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RADIATION DOSE RECONSTRUCTION U.S. OCCUPATION FORCES IN HIROSHIMA AND NAGASAKI, JAPAN, 1945-1946.

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6 August 1980

Final Report for Period 1 March 1980—6 August 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Upper limit dose estimates (internal and external) are determined for those units of the U.S. occupation forces assigned to Hiroshima or Nagasaki following the detonations of atomic weapons in those two cities. In the absence of specific maneuver and patrol data, these dose estimates are based on the maximum recorded activity levels with exposure over the entire stay period for each unit. The upper limit external dose is .03 rem for Hiroshima and .08 rem for Nagasaki. For the Nishiyama area, the upper limit is 0.63 rem. The dose from internal emitters (inhalation and ingestion) is considerably less.

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20. ABSTRACT (Continued)

There is no basis for assuming that any individual in the occupation units received these upper limit doses.

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Section 1
INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

The detonation of atomic bombs over Hiroshima and Nagasaki, Japan brought World War II to a rapid conclusion. After the Japanese surrender, U.S. military forces occupied these cities and may have been exposed to the residual radioactive contamination produced by the nuclear detonations. The purpose of this report is to present estimates of the radiation doses received by these U.S. occupation forces. The dose estimates include the contribution from radioactive material that may have been inhaled or ingested (drinking water) during the occupation period. These estimates are based on historical documents prepared by U.S. military organizations and technical information published in the scientific literature. Since the historical documents pertain to unit rather than individual activities and do not contain extensive specific details regarding operations within the contaminated areas, these estimates represent reasonable upper limits derived from a "worst case" scenario.

1.2 BACKGROUND

Atomic bombs were detonated over Hiroshima and Nagasaki, Japan on 6 August and 9 August, 1945, respectively. Both weapons were detonated high above the ground (1670 ft at Hiroshima; 1640 ft at Nagasaki) resulting in massive destruction but relatively small areas of significant residual radioactive contamination. The two weapons differed considerably in design and yield. The Hiroshima weapon was a gun-assembly type which employed U-235 as the fissionable material and had a yield of approximately 13 kilotons (kt). The Nagasaki weapon was a Pu-239 implosion device with a yield of approximately 23 kt.[1]

Section 2
BOMB DAMAGE AND RESIDUAL RADIATION ENVIRONMENT

2.1 BOMB DAMAGE[12]

In both Hiroshima and Nagasaki, the blast from the bombs destroyed practically everything within a radius of 1 mile from the point directly under the explosions, or Ground Zero (GZ). The only surviving objects were the frames of a small number of reinforced concrete buildings; most of these buildings suffered extensive damage from interior fires, had their windows, doors, and partitions knocked out, and had all other fixtures which were not integral parts of the reinforced frames burned or blown away. In Hiroshima fires sprang up all over the wide, flat, central portion of the city; these fires soon combined into an immense "fire storm" which burned out almost everything that had not already been destroyed by the blast in a roughly circular area of about 4.4 square miles centered at GZ. Similar fires broke out in Nagasaki, but no devastating fire storm resulted as in Hiroshima because of the irregular shape of the city. However, the badly burned area included the entire northern portion of the city and extended more than two miles south from GZ. Figures 1-4 illustrate the perimeter of virtually complete destruction resulting from blast and fire.

2.2 RADIOLOGICAL SURVEYS[9,10]

The residual radiation levels in Hiroshima and Nagasaki about the time of occupation troop arrival are fairly well-documented. As discussed in more detail subsequently in Section 3, a scientific group organized by the Manhattan Engineer District conducted radiological surveys in Nagasaki from 20 September to 6 October 1945, and in Hiroshima from 3 to 7 October 1945. Later surveys were conducted in Nagasaki (15-27 October 1945) and Hiroshima (1-2 November 1945) by a team from the Naval Medical Research Institute (NMRI). The NMRI surveys were supplemented by measurements made by Japanese scientists at even later dates.

For the survey at Hiroshima, the Manhattan Engineer District survey team used two Lauritzen-Wollan electroscopes and two portable counters (type unspecified) developed by the University of Chicago, and manufactured by the Victoreen Instrument Company. At Nagasaki all measurements were made with

