;
      PRINT A$
300  IF A$ = 'N' THEN 470
310  INPUT 'WHICH ONE ? '; A$
320  J = VAL (A$)
330  IF J < ISTART THEN
      PRINT 'BAD INPUT';
      FOR J = 0 TO 500:
          NEXT ;
GOTO 230
340 IF J > NTILL THEN
   PRINT "BAD INPUT";
   FOR J = 0 TO 500:
      NEXT ;
   GOTO 230
350 PRINT "DELETE?";
   GET A$;
   PRINT A$
360 IF A$ = "Y" THEN 390
370 INPUT "NEW DOSE = ";PDOSE(J)
380 GOTO 230
390 IF J = Passes THEN 450
400 FOR I = J TO Passes - 1
410 PTIME$(I) = PTIME$(I + 1)
420 PNAME$(I) = PNAME$(I + 1)
430 PDOSE(I) = PDOSE(I + 1)
440 NEXT I
450 Passes = Passes - 1
460 GOTO 220
470 IF NTILL = Passes THEN 490
480 ISTAR$ = NTILL + 1;
   GOTO 210
490 HOME :
   VTAB 10
500 PRINT "SAVE THIS VERSION OF FILE ? ";
510 GET A$;
   PRINT A$
520 PRINT :
   PRINT
530 IF A$ <> "Y" THEN 650
540 PRINT D$;"OPEN ";IZ$;"D2"
550 PRINT D$;"DELETE";IZ$
560 PRINT D$;"OPEN ";IZ$
570 PRINT I$;"WRITE ";IZ$
580 PRINT Passes
590 FOR I = 1 TO Passes
600 PRINT PTIME$(I)
610 PRINT PNAME$(I)
620 PRINT PDOSE(I)
630 NEXT I
640 PRINT D$;"CLOSE ";IZ$
650 PRINT D$;"RUN MENU,D1"

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Program: PATH REPORT

Program Objective: To print out path data for ships in Bikini Lagoon.

Description: This program reads "ship" PATH and PASSES files and print information, either on screen or on printer. The dose for a passing ship is printed immediately after the target ship name.

Input:
File "ship" PATH
File "ship" PASSES

Output: A complete report on the input data for a ship, displayed either on the screen or on the printer.
Table 4-11  Path Report

1  HOME:
VTA# 1
10  D# = CHR#(4)
20  DIM TIME$(300), PNAME$(300), PIDSE$(300)
30  DIM PLACE$(300), TIME$(300), SHIP$(300)
40  INPUT "NAME OF SHIP ";X$:
     Z$ = X$ + " PATH"
50  Y$ = X$ + " PASSES"
60  PRINT "SEND TO PRINTER ":
    GIL A$:
    PRINT A$
61  IF A$ = "Y" THEN
       PRINT "WHAT SLOT IS THE PRINTER IN?":
       GET P$:
       PRINT P$
62  IF A$ = "Y" AND P$ > "3" OR A$ = "Y" AND P$ < "1" THEN
HOM$:
   VTA# 8:
   PRINT X$:
   PRINT ;
   GOTO 60
70  PRINT
80  PRINT D$="OPEN ";Y$,"D2"
90  PRINT D$="READ ";Y$
100  INPUT PASSES:
     IF PASSES = 0 THEN 140
110  FOR I = 1 TO PASSES
120     INPUT TIME$(I), PNAME$(I), PIDSE$(I)
130     NEXT
140  PRINT D$="CLOSE ";Y$
150  PRINT D$="OPEN ";Z$,"D2"
160  PRINT D$="READ ";Z$
170  INPUT NTIMES
180  FOR I = 1 TO NTIMES - 1
190     (INPUT TIME$(I), PLACE$(I), SHIP$(I)
200     NEXT
210  PRINT D$="CLOSE ";Z$
220  IF NTIMES < 2 THEN PAGE
230  IF A$ = "Y" THEN
       PRINT D$="PR# ";P$
240  PRINT E:
PRINT
250 IF A$ <> 'Y' THEN
    HOME:
    PRINT:
    SPEED = 200
255 PRINT 'PATH REPORT FOR THE USS 'X$':
PRINT
260 PRINT 'TIME':
POKE 36,8:
PRINT 'PLACE':
POKE 36,15:
PRINT 'REMARKS'
270 PRINT '---------- ----- --------------------------'
280 POKE 34,3:
VTAB 4
285 POKE 1786,104
290 K = 1
295 FOR I = 0 TO NTIMES - 1
300 PRINT TIME$(I):
310 POKE 36,8:
320 PRINT PLACE$(I):
330 L$ = LEFT$(SHIP$(I),1)
340 IF L$ = 'N' AND LEN(SHIP$(I)) = 1 THEN
    PRINT:
    GOTO 440
350 POKE 36,15
360 L = LEN(SHIP$(I)): SHP$ = MID$(SHIP$(I), L - 1)
370 IF L$ = 'N' THEN
    PRINT SHP$:
    GOTO 440
380 IF L$ = 'A' THEN
    PRINT 'ALONGSIDE '; SHP$:
    GOTO 440
390 IF L$ = 'L' THEN
    PRINT 'LEAVING '; SHP$:
    GOTO 440
400 IF L$ = 'P' THEN
    PRINT 'PASSING '; SHP$:
    GOSUB 420:
    GOTO 440
410 PRINT L$
420 PRINT SHIP$(I), SHP$
430 STOP
440 NEXI:
450 IF A$ = 'Y' THEN
    PRINT D$; 'PRO},':
    HOME
455 IF A$ <> 'Y' THEN
    SPEED = 255
470 POKE 34,0
480 PRINT D$; 'RUN MENU, D1':
490 IF D$ <> '0' THEN
RETURN
500 IF TIME$(I) > PTIME$(K) THEN 550
510 IF SHP$ < PNAME$(K) THEN 550
520 PRINT ' *IPDOSE(K)
530 K = K + 1
540 RETURN
550 PRINT 'WHAT SLOT IS THE PRINTER IN''
PRINT P#$
551 IF P$ > '3' OR P$ < '1' THEN 550
555 A$ = 'Y'
SPEED = 255:
PRINT :
PRINT :
PRINT
560 PRINT D$;"PR";P$:
570 FOR J = 1 TO PASSES
580 PRINT PTIME$(J),PNAME$(J):PODGE(J)
590 NEXT
600 PRINT 'ERROR IN FILE'
610 C9 = 1!
RETURN
9000 PRINT 'NOT ENOUGH DATA , ONLY "PTIMES:" POINTS'
9010 GET A$:
PRINT :
PRINT D$;"RUN MENU:D1"
Program: UPDATE SHIP CONTAMINATION

Program Objective: To allow manual changes to the doses contained in the SHIP CONTAMINATION file to account for special circumstances.

Description: This program reads in "ship" SELF file, displays values on screen, allows the input of new values for any day, and outputs a revised file.

This program is not intended for use when the path of a ship has been changed - SHIP CONTAMINATION should be re-executed in that case. This program only allows the modification of specific values, as might be appropriate when sailing through a radioactive oil slick.

Input: Existing file "ship" SELF

Output: Updated file "ship" SELF
Table 4-12  Update Ship Contamination

10  D$ = CHR$(4)
20  HOME:
    VTAB 8
30  DIM SELF(100)
40  INPUT "NAME OF SHIP IS?"; $X$
50  I$ = $X$ + " SELF"
60  PRINT D$:"OPEN ";I$";D2"
70  PRINT D$:"READ ";I$
80  INPUT BDAY
90  INPUT NDAY
100 FOR I = 0 TO NDAY
110    INPUT SELF(I)
120    NEXT I
125 INPUT ITEM
130 PRINT D$:"CLOSE ";I$
140   I1 = 0;
150   I2 = I1 + 19
160 IF I2 > NDAY THEN
170    I2 = NDAY
160 IF I1 > NDAY THEN
    HOME:
    VTAB 10:
    GOTO 300
170 HOME
180 PRINT "DAY*:SHIP-CONTAMINATION"
190 FOR I = I1 TO I2
200    PRINT I*SELF(I)
210    NEXT I
220 PRINT "ARE THESE OK?";
230 GET A$;
    PRINT A$;
240 IF A$ = "Y" THEN
190    I1 = I2 + 1;
200    I2 = I1 + 19;
    GOTO 150
250 IF A$ <> "N" THEN 170
260 INPUT "WHICH DAY NEEDS CHANGING?";K
270 INPUT "NEW VALUE =";SELF(K)
280 GOTO 150
290 STOP
300 PRINT
310 INPUT "DO YOU WANT TO SAVE THESE CHANGES IN A NEW FILE?";AN$
320 IF AN$ < > 'Y' THEN 430
330 PRINT D$;"OPEN *;Z$';D2"
340 PRINT D$;"DELETE";Z#
350 PRINT D$;"OPEN *;Z#
360 PRINT D$;"WRITE ";Z#
370 PRINT BDAY
380 PRINT NDAY
390 FOR I = 0 TO NDAY
400 PRINT SELF(I)
410 NEXT I
415 PRINT ITEM
420 PRINT D$;"CLOSE ";Z#
430 PRINT D$;"PRIO"
440 PRINT D$;"RUN MENU;D1"
Section 5
USS RECLAIMER OPERATIONS

To demonstrate the application of the dose reconstruction methodology, a detailed examination is made of the operations of the USS RECLAIMER (ARS-42).