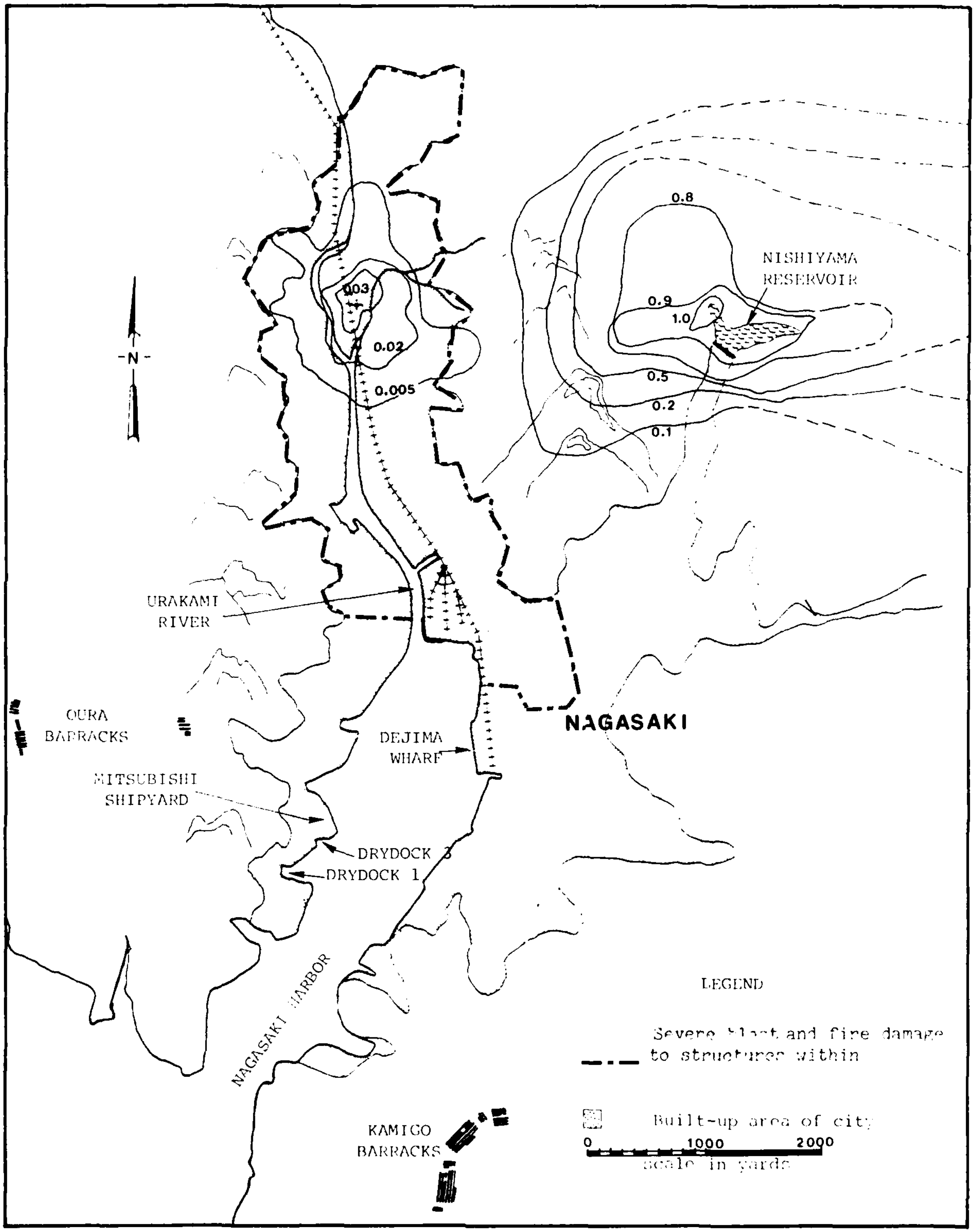

Figure 1.
RESULTS OF MANHATTAN DISTRICT SURVEY
READINGS IN MR HR AS OF 21 SEPT-4 OCT 1945

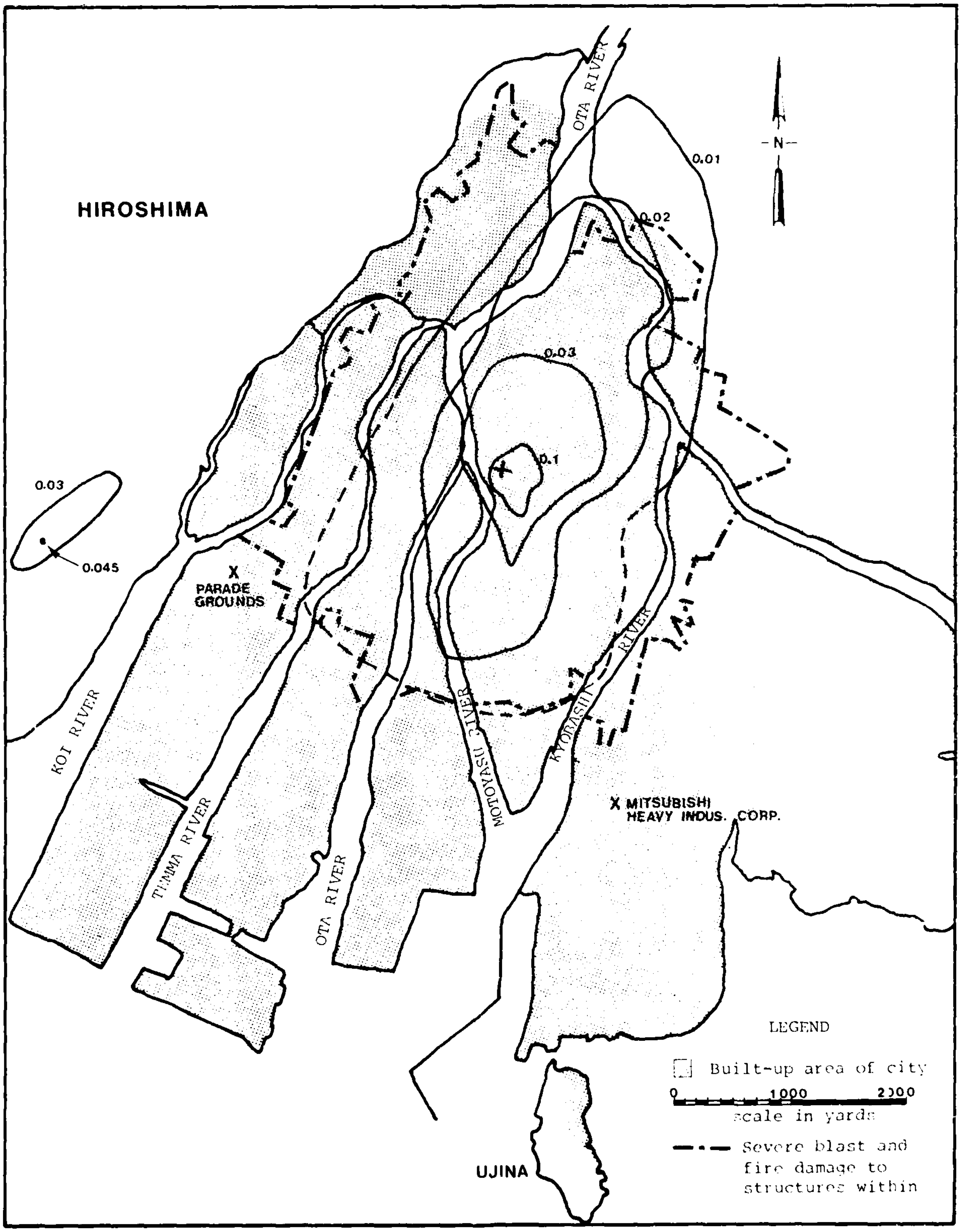

Figure 2.
RESULTS OF MANHATTAN DISTRICT SURVEY
READINGS IN MR/HR AS OF 3-7 OCT 1945

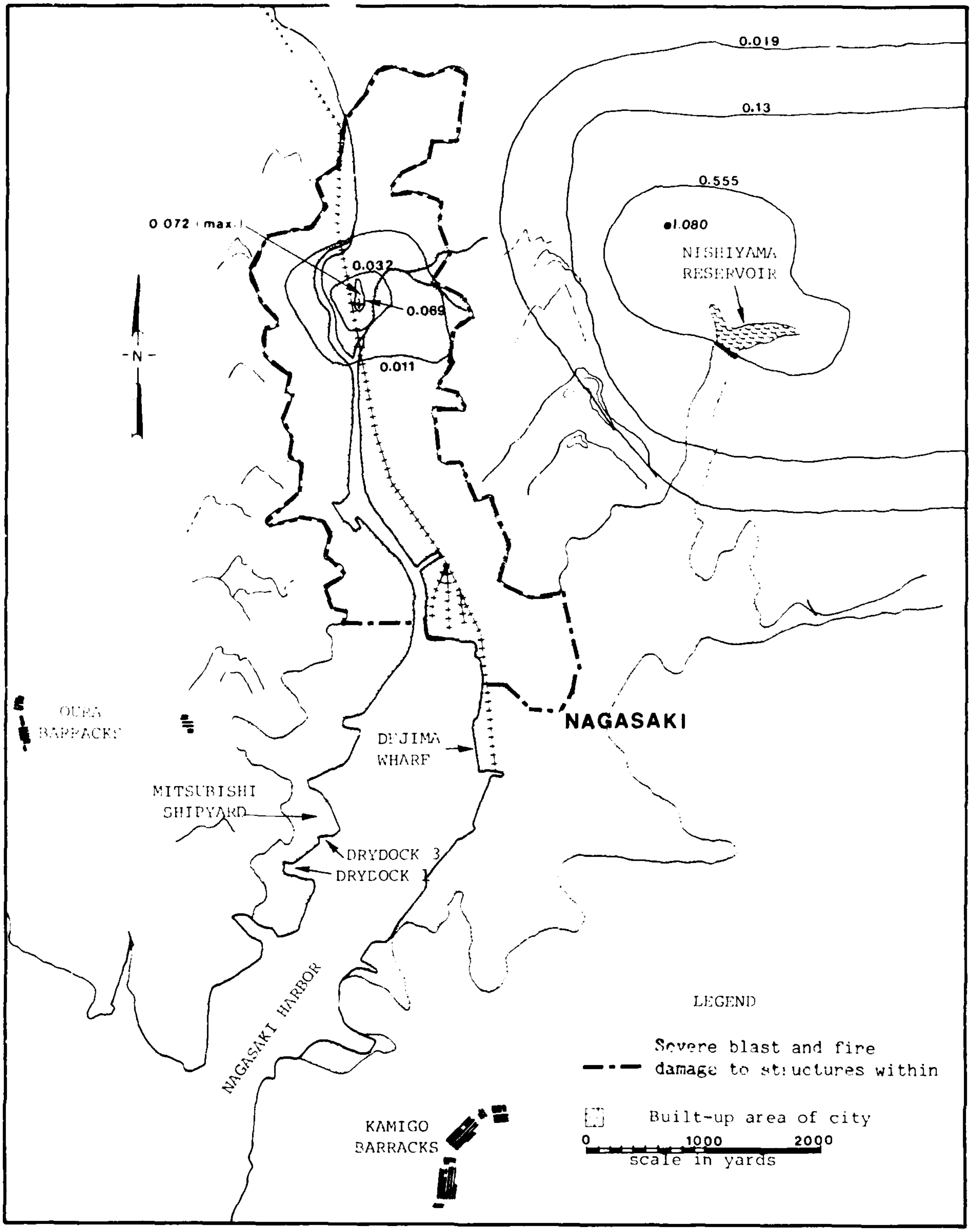

Figure 3.
RESULTS OF NAVAL MEDICAL RESEARCH INSTITUTE SURVEY
READINGS IN MR/HR AS OF 15-27 OCT 1945

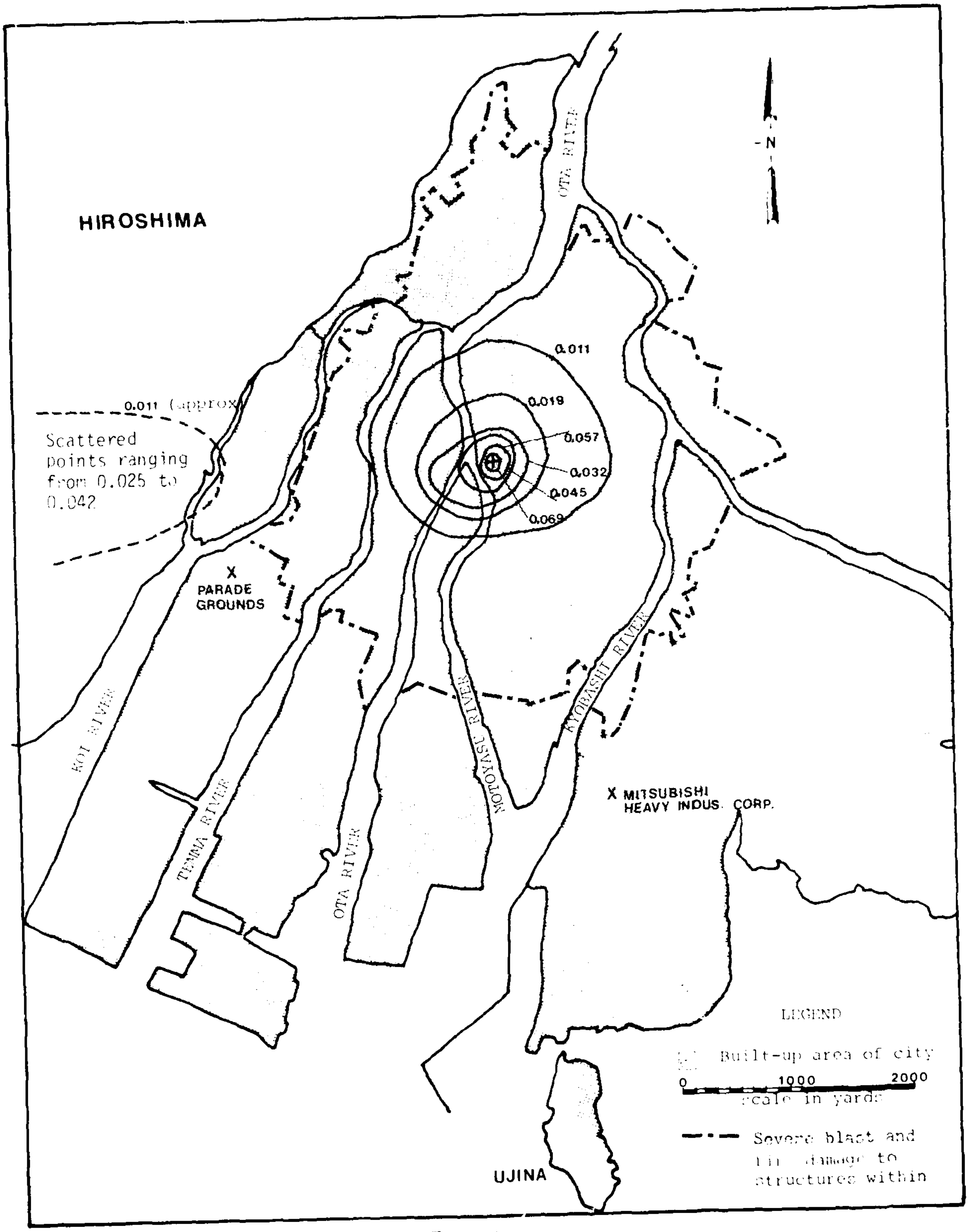

Figure 4.
RESULTS OF NAVAL MEDICAL RESEARCH INSTITUTE SURVEY
READINGS IN MR/HR AS OF 1-2 NOV 1945

two portable Geiger Muller counters made by the Victoreen Instrument Company. All instruments were calibrated against a standard radium source and the measurements were made with the instrument held 2 inches (5 centimeters) above the ground.

The Naval Medical Research Institute survey team used a Geiger-Muller type instrument constructed "in-house" for their measurements. The NMRI instrument was also calibrated against a radium standard source; however, most of their measurements were made at a height of one meter above the ground. The NMRI team observed that readings in the area around ground zero did not change as instrument height above the ground was varied from 5 centimeters to 1 meter; however, in the downwind contaminated areas readings taken at 5 centimeters above the ground were approximately double those taken at 1 meter above the ground. They attributed the difference to an increased ratio of detectable beta activity in the downwind areas. The results of these surveys are shown as follows:

Figure 1: Manhattan District survey of Nagasaki[9]
Figure 2: Manhattan District survey of Hiroshima[9]
Figure 3: NMRI survey of Nagasaki[10]
Figure 4: NMRI survey of Hiroshima[10]

2.3 ANALYSIS OF SURVEY RESULTS

Since the two surveys were conducted by different groups using different instrumentation and survey techniques (measurement height above the ground) and since there were changes in the environment (weathering, clearing of rubble in the ground zero area by the Japanese, etc.) between surveys, it is difficult to arrive at consistent conclusions based on a comparison of the survey results. For example, a comparison of the two surveys at Hiroshima (Figures 2 and 4) clearly indicates a decay in the radiation intensity around the ground zero (GZ) area in the month between surveys. A similar comparison of the Nagasaki surveys (Figures 1 and 3) does not reveal such a clear pattern. Perhaps this is due to the fact the Nagasaki surveys took longer to conduct and there was a shorter time interval between them. Nevertheless, two important facts are evident from these surveys:

- Both surveys identified two distinct areas of contamination--one centered around GZ and the other some distance downwind.

- Both surveys indicated very low residual radiation levels (in general, much less than one milliroentgen per hour (mR/hr).