5.1 USS RECLAIMER Dose Reconstruction

As a salvage ship and the flagship of the Director of Ship Material (DSM), the RECLAIMER participated in nearly all radiologically significant operations, and her movements are well-documented. After each detonation, she followed the PGM/LCPL radiological monitors into the lagoon; onboard, the DSM made the first inspections of the target array and supervised the conduct of salvage operations. Data sources on ship operations include deck logs, salvage ship summaries (Reference 22), operation summaries (Reference 21), and reports of the Director of Ship Material activities (Reference 32). Additionally, operational data are obtained from original message traffic and Director of Ship Material target ship inspection reports.

An Information Summary for the RECLAIMER is contained in Table 5-1, and a Path Report in Table 5-2. The information recorded in the Path Report includes time, location, and ship activity (such as passing close to or moored alongside a target ship). The time is given as a six-digit date-time group, the first two digits of which is the day, with 1 July 1946 as day 01 and numbered consecutively thereafter (e.g., 1 August 1946 = day 32). The remaining four digits is the military time. The date-time group of each change of status of the RECLAIMER is recorded through 39 days after Shot BAKER, after which she departed Bikini Lagoon for Kwajalein. The location is given using a grid coordinate system, described in Section 4.1, which is based on Navy Hydrographic Office Misc. Chart Number 11854. Portions of this chart are reproduced in Figures B-1, 2, 3, and 4 of Appendix B. The results of the analysis of the RECLAIMER are contained in Table 5-3, the Radiation Report. This report is a day-by-day compilation of the reconstructed film badge doses from the various radiation sources that this ship encountered while in Bikini Lagoon. Daily and cumulative totals are also included until departure from Bikini. A detailed explanation of each source is found in Section 2 of this volume.
Table 5-1
Support Ship Information Summary

SHIP: USS RECLAIMER (ARS-42)

CREW SIZE: 73

GROUP: SALVAGE

MISSION: RECLAIMER arrived at Bikini on June 1, 1946 and began to prepare for the operation. As a member of the Salvage Unit, RECLAIMER's duties included salvaging the damaged target vessels after the tests, performing emergency repairs, and fighting fires. In addition, the Director of Ship Material (DSM) was embarked aboard the RECLAIMER from where he coordinated all salvage operations. The DSM, in RECLAIMER, made the first inspection of the target array, operating on numerous occasions between the Red and Blue lines.

<table>
<thead>
<tr>
<th>SHOT DATA:</th>
<th>TEST</th>
<th>DATE (TIME)</th>
<th>YIELD</th>
<th>TYPE DETONATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABLE</td>
<td>1 July 46 (0900)</td>
<td>23 KT</td>
<td>Air Burst (+520 feet)</td>
<td></td>
</tr>
<tr>
<td>BAKER</td>
<td>25 July 46 (0835)</td>
<td>23 KT</td>
<td>Shallow Underwater (-90 feet)</td>
<td></td>
</tr>
</tbody>
</table>

PATH REPORT: This report contains the geographic locations of CTJF-1 support vessels within Bikini lagoon. The time is in Day-Hour-Minutes and begins 1 July 1946. All days are July (e.g., 1 Aug = 32 July, etc.). Place is the grid square within Bikini lagoon from Hydrographic Office Misc. Chart number 11854, portions of which are reproduced in Figures B-1, 2, 3, 4.

RADIATION REPORT: This report is a day-by-day compilation of the reconstructed film badge dose for this unit from the various sources which it encountered while at Bikini lagoon. A daily total and cumulative total are also included up to departure from Bikini. A detailed explanation of each source contribution is contained in the basic report, Section 2.

Total calculated dose received while at Bikini: 1,679 REM

Date unit departed Bikini: September 1, 1946 (BAKER + 38)

Ship contamination factor when departing Bikini: 4
   (this value is for use with the nomograph in Figure B-5)
### Table 5-2 RECLAIMER Path Report

**PATH REPORT FOR THE USS RECLAIMER**

<table>
<thead>
<tr>
<th>TIME</th>
<th>PLACE</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>010900</td>
<td>2591M</td>
<td>OBSERVED SHOT ABLE FROM APPROXIMATELY 27 MILES</td>
</tr>
<tr>
<td>011219</td>
<td>2592M</td>
<td>ENTERED BIKINI LAGOON</td>
</tr>
<tr>
<td>011300</td>
<td>2592M</td>
<td>PROCEEDING TO VICINITY OF USS SARATOGA</td>
</tr>
<tr>
<td>011325</td>
<td>2399A</td>
<td>PASSING SARATOGA</td>
</tr>
<tr>
<td>011524</td>
<td>2399A</td>
<td>LEAVING USS SARATOGA</td>
</tr>
<tr>
<td>011525</td>
<td>2200U</td>
<td>PASSING PENNSYLVANIA</td>
</tr>
<tr>
<td>011600</td>
<td>2200U</td>
<td>LEAVING USS PENNSYLVANIA</td>
</tr>
<tr>
<td>011601</td>
<td>2301U</td>
<td>PASSING NEW YORK</td>
</tr>
<tr>
<td>011625</td>
<td>2301U</td>
<td>LEAVING USS NEW YORK</td>
</tr>
<tr>
<td>011733</td>
<td>2201P</td>
<td>PASSING NEVADA</td>
</tr>
<tr>
<td>011742</td>
<td>2201P</td>
<td>LEAVING USS NEVADA</td>
</tr>
<tr>
<td>011759</td>
<td>2001R</td>
<td>NEAR USS DAWSON</td>
</tr>
<tr>
<td>011812</td>
<td>1800W</td>
<td>NEAR USS COURTLAND</td>
</tr>
<tr>
<td>011820</td>
<td>2002V</td>
<td>NEAR PRINZ EUGEN</td>
</tr>
<tr>
<td>011828</td>
<td>2006J</td>
<td>MANEUVERING AS BEFORE</td>
</tr>
<tr>
<td>011839</td>
<td>2400J</td>
<td>ANCHORED IN VICINITY OF BERTH 190</td>
</tr>
<tr>
<td>020000</td>
<td>2400J</td>
<td>UNDERWAY</td>
</tr>
<tr>
<td>021131</td>
<td>2201P</td>
<td>PASSING NEVADA</td>
</tr>
<tr>
<td>021135</td>
<td>2201P</td>
<td>SECURED FROM FIGHTING FIRE ON USS NEVADA</td>
</tr>
<tr>
<td>021305</td>
<td>2102S</td>
<td>PASSING LAMSON</td>
</tr>
<tr>
<td>021620</td>
<td>2101S</td>
<td>NEAR SKATE</td>
</tr>
<tr>
<td>021733</td>
<td>2101X</td>
<td>PASSING INDEPENDENCE</td>
</tr>
<tr>
<td>021757</td>
<td>2101X</td>
<td>PROCEEDING AWAY FROM USS INDEPENDENCE</td>
</tr>
<tr>
<td>021848</td>
<td>2404C</td>
<td>ANCHORED IN BERTH #42</td>
</tr>
<tr>
<td>030757</td>
<td>2404C</td>
<td>UNDERWAY</td>
</tr>
<tr>
<td>031600</td>
<td>2100G</td>
<td>PASSING ARDC-13</td>
</tr>
<tr>
<td>031030</td>
<td>2100G</td>
<td>PROCEEDING TO USS NEVADA</td>
</tr>
<tr>
<td>031041</td>
<td>2201P</td>
<td>ALONGSIDE NEVADA</td>
</tr>
<tr>
<td>031210</td>
<td>2201P</td>
<td>LEAVING NEVADA</td>
</tr>
<tr>
<td>031220</td>
<td>2101E</td>
<td>ALONGSIDE ARKANSAS</td>
</tr>
<tr>
<td>031210</td>
<td>2101E</td>
<td>LEAVING ARKANSAS</td>
</tr>
<tr>
<td>031435</td>
<td>2795K</td>
<td>IN SALVAGE UNIT ANCHORAGE AREA</td>
</tr>
<tr>
<td>031500</td>
<td>21010</td>
<td>ALONGSIDE YO-160</td>
</tr>
<tr>
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<td>21010</td>
<td>LEAVING YO-160</td>
</tr>
<tr>
<td>031530</td>
<td>2001I</td>
<td>ALONGSIDE CRITTENDEN</td>
</tr>
<tr>
<td>031556</td>
<td>2001I</td>
<td>LEAVING CRITTENDEN</td>
</tr>
<tr>
<td>031645</td>
<td>2795K</td>
<td>ANCHORED IN BERTH &quot;BAKER&quot;</td>
</tr>
<tr>
<td>031700</td>
<td>2795K</td>
<td>PASSING SUMMARY 12</td>
</tr>
<tr>
<td>042400</td>
<td>2795K</td>
<td>ANCHORED IN BERTH &quot;BAKER&quot;</td>
</tr>
<tr>
<td>250835</td>
<td>2591M</td>
<td>OBSERVED SHOT BAKER FROM A DISTANCE IN EXCESS OF 14 MILES</td>
</tr>
<tr>
<td>251100</td>
<td>2592M</td>
<td>ENTERED BIKINI LAGOON</td>
</tr>
<tr>
<td>251250</td>
<td>2493M</td>
<td>APPROACHING TARGET ARRAY</td>
</tr>
<tr>
<td>251330</td>
<td>2297M</td>
<td>ESTIMATED POSITION</td>
</tr>
<tr>
<td>251405</td>
<td>2299A</td>
<td>ESTIMATED POINT OF CROSSING RED LINE</td>
</tr>
<tr>
<td>251530</td>
<td>2001N</td>
<td>ESTIMATED POSITION</td>
</tr>
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</table>