The fact that there were two distinct areas of contamination in each city provides an important clue relative to the nature of the radiation sources. According to Glasstone[1], the maximum height above the ground at which a nuclear detonation will normally produce significant local fallout is related to weapon yield by the following equation:

$$H \quad 180W^{0.4}$$

where H = height of detonation in feet
W = weapon yield in kilotons

Using this equation, the maximum detonation heights at which the Hiroshima and Nagasaki weapons would produce significant fallout are approximately 500 and 630 feet, respectively. Since both weapons were detonated above 1600 feet, fallout in the immediate area around GZ would be extremely unlikely. Therefore, the contamination in the GZ area resulted primarily from activation of the soil and building materials by the neutrons released at the instant of the nuclear detonation rather than by fallout (including unfissioned plutonium/uranium). Evidence that supports this conclusion includes the following:

- The maps (Figures 1-4) portraying the residual radiation intensity in the GZ area of each city, particularly those recorded by the NMRI team, show approximately circular patterns of equal intensity around GZ. Roughly circular patterns are typical of neutron-induced activity fields produced by high altitude nuclear weapons test shots at the Nevada Test Site during the 1950's.
- An analysis of the NMRI survey data (residual radiation intensity as a function of distance from GZ) by Pace and Smith in 1959 was consistent with the assumption that the residual radiation around GZ resulted from neutron-induced activity.[10]
- Laboratory neutron-activation of soil and building materials (concrete, brick, and roof tiles) taken from Hiroshima and Nagasaki by Hashizume[15] and Arakawa[14] revealed that the only radioisotopes of significance that would remain after 42 days

(starting date of Manhattan District Survey) were Scandium-46 (half-life 84 days) and Cobalt-60 (half-life 5.2 years). The calculated radiological decay of the mixture of Co-60 and Sc-46 determined by Hashizume and Arakawa compares favorably with the late time measurements made by the Japanese scientists that supplemented the NMRI survey.

Both cities reported that "black rain" fell in the downwind contaminated areas approximately 30 minutes after the bomb detonation. This is indicative of precipitation scavenging of the nuclear cloud, or "rainout"; therefore, the downwind contaminated areas almost certainly resulted from deposition of fission products. Evidence that supports this conclusion includes the following:

- The contaminated area around the Nishiyama Reservoir (a mile or more downwind from the burst) was shielded by Mt. Kompira from direct neutron exposure. In addition, the contours show a decreasing intensity toward the burst. Both of these aspects imply that the contamination could not result from neutron activation.

- The maximum radiation levels detected around the Nishiyama Reservoir were 1.0 to 1.8 mR/hr on 26 September 1945[9]. According to Reference 10, measurements in the same general area on 12 November 1945, exhibited a mean of 0.7 mR/hr. This decay is consistent with the "$t^{-1.2}$ rule" established for fission products (fallout) for the first 6 months after detonation[1].

Section 3

OCCUPATION HISTORY

The occupation of western Honshu, Japan's main island where Hiroshima is located, and the southern islands of Shikoku and Kyushu, where Nagasaki is located, was assigned to the Sixth U.S. Army. These areas are depicted in Figure 5. Major forces assigned to the Sixth Army for the occupation were the I Corps, X Corps, and the V Amphibious Corps (VAC) which, together with supporting units, totaled some 240,000 troops.[3]

3.1 OCCUPATION MISSION

The mission of the occupation troops was to establish control of the area, insure compliance with surrender terms, and demilitarize the Japanese war machine. The infantry regiment was the basic organization used to accomplish this mission, and occupation plans were based upon the presence of such regiments in all prefectures (like U.S. counties) within Japan. The following summary extracted from Reference 3 is a description of the operations of a typical regiment:

> The outline of occupation duties was fairly well standardized throughout the Sixth Army zone. The division of responsibility was based upon the lines of Japanese prefectures so as to utilize the governmental structure that lay within the area. Sixth Army assigned a number of prefectures to each corps proportionate to the number of troops available. The corps in turn assigned a specific number of prefectures to a division. Regimental zones of responsibility were usually a single prefecture except where more than three prefectures lay within the division zone, in which case a regiment was to assume responsibility for more than one prefecture. This exception occurred in lightly populated prefectures which contained limited industrial or military potentialities.
>
> An infantry regiment moved into a prefecture with the mission of supervising the execution of the Japanese surrender terms within its zone of responsibility. The regimental commander was particularly

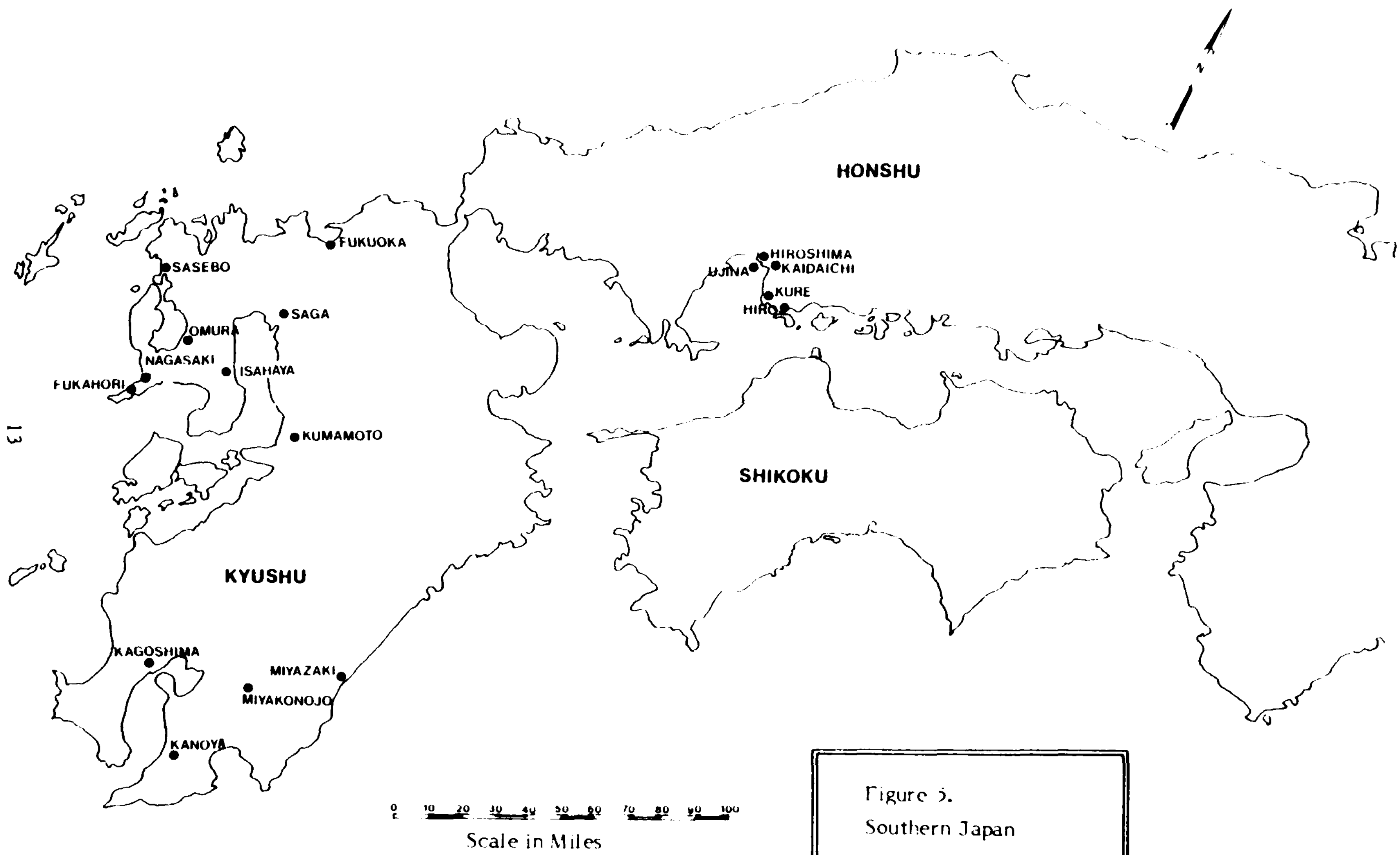

Figure 5.
Southern Japan

responsible for seizing all Japanese Armed Forces installations and disposition of all material therein, security of all enemy stores not subject to immediate disposition, and supervision of demobilization of Japanese Armed Forces when their services were no longer required for maintenance of captured arms and material. A zone commander effected demobilization by an order to the Japanese commander at the garrison or post that had been seized.