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251545 2000J ESTIMATED POSITION
251555 2000X ESTIMATED POSITION
251605 2100L ESTIMATED POSITION
251737 2595M ANCHORED IN BERTH #36B
251900 2595M PASSING PARCHE 2
260001 2595M ANCHORED AS BEFORE
261425 2595M UNDERWAY
261450 2200G PASSING GASCONADE 15
261500 2201N ALONGSIDE HUGHES
261518 2201N LEAVING HUGHES
261640 2793M ALONGSIDE HUGHES
261648 2793M LEAVING HUGHES
261740 2793M ALONGSIDE HUGHES
261749 2793M LEAVING HUGHES
261805 2101M IN VICINITY OF USS FALLO
261815 2101M LEAVING VICINITY OF USS FALLO
261822 2100I SUB AREA
261854 2695M ANCHORED IN BERTH #370
270615 2695M UNDERWAY
270844 2201E PASSING SALT LAKE CITY 3
270855 2101I PASSING FALLO 6
270935 2200Q PASSING PENNSYLVANIA 9
270940 2200X PASSING BRACKEN 9
271046 2200S PASSING CATRON 6
271025 2595M ANCHORED NEAR BERTH #36B
271200 2595M UNDERWAY
271210 2793M PASSING HUGHES 0
271220 2693M ANCHORED NEAR ENYU ISLAND - "A" 126.5 DEG - "B" 27 DEG
271540 2693M UNDERWAY
271608 2200D PASSING PENNSYLVANIA 12
271610 2200G PASSING GASCONADE 3
271616 2201Y PASSING NEW YORK 4
271630 2202V PASSING NAGATO 4
271631 2202K PASSING NEVADA 6
271637 2100I SUB AREA
271655 2000D PASSING INDEPENDENCE 4
271733 2695M ANCHORED NEAR BERTH #370
271900 2695M PASSING LST-133 3
271901 2695M PASSING PARCHE 0
271902 2695M PASSING RALPH TALBOT 1
271903 2695M PASSING MUSTIN 3
280821 2695M UNDERWAY FROM BERTH #370
280835 2100U NEAR SUBMARINES IN TARGET ARRAY
280845 2199F NEAR USS TUNA
280952 2200P PASSING PENNSYLVANIA 4
280900 2200H PASSING BRISCOE 4
280903 2201S PASSING NEW YORK 4
280923 2101D PASSING PENSACOLA 4
280937 2201I PASSING LST-133 0
280940 2301A PASSING SALT LAKE CITY 4
280945 22020 PASSING NAGATO 4
280950 22020 PASSING NEVADA 4
281000 19030 NEAR LCT-114
281009 21051 NEAR LST-545
281017 21040E PASSING LST-220 4
281030 22020B PASSING LST-52 9
281050 21000C PROCEEDING TO SUB AREA
281219 22010Y PASSING NEW YORK 5
281230 22000M MANEUVERING AS BEFORE
281245 2695M ANCHORED IN BERTH #370
281543 2695M UNDERWAY
281555 2795M STANDING BY BEACHING OF USS DENTUDA IN BEACHING AREA OFF ENYU ISLAND
281630 22000M PROCEEDING TOWARD USS BRISCOE
281637 22000H PASSING BRISCOE 4
281652 22020 PASSING NAGATO 4
281655 20020M PASSING NEVADA 4
281810 21000C IN SUBMARINE AREA
281825 2094S ANCHORED IN BERTH #380
281900 2094S PASSING LST-661 2
281901 2094S PASSING YDG-83 1
281902 2094S PASSING CONYNGHAM 1
281903 2094S PASSING MUGFORD 1
281904 2094S PASSING RALPH TALBOT 3
281905 2094S PASSING MAYRANT 3
281906 2094S PASSING TRIPPE 1
281907 2094S PASSING RHIND 2
281908 2094S PASSING STACK 5
281909 2094S PASSING WILSON 3
281910 2094S PASSING MUSTIN 1
281911 2094S PASSING WAINWRIGHT 1
290855 2094S UNDERWAY FROM BERTH #380
290920 22000D PASSING PENNSYLVANIA 4
290935 22010U PASSING SARATOGA 4
290939 22000G PASSING GASCONADE 9
290943 22000S PASSING CATRON 4
290952 2200H PASSING BRISCOE 9
291009 22010E PASSING SALT LAKE CITY 6
291015 22020V PASSING NAGATO 6
291020 22020K PASSING NEVADA 4
291032 21010G PASSING BRULE 9
291039 21010D PASSING PENSACOLA 9
291058 22010Y ALONGSIDE NEW YORK 1
291105 22010Y LEAVING NEW YORK 1
291120 2298S ANCHORED IN BERTH #282
291429 2298S UNDERWAY
291504 2793M OFF ENYU ISLAND
291605 2793M OFF ENYU ISLAND
291634 22010Y ALONGSIDE NEW YORK 1
291639 22010Y LEAVING NEW YORK 1

133
291648 2201E PASSING SALT LAKE CITY 4
291651 2202V PASSING NAZATO 6
291653 2202H PASSING NEVADA 12
291715 21010 PASSING PENSACOLA 7
291720 2054S ANCHORED IN VICINITY OF BERTH # 380
291720 2054S PASSING YOG-83 8
301040 2054S UNDERWAY FROM BERTH # 380
301040 2201M IN TARGET ARRAY
301040 2201M LEAVING TARGET ARRAY
301057 2054M ANCHORED OFF ENYU ISLAND - "A" 151 DEG "B" 21 DEG
301050 2054M PASSING MAYFANT 4
301051 2054M PASSING TRIPPE 3
301052 2054M PASSING RHIND 3
301054 2054M PASSING WILSON 3
301430 2054M UNDERWAY FROM ANCHORAGE
301525 2201V ALONGSIDE NEW YORK
301525 2201V LEAVING NEW YORK
301600 2101D ALONGSIDE PENSACOLA
301605 2101D LEAVING PENSACOLA
301715 2101D ALONGSIDE PENSACOLA
301720 2101D LEAVING PENSACOLA
301825 2054M ANCHORED OFF ENYU ISLAND - "A" 166 DEG "B" 18 DEG
310002 2054M UNDERWAY FROM ANCHORAGE NEAR BERTH # 370
310020 2201M INSPECTING TARGET ARRAY
311100 2201M UNDERWAY TO ANCHORAGE
311110 2402W ANCHORED IN BERTH # 145
311450 2402W UNDERWAY
311450 2201M UNDERWAY AS BEFORE
311455 2201E PASSING SALT LAKE CITY 4
311503 1902D ALONGSIDE CONYNGHAM
311503 1902D LEAVING CONYNGHAM
311551 1902D ALONGSIDE WAINWRIGHT 1
311595 1902D LEAVING WAINWRIGHT 1
311615 1902E ALONGSIDE MUGFORD 1
311650 1902E LEAVING MUGFORD 1
311705 2402E ANCHORED IN VICINITY OF BERTH # 145
311835 2402W UNDERWAY FROM VICINITY OF BERTH # 145
311835 2101D ALONGSIDE PENSACOLA
311920 2101D LEAVING PENSACOLA
311930 2201D LAYING TO IN VICINITY OF USS SALT LAKE CITY IN BERTH # 183
311944 2301A PROCEEDING TO USS PENSACOLA
321415 2101D ALONGSIDE PENSACOLA
321526 2101D LEAVING PENSACOLA
321537 2100B ANCHORED IN VICINITY OF BERTH # 219
321745 2100B UNDERWAY
321935 2101D ALONGSIDE PENSACOLA
321935 2101D LEAVING PENSACOLA
321945 2101D ANCHORED IN VICINITY OF BERTH # 156 - "D" 14 DEG "C" 3
359 DEG "B" 71.5 DEG