The mechanics of carrying out the regimental mission followed a simple pattern. Initially the regiment moved into a bivouac area within or near the zone of responsibility. The local Japanese military commanders and prefects of police submitted lists of all Japanese installations, and inventories of material within the area for consolidation and survey by the regimental commander. Shortly thereafter, reconnaissance patrols consisting of an officer and a rifle squad patrolled sectors of the area to verify these inventories and also search for any unreported installations or caches of material. With this information the regimental commander was able to divide the regimental zone into battalion zones of responsibility and the battalion commanders sub-divided their areas into company zones of responsibility.

The infantry company then became the working unit which actually accomplished the destruction or consignment of material, or the demobilization of Japanese Armed Forces that remained within the company zones. The company commander was empowered to seize installations within his zone and, with the use of available Japanese army personnel not yet demobilized and laborers obtained through the Japanese Home Ministry representative in his area, either destroy or turn over to the Japanese Home Ministry all material within the installation. U.S. Army personnel were used only to supervise this work and to see that complete destruction was accomplished.

The company commander disposed of material in accordance with procedures outlined in the Ordnance Technical Division of the Supreme Commander of Allied Powers (SCAP). All material fell into the following categories: that to be destroyed or scrapped (explosives and armament not needed for souvenirs or training purposes were chief items); that to be used for our operation (telephones, radios, and vehicles); that to be returned to the Japanese Home Ministry (fuel, lumber, etc.); that to be issued our forces as trophies; or that to be shipped to the U.S. for training purposes or as war trophies. Material not marked for destruction was separated and shipped to designated warehouses or dumps. Material marked for destruction was disposed of by prescribed methods. Japanese labor hauled explosives aboard Japanese trucks to approved burning areas, or if the installation was located near a deep sea waterway the explosives were dumped at sea--the safest and therefore preferable method. Unneeded metal items were made ineffective and turned over to the Japanese for scrap.

Physical control of the zone of responsibility proved remarkably easy, for the Japanese were compliant and cooperative. Any disorders among the Japanese themselves came within the authority of the prefectural police, but any disorder involving action by the Japanese against the Allied troops led to apprehension of the offenders by the military police and the imposition of a penalty prescribed by the area commander.

3.2 INITIAL ENTRY - RADIOLOGICAL SURVEY

It was recognized that entry into the atomic-bombed cities of Hiroshima and Nagasaki might expose the occupation troops to residual radiation resulting from the nuclear detonations. Therefore, with the concurrence of General George Marshall, Chief of Staff, and General Douglas MacArthur, Theater Commander, a special scientific group was organized by the Manhattan Engineer District. The primary objective of this group was to insure that occupation troops would not be subjected to any possible "toxic" effects. The group consisted principally of medical personnel headed by Col. Stafford L. Warren (U.S. Army Medical Corps) and civil and electrical engineers. In order to survey these areas as quickly as possible, the group was split. One-half of the group was in Nagasaki from 20 September to 6 October; the other half was in Hiroshima from 3 to 7 October 1945. The group reported that the radiation levels in both cities were very low and that these levels would not present a hazard to the occupation forces.[2]

3.3 OCCUPATION SCENARIO

The presence of pressure mines dropped by U.S. aircraft into major Japanese harbors played a significant role in the deployment of occupation forces. Studies by the Navy indicated that no difficulties would be encountered in the Nagasaki harbor, but the harbor at Hiroshima would be inaccessible for an indefinite period.[3] Therefore, occupation troops arrived at Nagasaki well in advance of troops in Hiroshima. For the same reason, Nagasaki was chosen to be a primary staging area for the deployment of occupation troops throughout the surrounding area; Hiroshima was not. Details regarding the occupation of each city follow (see Figures 5-7 for locations of areas mentioned):

3.3.1 NAGASAKI[6,7,8]

Prior to the arrival of occupation troops, a POW recovery team landed at Nagasaki (Figure 6) on 11 September 1945. The team was accompanied by a detachment of Marine guards from the USS Biloxi and the USS Wichita. During the period 11-23 September, approximately 10,000 U.S. and allied POW's that had been captive on the island of Kyushu were processed through Nagasaki for evacuation to hospital ships awaiting in Nagasaki Harbor. While in Nagasaki, the group operated from a POW Processing Center located near Dejima Wharf. The location of their billets is unknown, but it is logical to assume that they were near-by. The Marine guards were relieved on 23 September when the 2d Marine Division landed. Records indicate that the POW recovery team's mission was complete by 23 September; therefore, it is assumed that they also departed Nagasaki on or about that date.

The occupation of the Nagasaki area was assigned to the 2d Marine Division, 5th Amphibious Corps (VAC) of the Sixth U.S. Army. The occupation began with the arrival of a small advance party on 16 September. The advance party consisted of three officers from the Division Headquarters, one officer from each of the Division Regimental Combat Teams, and several officers from the VAC, making a total of approximately twelve members. The party established liaison with Japanese authorities, located areas for troop billets, and made preparations for the landing of the occupation troops. These objectives indicate that most of the advance party activities were conducted in