134
341500 2195P UNDERWAY FROM ANCHORAGE
341623 2000E ANCHORED IN BERTH #219
341829 2000E UNDERWAY PROCEEDING TO ANCHORAGE IN VICINITY OF USS FALL RIVER
341850 2194B ANCHORED IN BERTH #357
352400 2194B ANCHORED AS BEFORE
361425 21010 ALONGSIDE PENSACOLA
361510 21010 LEAVING PENSACOLA
370932 21010 ALONGSIDE PENSACOLA
370937 21010 LEAVING PENSACOLA
371335 21010 ALONGSIDE PENSACOLA
371410 21010 LEAVING PENSACOLA
381415 21010 ALONGSIDE PENSACOLA
381548 21010 LEAVING PENSACOLA
391509 21010 ALONGSIDE PENSACOLA
391610 21010 LEAVING PENSACOLA
400856 2102S ALONGSIDE MAYRANT2
400946 2102S LEAVING MAYRANT2
411025 21010 ALONGSIDE PENSACOLA
411126 21010 LEAVING PENSACOLA
441630 21010 ALONGSIDE PENSACOLA
441638 21010 LEAVING PENSACOLA
470800 2201Y ALONGSIDE NEW YORK2
471500 2201Y LEAVING NEW YORK2
480810 2201P ALONGSIDE NEVADA2
481600 2201P LEAVING NEVADA2
500875 22000 ALONGSIDE PENNSYLVANIA
501622 22000 LEAVING PENNSYLVANIA
510851 22000 ALONGSIDE PENNSYLVANIA
511745 22000 LEAVING PENNSYLVANIA
520820 2201Y ALONGSIDE NEW YORK2
521238 2201Y LEAVING NEW YORK2
521345 22000 ALONGSIDE PENNSYLVANIA
521412 22000 LEAVING PENNSYLVANIA
531425 2102S ALONGSIDE MAYRANT2
531505 2102S LEAVING MAYRANT2
571042 2591M ALONGSIDE CRITTENDEN
571335 2591M LEAVING CRITTENDEN
581247 2101M ALONGSIDE FALLON
581415 2101M LEAVING FALLON
581505 2101M ALONGSIDE FALLON
581625 2101M LEAVING FALLON
610723 2101M ALONGSIDE FALLON
611126 2101M LEAVING FALLON
631150 2101M ALONGSIDE FALLON
631245 2101M LEAVING FALLON
631500 2592M DEPARTED BIKINI LAGOON ON 1 SEPTEMBER 1946 - ENROUTE KWAJALEIN
<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
<th>LAGOON WATER</th>
<th>TARGET SHIPS</th>
<th>SHIP CONTAMINATION</th>
<th>DAILY TOTAL</th>
<th>CUM TOTAL</th>
</tr>
</thead>
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<tr>
<td>JUL 1</td>
<td>A+0</td>
<td>15</td>
<td>0</td>
<td></td>
<td>15</td>
<td>15</td>
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<td>JUL 2</td>
<td>A+1</td>
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<td>0</td>
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<td>21</td>
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<td>JUL 3</td>
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<td>8</td>
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<td>25</td>
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<td></td>
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<td>2?</td>
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<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>29</td>
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<td>JUL 25</td>
<td>B+0</td>
<td>29</td>
<td>1</td>
<td>45</td>
<td>75</td>
<td>104</td>
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<td>127</td>
<td>42</td>
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<td>282</td>
</tr>
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<td>11</td>
<td>51</td>
<td>60</td>
<td>122</td>
<td>404</td>
</tr>
<tr>
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<td>57</td>
<td>59</td>
<td>134</td>
<td>538</td>
</tr>
<tr>
<td>JUL 29</td>
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<td>84</td>
<td>40</td>
<td>129</td>
<td>667</td>
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<tr>
<td>JUL 30</td>
<td>B+5</td>
<td>3</td>
<td>32</td>
<td>31</td>
<td>66</td>
<td>733</td>
</tr>
<tr>
<td>JUL 31</td>
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<td>50</td>
<td>26</td>
<td>87</td>
<td>820</td>
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<tr>
<td>AUG 1</td>
<td>B+7</td>
<td>16</td>
<td>0</td>
<td>21</td>
<td>37</td>
<td>857</td>
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<td>AUG 2</td>
<td>B+8</td>
<td>14</td>
<td>81</td>
<td>18</td>
<td>113</td>
<td>975</td>
</tr>
<tr>
<td>AUG 3</td>
<td>B+9</td>
<td>1</td>
<td>0</td>
<td>16</td>
<td>17</td>
<td>987</td>
</tr>
<tr>
<td>AUG 4</td>
<td>B+10</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>14</td>
<td>1601</td>
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<td>1</td>
<td>27</td>
<td>12</td>
<td>46</td>
<td>1041</td>
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<tr>
<td>AUG 6</td>
<td>B+12</td>
<td>7</td>
<td>18</td>
<td>11</td>
<td>32</td>
<td>1073</td>
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<td>AUG 7</td>
<td>B+13</td>
<td>4</td>
<td>39</td>
<td>10</td>
<td>53</td>
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<td>B+14</td>
<td>10</td>
<td>23</td>
<td>9</td>
<td>42</td>
<td>1168</td>
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<td>B+15</td>
<td>9</td>
<td>15</td>
<td>8</td>
<td>32</td>
<td>1200</td>
</tr>
<tr>
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<td>20</td>
<td>8</td>
<td>36</td>
<td>1276</td>
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<tr>
<td>AUG 11</td>
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<td>0</td>
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<td>14</td>
<td>1280</td>
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<td>AUG 12</td>
<td>B+18</td>
<td>6</td>
<td>0</td>
<td>7</td>
<td>13</td>
<td>1283</td>
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<tr>
<td>AUG 13</td>
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<td>6</td>
<td>1</td>
<td>6</td>
<td>13</td>
<td>1275</td>
</tr>
<tr>
<td>AUG 14</td>
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<td>5</td>
<td>0</td>
<td>6</td>
<td>11</td>
<td>1286</td>
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<td>AUG 15</td>
<td>B+21</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>1297</td>
</tr>
<tr>
<td>AUG 16</td>
<td>B+22</td>
<td>4</td>
<td>8</td>
<td>5</td>
<td>17</td>
<td>1314</td>
</tr>
<tr>
<td>AUG 17</td>
<td>B+23</td>
<td>4</td>
<td>30</td>
<td>5</td>
<td>39</td>
<td>1353</td>
</tr>
<tr>
<td>AUG 18</td>
<td>B+24</td>
<td>3</td>
<td>0</td>
<td>4</td>
<td>7</td>
<td>1360</td>
</tr>
<tr>
<td>AUG 19</td>
<td>B+25</td>
<td>3</td>
<td>62</td>
<td>4</td>
<td>69</td>
<td>1429</td>
</tr>
<tr>
<td>AUG 20</td>
<td>B+26</td>
<td>3</td>
<td>67</td>
<td>4</td>
<td>74</td>
<td>1503</td>
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<tr>
<td>AUG 21</td>
<td>B+27</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>13</td>
<td>1516</td>
</tr>
<tr>
<td>AUG 22</td>
<td>B+28</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>10</td>
<td>1526</td>
</tr>
<tr>
<td>AUG 23</td>
<td>B+29</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>1532</td>
</tr>
<tr>
<td>AUG 24</td>
<td>B+30</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>1535</td>
</tr>
<tr>
<td>AUG 25</td>
<td>B+31</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>1538</td>
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<tr>
<td>AUG 26</td>
<td>B+32</td>
<td>0</td>
<td>10</td>
<td>3</td>
<td>13</td>
<td>1551</td>
</tr>
<tr>
<td>AUG 27</td>
<td>B+33</td>
<td>0</td>
<td>39</td>
<td>3</td>
<td>42</td>
<td>1593</td>
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<tr>
<td>AUG 28</td>
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<td>1</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>1597</td>
</tr>
<tr>
<td>AUG 29</td>
<td>B+35</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>1601</td>
</tr>
<tr>
<td>AUG 30</td>
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<td>1</td>
<td>58</td>
<td>3</td>
<td>62</td>
<td>1663</td>
</tr>
<tr>
<td>AUG 31</td>
<td>B+37</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>1667</td>
</tr>
<tr>
<td>SEP 1</td>
<td>B+38</td>
<td>0</td>
<td>10</td>
<td>2</td>
<td>12</td>
<td>1679</td>
</tr>
</tbody>
</table>
Although the RECLAIMER operated on numerous occasions between the blue and red lines, the water activation model indicates that she operated within the red line (i.e., greater than 1 R/24 hr) only once. It appears that constant attention was paid to total daily accumulated dose, as the model predicts a daily dose of approximately 100 mrem for the first few days after Shot BAKER. The standard at Bikini was 100 mrem daily dose.

The Information Summary, Path Report, and Radiation Report for each support ship of CJTF-1 are presented in Appendix B: Support Ships, and constitute the final results for each vessel.

5.2 USS RECLAIMER Boarding Parties

The term "boarding party" is found throughout the deck logs of the RECLAIMER without differentiation as to type, as defined in Section 3.3. The relevant documented boardings and calculated doses of the various boarding parties from the RECLAIMER are presented in Table 5-4. While several instances of target vessel boarding are found in RECLAIMER's deck log, only those for which dosimetry is available are shown. The total boarding time in each case is assumed to have been topside in the absence of additional information. Intensities are taken from the target ship intensity graphs of Appendix A. The below-deck (interior) intensity is used only when appropriate, as on B+8 when personnel were installing a pump on the USS PENSACOLA for dewatering purposes. The times spent onboard the target vessels are not well documented beyond B+25; hence, no entries are included after that date.

To calculate the dose for a member of a boarding party, the daily dose appearing in the Radiation Report (which includes a dose contribution for alongside the target ship) is supplemented by the additional dose accrued during boarding operations. This is accomplished by calculating the dose accrued while aboard the target vessel and subtracting the dose that personnel remaining aboard the alongside support ship accrued during the same time period. Both the daily (24-hour) dose and the supplemental dose from boarding operations are shown in the table.
Table 5-4  
Boarding Team Dose Reconstruction, USS RECLAIMER

<table>
<thead>
<tr>
<th>Date</th>
<th>Ship Boarded or Alongside</th>
<th>Time (min)</th>
<th>Intensity (R/day)</th>
<th>Calculated Dose (mrem)</th>
<th>Average Crew (daily)</th>
<th>Boarding Team (while aboard target ship)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31 July (B+6)</td>
<td>CONYNGHAM</td>
<td>34</td>
<td>34</td>
<td>0.5</td>
<td>116</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>WAINWRIGHT</td>
<td>24</td>
<td>18</td>
<td>1.5</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>MUGFORD</td>
<td>14</td>
<td>9</td>
<td>5.9</td>
<td>26</td>
<td>51</td>
</tr>
<tr>
<td>2 Aug (B+8)</td>
<td>PENSACOLA</td>
<td>104</td>
<td>Topside 20</td>
<td>12.4</td>
<td>139</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Interior 69</td>
<td>0.9</td>
<td>29</td>
<td>149</td>
</tr>
<tr>
<td>5 Aug (B+11)</td>
<td>PENSACOLA</td>
<td>53</td>
<td>53</td>
<td>8.2</td>
<td>65</td>
<td>210</td>
</tr>
<tr>
<td>7 Aug (B+13)</td>
<td>PENSACOLA</td>
<td>93</td>
<td>93</td>
<td>6.6</td>
<td>70</td>
<td>297</td>
</tr>
<tr>
<td>8 Aug (B+14)</td>
<td>PENSACOLA</td>
<td>61</td>
<td>60</td>
<td>6.0</td>
<td>51</td>
<td>174</td>
</tr>
<tr>
<td>13 Aug (B+19)</td>
<td>PENSACOLA</td>
<td>8</td>
<td>8</td>
<td>4.0</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>17 Aug (B+23)</td>
<td>PENSACOLA</td>
<td>-</td>
<td>45*</td>
<td>3.1</td>
<td>45</td>
<td>68</td>
</tr>
<tr>
<td>19 Aug (B+25)</td>
<td>PENSACOLA</td>
<td>-</td>
<td>92*</td>
<td>2.8</td>
<td>75</td>
<td>125</td>
</tr>
</tbody>
</table>

*4 five-minute boat trips subtracted.
5.3 Comparison With Film Badge Data

Analysis of the dosimetry and personnel rosters showed that most film badges were issued to members of boarding parties and the remainder to RECLAIMER crew members. To compare recorded dosimetry with a calculated dose, it is necessary to identify boarding events and recorded times with corresponding dosimetry. There are numerous records of target ship boardings in the deck log of the RECLAIMER, but most are unusable due to undetermined periods, unknown participants, and no corresponding dosimetry. Likewise, there is dosimetry for RECLAIMER, but some for periods in which RECLAIMER remained at anchor and did not participate in target ship boardings. In these cases, the film badge likely reflects an unrecorded activity for which no reconstruction or calculation is possible. Table 5-4 lists those target ship boardings reported in the deck logs of the RECLAIMER that are also supported by relevant dosimetry. It is assumed that film badges were issued for daily use to members of the boarding teams, and that the badges were exposed for an average 8-hour work day by a combination of support ship (i.e., RECLAIMER) and target ship boarding time.

Using the above assumption, the film badge dose for boarding parties is determined by adding the dose accrued on the support ship for the remainder of the 8-hour badge period to the dose accrued during actual boarding operations shown in Table 5-4. The total dose is shown in Table 5-5, as is the dosimetry for the same assumed badge period. Calculated values agree reasonably well with the film badge averages, except for 13 and 19 August. On 13 August, there were two additional reported boarding parties that left the RECLAIMER for a total of 3½ hours to service pumps aboard the PENSACOLA and MAYRANT. However, because the RECLAIMER was not reported alongside either ship during that time and because no realistic estimate of the time spent aboard those ships can be made, they are not included in this comparison. Inclusion would increase the calculated dose. For 19 August, film badge readings may be low due to time spent below. However, the calculated dose reflects only topside exposure and is thus high-sided in this instance.
Table 5-5
Comparison of RECLAIMER Calculated Doses with Dosimetry

<table>
<thead>
<tr>
<th>Date</th>
<th>Number of Badges</th>
<th>Range (mrem)</th>
<th>Average (mrem)</th>
<th>Calculated Dose* (mrem)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31 July</td>
<td>5</td>
<td>50–50</td>
<td>50</td>
<td>85</td>
</tr>
<tr>
<td>2 Aug</td>
<td>6</td>
<td>50–380</td>
<td>187</td>
<td>185</td>
</tr>
<tr>
<td>5 Aug</td>
<td>1</td>
<td>--</td>
<td>300</td>
<td>229</td>
</tr>
<tr>
<td>7 Aug</td>
<td>1</td>
<td>--</td>
<td>370</td>
<td>316</td>
</tr>
<tr>
<td>8 Aug</td>
<td>3</td>
<td>100–230</td>
<td>147</td>
<td>187</td>
</tr>
<tr>
<td>13 Aug</td>
<td>6</td>
<td>60–210</td>
<td>95</td>
<td>23**</td>
</tr>
<tr>
<td>17 Aug</td>
<td>2</td>
<td>60–60</td>
<td>60</td>
<td>82</td>
</tr>
<tr>
<td>19 Aug</td>
<td>3</td>
<td>50–60</td>
<td>53</td>
<td>145</td>
</tr>
</tbody>
</table>

*Includes appropriate target ship and support ship doses for the assumed 8-hour badge period.

**Does not include all reported exposure (see text).
Section 6
UNCERTAINTY ANALYSIS

Two features of Operation CROSSROADS stand out in the dose reconstruction analysis: the radiation environment and ship operations were complex, and relevant data are not abundant. Therefore it is not unexpected that the uncertainties in calculated doses are rather large. In all calculations the quantity of interest is the film badge dose of an average sailor, defined as one who moved about a support ship subject to the constraint that he spent 1/3 time topside and 2/3 below decks (eating, sleeping, working or participating in other activities, but remaining outside the engine room) and who was exposed to the average dose of the appropriate location (topside, amidships, below decks) while on a target ship. Although some crew members probably spent more than eight hours per day topside, this constraint provides higher calculated doses for average crew members. Each dose contribution (ABLE water, ABLE target ship, BAKER water, BAKER target ship, and ship contamination) must be analyzed separately, and an uncertainty assigned to each. Since the environmental models developed in Section 2 are generally based on data sets of limited extent and accuracy, it is impractical to perform error analyses using standard techniques in all cases. Rather, best estimates of upper and lower bounds, expressed in terms of error factors, and a description of the methodology are provided. Wherever possible, these error factors are derived such that the bounds correspond approximately to 90-percent confidence limits. The upper confidence limit of a calculated dose is the product of that dose and the error factor; the lower confidence limit equals the dose divided by the error factor. It often occurs in the following analyses that the uncertainty in dose not symmetrical, so that the error factors used to determine the upper and lower confidence limits are not equal.