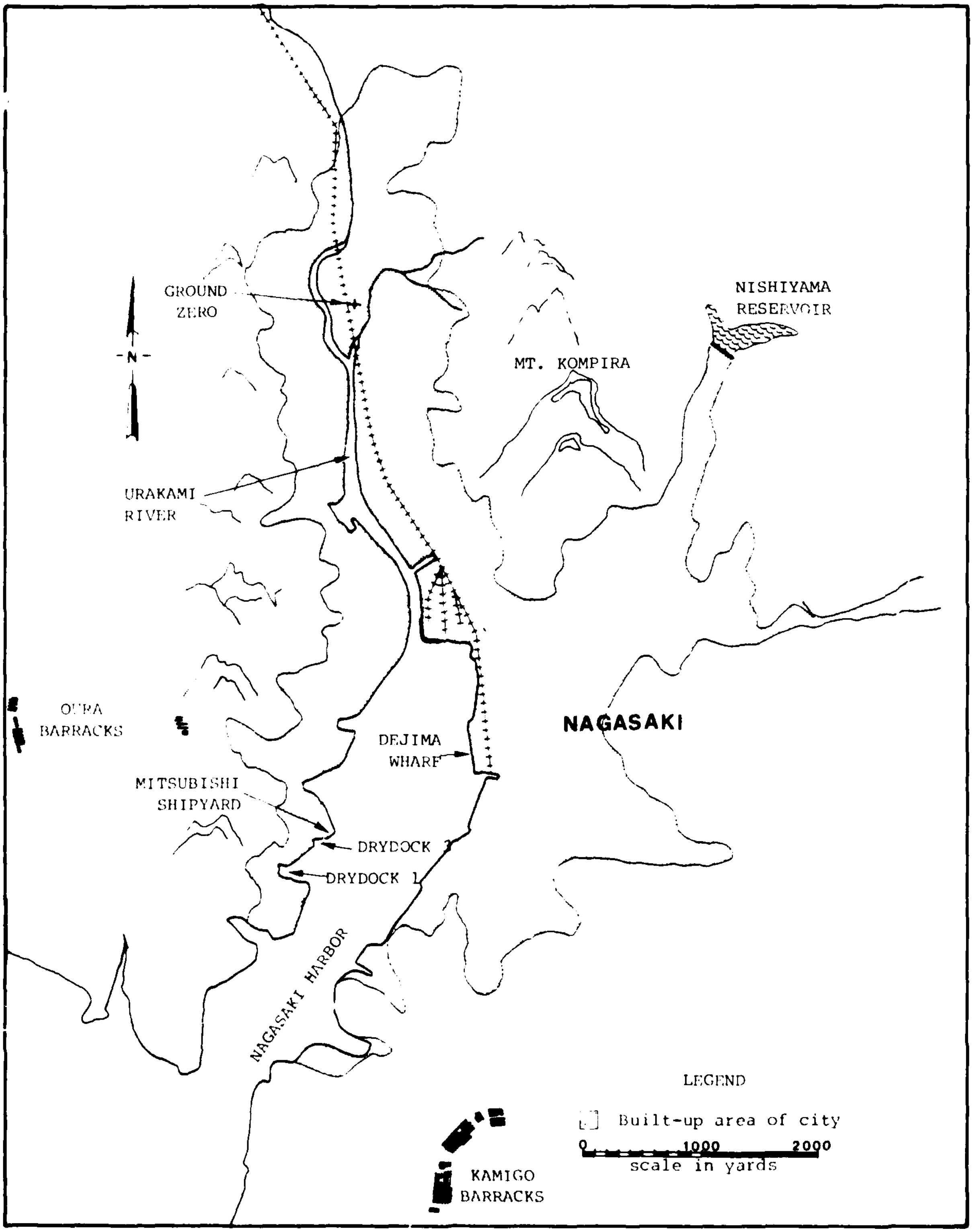

Figure 6. Nagasaki

the southern portion of the city where bomb damage was least. The team joined the remainder of the 2d Division when they landed 23-28 September 1945.

The 2d Marine Division (reinforced) had an assigned strength of 21,469 (includes 791 Army and 1328 Navy personnel) as of 26 September 1945, and was organized as follows (see Table 1 for Task Organization details):

- Support Group
  - Division Troops
  - Service Troops
  - Engineer Group
- Regimental Combat Team 2 (RCT-2)
- Regimental Combat Team 6 (RCT-6)
- Regimental Combat Team 8 (RCT-8)
- Artillery Group (basically the 10th Marine Regiment)
- 2d Tank Battalion
- Marine Observation Squadron #2 (VMO-2)

The number of U.S. occupation troops in Nagasaki steadily decreased from the peak in September 1945, until the end of the 2d Marine Division occupation period in July 1946. This decrease is illustrated by the 2d Marine Division Muster Roll records shown in Table 2. The Second Marine Division Muster Roll records are on file at the Marine Corps Historical Center, Washington, D.C. Note that Table 2 includes only U.S. Marine Corps personnel and cannot be compared directly with the assigned strength figures shown in Tables 1 and 3 which include Army and Navy personnel. Also, Table 2 indicates that the 10th Marine Regiment stayed in Nagasaki for the duration of the 2d Division occupation period while historical records show that the 10th Regiment moved to Isahaya shortly after debarkation in Nagasaki. Perhaps the inconsistency results from variations in the interpretation of reporting criteria.

Most units assigned to the 2d Marine Division experienced a large turnover of personnel during the occupation period. Every effort was made to allow eligible personnel to return to the United States as soon as possible after the war. For example, when the 5th Marine Division that occupied the Sasebo area was released from its assignment on 1 December 1945, for return to the

TABLE 1

TASK ORGANIZATION
2d MARINE DIVISION, REINFORCED
(As of 11 October 1945 - Operation Order 59)

DIVISION TROOPS (Assigned strength - see note)

- Division Headquarters Battalion (less detachments)
- Company D, 3d MP Battalion (Prov)
- 2d War Dog Platoon
- 54th CIC, A2B2 Detachment (Area)
- 498th CIC, B3 Detachment (Combat)
- 93d Headquarters & Headquarters Detachment, Military Government Group

SERVICE TROOPS (Assigned strength - see note)

- 2d Service Battalion (less detachments)
- 2d Medical Battalion* (less detachments)
- 2d Motor Transportation (MT) Battalion (less detachments)
- 4th Separate Laundry Platoon
- 3d Platoon, 4th Salvage & Repair Company
- 3656th QM Truck Company (USA)

ENGINEER GROUP (Assigned strength - see note)

- 2d Engineer Battalion (less detachments)
- 2d Pioneer Battalion (less detachments)
- 43d Naval Construction Battalion
- 1298th Combat Engineer Battalion (USA)
- 2d Platoon, Bomb Disposal Company, H&S Battalion, VAC

ARTILLERY GROUP (Assigned strength - 3083)

- 10th Marine Regiment
- 2d Amphibious Truck Company
- Company A, 20th Amphibious Truck Battalion
- 1 SP Com Party
- Detachment, Division Recon Company

REGIMENTAL COMBAT TEAM-2 (Assigned strength - 4075)

- 2d Marine Regiment (less detachment)
- Company C, 2d MT Battalion
- Company B, 2d Med. Battalion*
- Company A, 2d Engr. Battalion
- 1st Platoon, Ordnance Company, 2d Service Bn
- 1st Platoon, Service Company, 2d Service Bn
- 1st Platoon, Automotive Repair Company, 2d MT Bn

---

*Majority were Navy Hospital Corpsmen

NOTE: The combined assigned strength of the Division Troops, Service Troops, and the Engineer Group was 5695 personnel.

TABLE 1 (Continued)

<u>REGIMENTAL COMBAT TEAM-6</u> (Assigned strength - 4037)

- 6th Marine Regiment
- Company A, 2d MT Battalion
- Company A, 2d Med. Battalion*
- Company B, 2d Engr. Battalion
- 3d Platoon, Ordnance Company, 2d Service Bn
- 2d Platoon, Service Company, 2d Service Bn
- 2d Platoon, Supply Company, 2d Service Bn
- 2d Platoon, Automotive Repair Company, 2d MT Bn
- 1 SP Com Party

<u>REGIMENTAL COMBAT TEAM-8</u> (Assigned strength - 3914)

- 8th Marine Regiment
- Company B, 2d MT Battalion
- Company E, 2d Med. Battalion*
- Company C, 2d Engr. Battalion
- 2d Platoon, Ordnance Company, 2d Service Bn
- 3d Platoon, Service Company, 2d Service Bn
- 3d Platoon, Automotive Repair Company, 2d MT Bn
- Detachment, 2d Marine
- Division Recon Group (less detachment)

TANK BATTALION (Assigned strength - 615)

OBSERVATION SQUADRON (VMO-2)