6.1 Uncertainty of Shot ABLE Water Doses

The uncertainty in the calculated water intensity for Shot ABLE is the major source of uncertainty in these doses. Except for the PGMs and LCPLs, the paths of support ships through the radioactive environment are known with a high degree of accuracy. Therefore, it is sufficient to concentrate on the water intensity, which is expressed in Section 2.1 as:
\[ I(r,t) = t^{-3/2} \exp \left[ -A \left( \frac{r^2}{t} \right) - \lambda t + B \right]. \]

The value of \( B \) (0.503) is determined from the observation that the blue line vanished 25 hours after detonation. This is considered the most accurate data point in Table 2-1. The remaining data in this table are then used to determine a mean value of the constant \( A \) (4.56x10^{-6}). This is accomplished by calculating a value of \( A \) for each of the data points in this table (excluding the data corresponding to zero radius, for which a value of \( A \) cannot be determined) and deriving an average; this also provides a distribution in the quantity \( A \) on which to base an error analysis. From this distribution, which appears log-normal, 90-percent upper and lower bounds on \( A \) are derived. Since the intensity is inversely related to the magnitude of \( A \), these values are used in the computerized methodology to determine lower and upper dose estimates, respectively, of the ABLE water doses for representative ships. The upper limit error factor \((f_u)\) derived from these dose estimates is approximately 2.4; the lower limit error factor \((f_l)\) approximately 3.1.

6.2 Uncertainty of Shot ABLE Target Ship Doses

The largest uncertainty in doses received from the activated target ships at Shot ABLE is due to uncertainty in target ship intensities. Times of boarding and stay times on target ships are relatively well known. Therefore, it is sufficient to examine the modeling of target ship intensity, which is developed in Section 2.2. The target ship intensity at time \( t \) is expressed as:

\[ I(t) = CM f(t) R^{-2} e^{-R/\lambda}. \]

By fitting to the data of Table 2-3(a), the coefficient \( C \) is determined to be 1.1x10^7 \( \text{yd}^2 \cdot \text{R/day} \). This value is used in ABLE target ship dose estimates. The distribution of the values of \( C \) derived from the data in Table 2-3(a) allows an estimation of 90-percent upper and lower limits on this quantity:

\[
\begin{align*}
C \text{ (upper limit)} &\approx 2.5 \times 10^7 \\
C \text{ (lower limit)} &\approx 3.1 \times 10^6.
\end{align*}
\]
Therefore upper and lower limit error factors may be calculated:

\[
f_u = \frac{2.5 \times 10^7}{1.1 \times 10^7} = 2.3
\]

\[
f_l = \frac{1.1 \times 10^7}{3.1 \times 10^6} = 3.5
\]

6.3 Uncertainty of Shot BAKER Water Doses

As with Shot ABLE, the significant uncertainty for BAKER water doses is that of the water intensity. For most vessels (all except PGMs and LCPLs), the uncertainty in ship path is relatively small. As discussed in Section 2.3, the modeling of BAKER water intensities for BAKER Day through B+5 is accomplished primarily through analyses of reported red and blue line coordinates (e.g., Figure 2-3) and the water intensity contours of Reference 19 (Figure 2-5). The calibration of these contours (which were reported in arbitrary units) is accomplished so as to achieve maximum consistency with the red/blue line data for each day of interest. Upper and lower estimates of water intensities during this period are made by reviewing all relevant data, and determining maximum and minimum credible calibrations of the contours. The data base of the BAKER water intensity model is modified to incorporate these limiting calibration factors. The modeling of the water intensities after B+5 is based on a reported average intensity of 0.02 to 0.03 R per day on 15 August 1946 (a value of 0.025 R/day is used in the model), and on constraints imposed by the maximum initial inventory of radioactivity in the lagoon and subsequent decay and flushing rates. The size and location of the radioactive region, subject to these constraints, are chosen to maximize potential exposure to this environment. An upper estimate of the post-B+5 water environment is obtained by using the upper limit of the reported 15 August intensity range (0.03 R/day); the lower estimate is achieved by setting the water intensities to zero throughout the lagoon on B+8 (200 hours after detonation), as suggested by References 4 and 24.

Upper and lower limit BAKER water doses, calculated for nine representative ships, imply upper \((f_u)\) and lower \((f_l)\) error factors of approximately 1.7 and 5.8,
respectively. The large asymmetry in these factors results from the conservative assumptions incorporated into the model.

6.4 Uncertainty of Shot BAKER Target Ship Doses

The major uncertainty is the average target ship intensity, which includes uncertainties in the intensity measurements themselves, the representativeness of these readings, and the techniques (see Section 2.4) used to interpolate/extrapolate from these measurements. Although this uncertainty is dependent on the amount of data available for a particular ship, it is estimated that for an average ship, and average times of boarding, the ship intensities can generally be predicted to within a factor of 1.5. Boarding times and stay times on target ships are usually known to a high degree of accuracy. Therefore the upper and lower error factors for this dose contribution are estimated to be 1.5.

6.5 Uncertainty of Ship Contamination Doses

The methodology for calculating doses accrued during lagoon operations due to the radioactive contamination of support ships is developed by first reconstructing exterior hull intensities at the time of lagoon departure for each of twelve ships having documented post-Bikini hull intensity readings. These reconstructed intensities are then used to fix parameters in a mathematical model which allows hull intensities to be calculated for all support ships at any time during lagoon operations. Geometric models of the support ships and sources of radiation (hull and pipe contamination) are then used to calculate the radiation intensity distribution inside the support ships, and hence the doses to shipboard personnel. The methodology is described in detail in Section 2.5.

The uncertainty associated with the ship contamination doses can be estimated by considering possible sources of error in each step outlined above. These errors, quantified in terms of 90 percent error factors, are presented in Table 6-1. The error factors associated with the variations in the values of the parameter \( S \) are derived from the distributions of \( S \) given in Table 2-6; the error factor given for "other" ships
Table 6-1  
Sources of Uncertainty for Ship Contamination Doses

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>Error Factor (90%)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-Bikini hull intensity readings</td>
<td>1.2</td>
<td>Systematic errors in detectors and methods of measurement (random errors appear as variations in S).</td>
</tr>
<tr>
<td>Reconstruction of exterior hull intensity at lagoon departure</td>
<td>2.0</td>
<td>Systematic error in $t^{-1.3}$ hull decay factor, based on analysis of other reasonable decay rates. Error in steaming factor (%).</td>
</tr>
<tr>
<td>Modeling of exterior hull intensities during lagoon operations</td>
<td>1.5</td>
<td>Systematic errors in model.</td>
</tr>
<tr>
<td>Variations in S-values</td>
<td>1.7 for destroyers 2.1 for PGMs 2.0 for all others</td>
<td>Ship-to-ship variations in affinity for hull contamination. Random errors in post-Bikini hull readings.</td>
</tr>
<tr>
<td>Ship apportionment factors</td>
<td>1.5</td>
<td>Systematic errors in geometric modeling of radiation sources and ship interior. Errors in calculated intensity distribution.</td>
</tr>
</tbody>
</table>
(all ships except destroyers and PGMs) has been increased somewhat over that derived mathematically to reflect the additional uncertainty inherent in applying a single value of \( S \) (1570 mR-day\(^{0.3}\)) to a wide variety of ship types. The error factors assigned to other sources of uncertainty are based on semi-quantitative analyses and experience with radiation detection and modeling techniques. The combined error factor \( f \) is calculated by the relation (Reference 31)

\[
f = \exp \left \{ \sum \left \{ \ln f_i \right \}^2 \right \}^{1/2},
\]

where \( f_i \) are the individual error factors. The following combined error factors are thus derived from the data in Table 6-1:

- \( f = 2.9 \) for destroyers
- \( 3.3 \) for PGMs
- \( 3.2 \) for all other ships.

An additional uncertainty not addressed above is the possibility that an individual spent a significant amount of time in an engine room in the vicinity of radioactive sources such as evaporators and condensers. From the observation made in Section 2.5 that the engine room intensity was probably no greater than 1.5 times the exterior hull gamma intensity, it is possible to estimate the incremental dose received due to engine room duty. If a person spent eight hours per day in the engine room, eight hours topside, and eight hours below decks but outside the engine room, the contamination dose accrued by this individual is increased by a factor \( d \):

\[
d = \frac{F_a + 1.5}{2F_a},
\]

where \( F_a \) is the apportionment factor (Table 2-7) for the appropriate ship type. For example, if \( F_a = .50 \), \( d = 2.0 \) and the contamination dose should be doubled to account for this hypothesized engine room duty.

This uncertainty analysis does not include operational constraints such as the 100 mR/day dose limit. For many ships, the calculated upper limit daily doses due to ship contamination exceed the 100 mR/day criterion by such an amount that it is
extremely doubtful a ship contaminated to that degree would have been allowed to continue operations without decontamination of the ship or evacuation of personnel. Thus, while these upper limits are mathematically consistent, they may be operationally unrealistic and therefore in excess of the true 90-percent upper confidence limit for some ships.

6.6 Total Uncertainty

Summarized below are the upper and lower error factors for the various dose components.

<table>
<thead>
<tr>
<th>Error Factor</th>
<th>ABLE water</th>
<th>ABLE target ship</th>
<th>BAKER water</th>
<th>BAKER target ship</th>
<th>Ship contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_u$ (upper)</td>
<td>2.4</td>
<td>2.3</td>
<td>1.7</td>
<td>1.5</td>
<td>2.9 for destroyers 3.3 for PGMs 3.2 for all other ship types</td>
</tr>
<tr>
<td>$f_l$ (lower)</td>
<td>3.1</td>
<td>3.5</td>
<td>5.8</td>
<td>1.5</td>
<td>same</td>
</tr>
</tbody>
</table>

The confidence limits for a total dose are dependent on the magnitude of dose received from each dose component. The calculated film badge dose for the USS RECLAIMER, Table 5-3, serves as an example of how the approximate 90-percent upper and lower bounds of total dose may be determined from the component error factors developed in this section. From the data in this table and the component error factors, the dose in mrem from each component may be expressed as a best estimate plus and minus uncertainties in dose:

- **ABLE water**: $21^{+29}_{-14}$
- **ABLE target ship**: $8^{+11}_{-6}$
- **BAKER water**: $209^{+146}_{-173}$
BAKER target ship \[920^{+460}_{-310}\]

Contamination \[521^{+1146}_{-358}\]

(Since the RECLAIMER is an ARS, an error factor of 3.2 is used for contamination.)

The best estimates are added to determine the best estimate of total dose, 1679 mrem. However, it is incorrect to add the individual upper (or lower) uncertainties to determine the composite 90-percent total dose upper (or lower) limit. It is approximately correct to combine uncertainties in a manner similar to that used when combining standard deviations for summed quantities, i.e., the square root of the sum of the squares. These uncertainties then combine as follows:

For upper dose: \[\left[(29)^2 + (11)^2 + (146)^2 + (460)^2 + (1146)^2\right]^{1/2} = 1244 \text{ mrem.}\]

For lower dose: \[\left[(14)^2 + (6)^2 + (173)^2 + (310)^2 + (358)^2\right]^{-1/2} = 504 \text{ mrem.}\]

The approximate 90-percent upper and lower bounds for the RECLAIMER total film badge dose are then:

Upper bound: \[1679 + 1244 = 2923 \text{ mrem}\]
Lower bound: \[1679 - 504 = 1175 \text{ mrem.}\]

The combined upper and lower uncertainties in dose may be calculated by this technique for each support ship, based on the dose components presented in Appendix B.
Section 7
CONCLUSIONS

A methodology is developed that allows calculation of external gamma doses accrued by personnel aboard target and support vessels operating in Bikini Lagoon during Operation CROSSROADS. The significant radiation sources (radioactive lagoon water, target ships, and support ship contamination) are identified, analyzed, and mathematically modeled. Doses to personnel are calculated by developing the path histories of support and target vessels, and numerically integrating the local radiation intensities along the ship paths, as determined by the radiation source models. Calculations are presented in detail for the USS RECLAIMER. Mean film badge doses calculated for personnel aboard the various support ships during operations within Bikini Lagoon are presented in Table 7-1. This compilation is a summary of more detailed information (Information Summary, Path Report, and Radiation Report for each support ship) appearing in Appendix B, Support Ships. Calculated mean film badge doses for the crews of the various target ships are presented in Table 7-2. These values represent doses accrued aboard the support ships on which the target ship crews were embarked during the operation, plus doses accrued aboard the target ships for those that were remanned. More detailed information on target ship crew doses is contained in Appendix A, Target Ships. Also included in this appendix are intensity curves for target ships, from which boarding team doses may be calculated.

This report also provides the means to determine additional doses to crews after each ship departed from Bikini, based upon departure date, debarkation date, and the level of hull contamination at the time of departure (calculated in the methodology). Thus, the total external dose from all contributing sources, excluding post-CROSSROADS operations at Kwajalein Atoll, can be determined, based upon the specific parameters associated with each ship and with the crew (or individual) debarkation date for a particular ship. See Appendix B.

Mean film badge doses are reconstructed for 93 percent of the 39,418 Naval participants at Operation CROSSROADS. Doses are not specifically reconstructed for staff and air units, but can be derived from the ships to which they were assigned. Only 7 percent of the doses exceed 0.5 rem and less than 2 percent exceed 1.0 rem. The maximum mean dose is calculated to be about 1.7 rem. A summary of calculated film badge doses is displayed graphically in Figure 7-1.
<table>
<thead>
<tr>
<th>Support Ship</th>
<th>Crew Size</th>
<th>Total Film Badge Dose (inrem)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USS ACHOMAWI (ATF-148)</td>
<td>80</td>
<td>1245</td>
</tr>
<tr>
<td>USS AJAX (AR-6)</td>
<td>753</td>
<td>191</td>
</tr>
<tr>
<td>USS ALBEMARLE (AV-5)</td>
<td>569</td>
<td>0</td>
</tr>
<tr>
<td>USS ALLEN M. SUMNER (DD-692)</td>
<td>278</td>
<td>467</td>
</tr>
<tr>
<td>APL-27</td>
<td>23</td>
<td>131</td>
</tr>
<tr>
<td>USS APPLACHIAN (AGC-1)</td>
<td>614</td>
<td>1</td>
</tr>
<tr>
<td>USS APPLING (APA-58)</td>
<td>226</td>
<td>116</td>
</tr>
<tr>
<td>USS ARD-29</td>
<td>106</td>
<td>265</td>
</tr>
<tr>
<td>USS ARTEMIS (AKA-21)</td>
<td>160</td>
<td>216</td>
</tr>
<tr>
<td>USS ATA-124</td>
<td>44</td>
<td>359</td>
</tr>
<tr>
<td>USS ATA-180</td>
<td>45</td>
<td>547</td>
</tr>
<tr>
<td>USS ATA-185</td>
<td>43</td>
<td>593</td>
</tr>
<tr>
<td>USS ATA-187</td>
<td>33</td>
<td>347</td>
</tr>
<tr>
<td>USS ATA-192</td>
<td>15</td>
<td>547</td>
</tr>
<tr>
<td>USS ATR-40</td>
<td>68</td>
<td>903</td>
</tr>
<tr>
<td>USS ATR-87</td>
<td>69</td>
<td>485</td>
</tr>
<tr>
<td>USS AVERY ISLAND (AG-76)</td>
<td>483</td>
<td>147</td>
</tr>
<tr>
<td>USS BARTON (DD-722)</td>
<td>260</td>
<td>519</td>
</tr>
<tr>
<td>USS BAYFIELD (APA-33)</td>
<td>428</td>
<td>63</td>
</tr>
<tr>
<td>USS BEGOR (APD-127)</td>
<td>155</td>
<td>114</td>
</tr>
<tr>
<td>USS BENEVOLENCE (AH-13)</td>
<td>673</td>
<td>236</td>
</tr>
<tr>
<td>USS BEXAR (APA-237)</td>
<td>293</td>
<td>231</td>
</tr>
<tr>
<td>USS BLUE RIDGE (AGC-2)</td>
<td>534</td>
<td>1</td>
</tr>
<tr>
<td>USS BOTTINEAU (APA-235)</td>
<td>299</td>
<td>178</td>
</tr>
<tr>
<td>USS BOUNTIFUL (AH-9)</td>
<td>585</td>
<td>0</td>
</tr>
<tr>
<td>USS BOWDITCH (AGS-4)</td>
<td>296</td>
<td>143</td>
</tr>
<tr>
<td>USCG BRAMBLE (WAGL-392)</td>
<td>49</td>
<td>302</td>
</tr>
<tr>
<td>USS BURLESON (APA-67)</td>
<td>244</td>
<td>66</td>
</tr>
<tr>
<td>USS CEBU (ARG-6)</td>
<td>357</td>
<td>229</td>
</tr>
<tr>
<td>USS CHARLES P. CECIL (DD-835)</td>
<td>287</td>
<td>0</td>
</tr>
<tr>
<td>USS CHICKASAW (ATF-83)</td>
<td>78</td>
<td>400</td>
</tr>
<tr>
<td>USS CHIKASKIA (AO-54)</td>
<td>176</td>
<td>198</td>
</tr>
<tr>
<td>USS CHOWANOC (ATF-100)</td>
<td>88</td>
<td>401</td>
</tr>
<tr>
<td>USS CLAMP (ARS-33)</td>
<td>88</td>
<td>651</td>
</tr>
<tr>
<td>USS COASTERS HARBOR (AG-74)</td>
<td>195</td>
<td>195</td>
</tr>
<tr>
<td>USS CONSERVER (ARS-39)</td>
<td>86</td>
<td>919</td>
</tr>
<tr>
<td>USS COUCAL (ASR-8)</td>
<td>117</td>
<td>556</td>
</tr>
<tr>
<td>USS CREON (ARL-11)</td>
<td>144</td>
<td>284</td>
</tr>
<tr>
<td>USS CUMBERLAND SOUND (AV-17)</td>
<td>540</td>
<td>61</td>
</tr>
<tr>
<td>USS CURRENT (ARS-22)</td>
<td>94</td>
<td>885</td>
</tr>
<tr>
<td>USS DELIVER (ARS-23)</td>
<td>84</td>
<td>952</td>
</tr>
<tr>
<td>USS DIXIE (AD-14)</td>
<td>835</td>
<td>214</td>
</tr>
</tbody>
</table>
Table 7-1 (Continued)
Film Badge Dose Summary For Support Ship Crews