---

*Majority were Navy Hospital Corpsmen

TABLE 2

UNIT STRENGTH (MARINES ONLY)
2D MARINE DIVISION - NAGASAKI, JAPAN
1945-1946

		Arrival Date	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL
1.	Hq Bn	(23 Sep 45)	1737	1705	1430	1378	1454 (7 Jan 46)						
2.	2d Engineer Bn	(23 Sep 45)	888	716	711	706	791	827	691	798	658	649	395 (1 Jul 46)
3.	2d War Dog Plt	(23 Sep 45)	66 (30 Sep 45)										
4.	2d Med Bn	(23 Sep 45)	163	157	144	83	232	128	128	101	121	120 (1 Jun 46)	
5.	2d Motor Trans Bn	(24 Sep 45)	705	656	541	293	741	882	779	920	770	770 (1 Jun 46)	
6.	2d Pioneer Bn	(24 Sep 45)	708	703	640	658 (28 Dec 45)							
7.	2d Amphib Truck Co	(24 Sep 45)	194	197	193	65 (6 Dec 45)							
8.	2d Serv Bn	(23 Sep 45)	754	732	341	374	683 (5 Jan 46)						
9.	2d Tank Bn	(23 Sep 45)	620	621	496	243 (27 Dec 45)							
10.	H&S&W Co 2d Marines	(23 Sep 45)	441	414	404	228	461	449	445	455	377	306 (13 Jun 46)	
11.	1st Bn 2d Marines	(23 Sep 45)	984	958	907	458	913	923 (1 Feb 46)					
12.	2d Bn 2d Marines	(23 Sep 45)	967	968 (26 Oct 45)									
13.	3d Bn 2d Marines	(23 Sep 45)	976	965	904 (3 Nov 45)								
14.	H&S&W Co 6th Marines	(23 Sep 45)	508	418	465	284 (1 Dec 45 - Weapons Co; 6 Dec 45 - H&S Co)							
15.	1st Bn 6th Marines	(23 Sep 45)	935	941	889	461 (1 Dec 45)							
16.	2d Bn 6th Marines	(23 Sep 45)	931	942	891 (24 Nov 45)								
17.	3d Bn 6th Marines	(23 Sep 45)	938	944	904	446 (6 Dec 45)							
18.	H&S&W Co 8th Marines	(23 Sep 45)	461	507 (1 Oct 45)									
19.	1st Bn 8th Marines	(23 Sep 45)	957	942 (1 Oct 45)									
20.	2d Bn 8th Marines	(23 Sep 45)	979 (25 Sep 45)										
21.	3d Bn 8th Marines	(24 Sep 45)	969 (27 Sep 45)										
22.	H&S Battery 10th Marines	(23 Sep 45)	260	250	226	113	229	289	263	295	223	218 (21 Jun 46)	
23.	1st Bn 10th Marines	(23 Sep 45)	591	560	513	300	646	618	476	478	375	334 (21 June 46)	
24.	2d Bn 10th Marines	(23 Sep 45)	583	569	515	202	485	479	394	417	326	342 (21 Jun 46)	
25.	3d Bn 10th Marines	(23 Sep 45)	585	570	497	299	501	546	374	484	378	364 (26 Jun 46)	
26.	4th Bn 10th Marines	(23 Sep 45)	610	609	555	197 (1 Dec 45)					329	250 (21 Jun 46)	
27.	MD USS Biloxi	(18 Sep 45)	43 (23 Sep 45)										
28.	MD USS Wichita	(11 Sep 45)	46	46 (5 Oct 45)									
29.	Adv recon party	(16 Sep 45)	12 (30 Sep 45)										
	MONTHLY TOTALS		18,611	16,090	12,166	6,788	7,136	5,141	3,550	3,948	3,557	3,353	395

NOTE: Dates in parentheses indicate departure dates.

U.S., a large number of 2d Marine Division troops, eligible for return, transferred to the 5th Division. These personnel were replaced by troops from the 5th Division who were not eligible for return to the states. Therefore it is extremely unlikely that many 2d Division personnel remained in the Nagasaki area for the duration of the Division occupation period.

Division Troops. The Division Troops arrived in Nagasaki 23-28 September 1945, and established a Command Post in the Customs House on Dejima Wharf approximately 2 miles south of GZ. The exact location of troop billets is unknown; however, they were likely scattered in the same general area. Most of these troops were assigned to administrative or staff positions in the Division Headquarters Battalion. The Division Troops remained in Nagasaki until the Division Headquarters moved to Sasebo during the first week of January 1946.

Service Troops. The Service Troops also arrived in Nagasaki during the 23-28 September 1945, time period. The Service Troops Command Post was established near the Mitsubishi Trading Company on the east side of the harbor south of the Dejima Wharf (over 2.5 miles south of GZ). Specific billet locations are unknown; however, it is logical that these troops would be quartered in the same general area. The Division Hospital was located about 1000 feet further south. Most of the Service Troops Organizations provided sub-elements to the Regimental Combat Teams, and these personnel were deployed accordingly. The primary mission of the Service Troops billeted in Nagasaki was to support the Regimental Combat Teams in the field. The Service Battalion operated a supply depot, the Motor Transport Battalion provided a motor pool and vehicle maintenance, and the Medical Battalion was assigned to the Division Hospital. The Service Battalion transferred to Sasebo along with the Headquarters Battalion on 5 Jan, 1946, while the Motor Transport Battalion and the Medical Battalion remained in Nagasaki until 1 June 1946.

Engineer Group. Elements of the Engineer Group also arrived in Nagasaki during the 23-28 September period. The 2d Engineer Battalion, organized into a Headquarters and Service (H&S) Company, and three "letter" companies landed on 26 September. As soon as unloading was complete, each letter company joined its respective RCT, while the H&S Company remained with the Division headquarters and formed the nucleus of the Engineer Group with a Command Post approximately half a mile southeast of Dejima Wharf (approximately 2.5 miles south of GZ). It is assumed that these troops were billeted near-by. Second Marine Division Muster Roll records indicate that these troops were the last of the 2d Marine Division to depart Nagasaki. They left on 1 July 1946.

The 2d Pioneer Battalion landed on 23 September and engaged in the division unloading operations until 2 October 1945, when they became a part of the Engineer Group. Then, their primary responsibility became the rehabilitation and maintenance of roads south of Division Headquarters to the area occupied by the 2d Tank Battalion. The Battalion was also used to clear open storage areas for use by the Division Quartermaster and to rehabilitate two athletic fields in the "bombed" area of the city. While in Nagasaki, the Battalion was billeted at the Kaisei Middle School. According to Muster Roll records, the 2d Pioneer Battalion departed Nagasaki on 28 December 1945.

The 43d Naval Construction Battalion (NCB) landed on 23-24 September and established a Command Post in a warehouse south of Dry Dock No. 3 in the Mitsubishi Dockyard on the west side of Nagasaki Harbor (about 2.5 miles south of GZ). The 43d NCB also worked with the Shore Party unloading the 2d Division until 29 September, when they joined the Engineer Group. During the time the battalion was in Nagasaki, the troops were first billeted in a large warehouse near Dry dock No. 3, then they moved to a larger building near Dry Dock No. 1. Both areas were more than 2.5 miles south of GZ. NCB projects included the following:

- Rehabilitation of Dejima Wharf
- Improvement of ship landing area south of Dejima Wharf
- Repair Commissary Warehouse
- Repair warehouse for Division Quartermaster
- Repair and maintain road on west side of Nagasaki Harbor
- Rehabilitation of petroleum tanks in harbor area
- Construction of quarters for Strategic Bomb Survey Group
- Construction of athletic fields for 6th Marines near Mitsubishi Electric Company (west side of harbor, 1.7 miles south of GZ)
- Construction of Armed Forces Radio Station at Omura
- Extension of "Atomic Field" landing strip.

The 43d NCB remained in Nagasaki until the unit was deactivated on 5 December 1945.

The 1298th Engineer Combat Battalion (U.S. Army) arrived in Nagasaki on 26-27 September, 1945, and immediately joined the Engineer Group. The troops were housed at the Oura School about 2.6 miles southeast of GZ. The battalion's primary mission was to repair and maintain main roads and bridges from northern Nagasaki to southern Nagasaki. They also constructed an airstrip ("Atomic Field") for liaison aircraft about 800-1000 feet southwest of GZ. This operation required one platoon of "A" Company and took 12 days to complete (30 September-11 October). On 31 October, the battalion began operation of a quarry near the airstrip.

Japanese labor was used as much as possible for projects accomplished by the Engineer Group. For example, some 350 Japanese laborers were used in the construction of the airstrip by the 1298th Combat Engineers. At least 150 Japanese laborers per day were employed by this group for other projects.