<table>
<thead>
<tr>
<th>Support Ship</th>
<th>Crew Size</th>
<th>Total Film Badge Dose (mrem)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USS DUTTON (AGS-8)</td>
<td>60</td>
<td>306</td>
</tr>
<tr>
<td>USS ENOREE (AO-69)</td>
<td>132</td>
<td>198</td>
</tr>
<tr>
<td>USS ETLAH (AN-79)</td>
<td>36</td>
<td>689</td>
</tr>
<tr>
<td>USS FALL RIVER (CA-131)</td>
<td>817</td>
<td>204</td>
</tr>
<tr>
<td>USS FLUSSE (DD-368)</td>
<td>146</td>
<td>428</td>
</tr>
<tr>
<td>USS FULTON (AS-11)</td>
<td>733</td>
<td>267</td>
</tr>
<tr>
<td>USS FURSE (DD-882)</td>
<td>293</td>
<td>2</td>
</tr>
<tr>
<td>USS GEORGE CLYMER (APA-27)</td>
<td>270</td>
<td>248</td>
</tr>
<tr>
<td>USS GUNSTON HALL (LSD-5)</td>
<td>305</td>
<td>211</td>
</tr>
<tr>
<td>USS GYPSY (ARSD-1)</td>
<td>77</td>
<td>516</td>
</tr>
<tr>
<td>USS HAVEN (AH-12)</td>
<td>476</td>
<td>250</td>
</tr>
<tr>
<td>USS HENRICO (APA-49)</td>
<td>424</td>
<td>226</td>
</tr>
<tr>
<td>USS HESPERIA (AKS-13)</td>
<td>139</td>
<td>245</td>
</tr>
<tr>
<td>USS INGRAHAM (DD-694)</td>
<td>237</td>
<td>505</td>
</tr>
<tr>
<td>USS JAMES M. GILLISS (AGS-13)</td>
<td>40</td>
<td>202</td>
</tr>
<tr>
<td>USS JOHN BLISH (AGS-10)</td>
<td>48</td>
<td>335</td>
</tr>
<tr>
<td>USS KENNETH WHITING (AV-14)</td>
<td>539</td>
<td>195</td>
</tr>
<tr>
<td>USS LAFFEY (DD-724)</td>
<td>231</td>
<td>332</td>
</tr>
<tr>
<td>USS LCI-977</td>
<td>35</td>
<td>176</td>
</tr>
<tr>
<td>USS LCI(L)-1062</td>
<td>35</td>
<td>362</td>
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<td>USS LCI-1067</td>
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<td>93</td>
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<td>35</td>
<td>380</td>
</tr>
<tr>
<td>USS LOWRY (DD-770)</td>
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<td>326</td>
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<tr>
<td>USS LST-388</td>
<td>80</td>
<td>277</td>
</tr>
<tr>
<td>USS LST-817</td>
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<td>182</td>
</tr>
<tr>
<td>USS LST-861</td>
<td>80</td>
<td>326</td>
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<td>USS LST-871</td>
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<td>USS LST-881</td>
<td>71</td>
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</tr>
<tr>
<td>USS LST-989</td>
<td>84</td>
<td>0</td>
</tr>
<tr>
<td>USS MENDER (ARSD-2)</td>
<td>49</td>
<td>307</td>
</tr>
<tr>
<td>USS MOALE (DD-693)</td>
<td>247</td>
<td>759</td>
</tr>
<tr>
<td>USS MOUNT MCKINLEY (AGC-7)</td>
<td>824</td>
<td>193</td>
</tr>
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<td>USS MUNSEE (ATF-107)</td>
<td>63</td>
<td>368</td>
</tr>
<tr>
<td>USS NEWMAN K. PERRY (DD-883)</td>
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<td>185</td>
</tr>
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<td>USS OBRIEN (DD-725)</td>
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<td>175</td>
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<td>262</td>
</tr>
<tr>
<td>USS OTTAWA (AKA-101)</td>
<td>67</td>
<td>63</td>
</tr>
<tr>
<td>USS PALMYRA (ARS(T)-3)</td>
<td>299</td>
<td>378</td>
</tr>
<tr>
<td>USS PANAMINT (AGC-13)</td>
<td>591</td>
<td>0</td>
</tr>
<tr>
<td>USS PGM-23</td>
<td>39</td>
<td>935</td>
</tr>
<tr>
<td>USS PGM-24</td>
<td>48</td>
<td>1293</td>
</tr>
<tr>
<td>Support Ship</td>
<td>Crew Size</td>
<td>Total Film Badge Dose (mrem)</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-----------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>USS PGM-25</td>
<td>53</td>
<td>1061</td>
</tr>
<tr>
<td>USS PGM-29</td>
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<td>USS PGM-31</td>
<td>55</td>
<td>812</td>
</tr>
<tr>
<td>USS PGM-32</td>
<td>27</td>
<td>1045</td>
</tr>
<tr>
<td>USS PHAON (ARB-3)</td>
<td>160</td>
<td>331</td>
</tr>
<tr>
<td>USS POLLUX (AKS-4)</td>
<td>154</td>
<td>117</td>
</tr>
<tr>
<td>USS PRESERVER (ARS-8)</td>
<td>85</td>
<td>1122</td>
</tr>
<tr>
<td>USS PRESQUE ISLE (APB-44)</td>
<td>194</td>
<td>280</td>
</tr>
<tr>
<td>USS QUARTZ (IX-150)</td>
<td>30</td>
<td>235</td>
</tr>
<tr>
<td>USS RECLAIMER (ARS-42)</td>
<td>73</td>
<td>1679</td>
</tr>
<tr>
<td>USS ROBERT K. HUNTINGTON (DD-781)</td>
<td>234</td>
<td>474</td>
</tr>
<tr>
<td>USS ROCKBRIDGE (APA-228)</td>
<td>206</td>
<td>334</td>
</tr>
<tr>
<td>USS ROCKINGHAM (APA-229)</td>
<td>297</td>
<td>241</td>
</tr>
<tr>
<td>USS ROCKWALL (APA-230)</td>
<td>288</td>
<td>208</td>
</tr>
<tr>
<td>USS ROLETTE (AKA-99)</td>
<td>151</td>
<td>241</td>
</tr>
<tr>
<td>USS SAUDOR (CVE-117)</td>
<td>854</td>
<td>68</td>
</tr>
<tr>
<td>USS SAINT CROIX (APA-231)</td>
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<td>72</td>
</tr>
<tr>
<td>USS SAN MARCOS (LSD-25)</td>
<td>631</td>
<td>249</td>
</tr>
<tr>
<td>USS SEVERN (AO-(W)-61)</td>
<td>145</td>
<td>137</td>
</tr>
<tr>
<td>USS SHAKAMAXON (AN-88)</td>
<td>38</td>
<td>643</td>
</tr>
<tr>
<td>USS SHANGRI-LA (CV-38)</td>
<td>1935</td>
<td>0</td>
</tr>
<tr>
<td>USS SIOUX (ATF-75)</td>
<td>66</td>
<td>301</td>
</tr>
<tr>
<td>USS SPHINX (ARL-24)</td>
<td>155</td>
<td>290</td>
</tr>
<tr>
<td>USS SUNCOCK (AN-80)</td>
<td>43</td>
<td>664</td>
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Table 7-2
Summary of Calculated Doses for Target Ship Crews

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<td>USS LCI(L)-549</td>
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<td>USS TUNA (SS-203)</td>
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**NON-REMANNEO**

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Table 7-2 (continued)
Summary of Calculated Doses for Target Ship Crews

NON-REMANIINDED (continued)

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Doses Calculated for:

Support Personnel 27,652
Target Ship Personnel
  Remanned 1,092
  Non-remanned 7,832
Doses Not Calculated 2,842
Total Naval Personnel 39,418

Figure 7-1  Distribution of Calculated Doses
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15. A2 Report, a compilation of reports concerning the ABLE detonation assembled by the Technical Director in July 1946.


23. Untitled manuscript assembled and edited by Dr. J.O. Hirschfelder, circa 1949. Copy found in archives at Los Alamos National Laboratory.

24. B2 Report, a compilation of reports concerning the BAKER detonation assembled by the Technical Director in September 1946.


33. Letter from Dr. William G. Myers to Col. Stafford Warren, 28 August 1946.

35. Memorandum dated 4 September 1946, Subject: "Measurement of Radioactivity aboard USS SAIDOR," from B. Groesbeck to Commanding Officer, USS SAIDOR.


39. Memorandum dated 19 August 1946, Subject: "Radiological Condition of the KENNETH WHITING Subsequent to Leaving Bikini," from Lieutenant Commander W.A. Kemper to Commanding Officer, USS KENNETH WHITING.

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