Regimental Combat Team - 2 (RCT-2). Regimental Combat Team 2 landed in the vicinity of the Dejima Wharf on the eastern side of Nagasaki Harbor on 23 September 1945. The principal elements of RCT-2 were three Battalion Landing Teams (BLTs). Company "A" of Battalion Landing Team 1 (BLT-1) was designated the regimental Military Police Company and immediately relieved the Marine security guards for the POW recovery operation. Late that afternoon the RCT proceeded to their billets at the Kamigo Barracks. They also established a Command Post at that location (about 4.5 miles south of GZ). The RCT-2 zone of occupation responsibility included all of the city of Nagasaki on the east side of Nagasaki Harbor and the Urakami River and the general area east, northeast, and southeast of the city. (See Figure 6). Note that this area includes the Nishiyama Reservoir. Initially, operations were limited to insuring that all large-caliber defense guns in the areas were inoperable. On 28 September, the RCT began sending patrols (on foot or by jeep) throughout their area of responsibility to locate Japanese military installations and supply areas, and to check on the observance of surrender terms. RCT-2 operated in this area until the following moves took place:

- On 30 October, 1945, BLT-2 moved to Kanoya, approximately 115 miles from Nagasaki
- On 6 November, 1945, BLT-3 and the RCT-2 Command Post moved to Miyakonojo, approximately 100 miles from Nagasaki
- On 12 November, 1945, BLT-1 moved to Miyazaki, approximately 110 miles from Nagasaki.

Regimental Combat Team-6 (RCT-6). Regimental Combat Team 6 also landed on 23 September, but on the west side of Nagasaki Harbor, in the Mitsubishi Shipyard Area (about 2.5 miles south of GZ). A temporary command post was established at the Tategami Wharf, and the RCT immediately began inspection of Japanese military coastal installations on the west side of the harbor. The RCT-6 was billeted in barracks about 1.5 miles west of Nagasaki at Oura. A permanent Command Post was established in the Mitsubishi Shipyard. The RCT-6 zone of responsibility included portions of Nagasaki west of the Harbor and the Urakami River and the general area west, northwest, and southwest of the city (see Figure 6). Their mission was identical to that of RCT-2, and they remained in the area until 25 November 1945 when BLT-2 moved to Saga, and BLT-1 and the RCT-6 Command Post moved to Sasebo. By 6 December 1945, all RCT-6 personnel had departed the Nagasaki area.

Regimental Combat Team-8 (RCT-8). These troops debarked at Nagasaki near the Dejima Wharf on 24 September. On the same day the entire RCT, with the exception of a few work parties unloading supplies, moved to Isahaya, about 10 miles northeast of Nagasaki. RCT-8 remained at Isahaya until 8 October when they moved to Kumamoto. Other than passing through on the day of arrival, RCT-8 had no involvement in the occupation of Nagasaki.

Artillery Group (Primarily the 10th Marine Regiment). The 10th Marine Regiment landed at Nagasaki on 24 September and proceeded directly to Isahaya where they established their command post and billets. The 10th Marine area of responsibility included the area around Isahaya and the Shimabara Peninsula. Their area of responsibility was expanded on 2 November 1945 when they were assigned the area in the vicinity of Nagasaki vacated by the move of RCT-2 to southern Kyushu. On 5 November, the 1st Battalion of the 10th Marines moved to Kamigo Barracks and took over the Military Police responsibility for the city of Nagasaki formally assigned to the 1st BLT of RCT-2. With the departure of RCT-6 (25 November-6 December, 1945), and the major elements of the 2d Division Headquarters during the first week of January 1946, the 10th Marines plus a cadre of remaining medical, service and engineer troops inherited sole responsibility for the occupation of Nagasaki. Second Marine Division Muster Rolls show the last of the 10th Marines Regiment departed Nagasaki on 21-26 June 1946.

Second Tank Battalion. The 2d Tank Battalion debarked at the Kowaminami Shipyard just north of the village of Fukahori, about 9 miles southeast of Nagasaki. Unloading operations were completed on 25 September 1945, and a command post and billets were established in the shipyard. Due to the nature of the terrain, tanks could not be easily operated in the area; therefore the 2d Tank Battalion remained headquartered in Fukahori throughout their occupation period. Fukahori was located in the RCT-2 zone of responsibility, and on 1 October the Tank Battalion was formally assigned to the RCT. From 17 October to 7 November 1945, the battalion furnished a guard detachment of 36 enlisted men and 2 officers to RCT-2 for Military Police duty in the city of Nagasaki. On 8 November 1945 the Tank Battalion was reassigned to the Artillery Group (10th Marines) as they had replaced RCT-2. Every other day beginning 8 November, the Battalion furnished 76 men to the 10th Marines for guard duty in Nagasaki. On 28 November 1945, the battalion was assigned a section of the city for full-time guard duty. This assignment required 60 men per day. Muster Rolls indicate that the 2d Tank Battalion departed the Nagasaki area on 27 December 1945.

Marine Observation Squadron 2 (VMO-2). The squadron debarked at Nagasaki on 23 September and went directly to Isahaya Airfield, over 10 miles northeast of Nagasaki. From there, the squadron conducted reconnaissance, courier, passenger, evacuation, and limited DDT spray flights. Some of these flights probably brought them to the "Atomic Field" landing strip in Nagasaki which opened on 11 October 1945.

Other Units. The above summary outlines the activities of the major units initially assigned to the 2d Marine Division for the occupation of the Nagasaki area. Certainly some other units moved into the area; for example, the 2d Marine Task Organization as of 8 November 1945 (Table 3) shows an

TABLE 3

TASK ORGANIZATION
2d MARINE DIVISION, REINFORCED
(As of 8 November 1945 - Operation Order 63)

DIVISION TROOPS (Assigned strength - see note)

- Division Headquarters Battalion (less detachments)
- 54th CIC A2B2 Detachment (Area)
- 498th CIC B3 Detachment (Combat)
- 498th CIC Detachment
- 93d Headquarters & Headquarters Detachment, Military Government Group
- 94th Material Control Detachment
- 1st Platoon 2d Amphibious Truck Company

SERVICE TROOPS (Assigned strength - see note)

- 2d Service Battalion (less detachments)
- 4th Separate Laundry Platoon
- 2d Medical Battalion* (less detachments)
- 2d Motor Battalion (less detachments)
- 3656th QM Truck Company (USA)
- Corps Evacuation Hospital #3
- Company "B" 264th Medical Battalion
- Company "C" 264th Medical Battalion
- 73d Field Hospital

ENGINEER GROUP (Assigned strength - see note)

- 2d Engineer Battalion (less Companies "A", "B" and "C")
- 43d NCB (less Company "A")
- 1298th Engineer (C) Battalion (USA)
- 2d Pioneer Battalion
- 2d Platoon, Bomb Disposal Company VAC

ARTILLERY GROUP (Assigned strength - 2950)

- 10th Marine Regiment
- Company "A" 43d NCB
- 2d Amphibious Truck Company (less 1st Platoon)
- Company "A" 20th Amphibious Truck Battalion (Prov)
- Detachment, Division Recon Company
- 2d Truck Battalion
- Tracked Vehicle Platoon, Ordnance Company

TABLE 3 (Continued)

REGIMENTAL COMBAT TEAM-2 (Assigned strength - 3615)

- 2d Marine Regiment
- Company C, 2d MT Battalion
- Company B, 2d Medical Battalion*
- Company C, 2d Medical Battalion
- Company A, 2d Engineer Battalion
- 1st Platoon Ordnance Company, 2d Service Battalion
- 1st Platoon Service Company, 2d Service Battalion
- 1st Platoon Automotive Repair Company, 2d MT Battalion
- Detachment Recon Unit
- Detachment A, Division Signal Company
- Detachment B, Division Signal Company
- 415th Malaria Survey Detachment
- Detachment VAC Military Government Team: MIYAZAKI

REGIMENTAL COMBAT TEAM-6 (Assigned strength - 3690)

- 6th Marine Regiment
- Company A, 2d MT Battalion
- Company A, 2d Medical Battalion*
- Company B, 2d Engineer Battalion
- 3d Platoon Ordnance Company, 2d Service Battalion
- 2d Platoon Service Company, 2d Service Battalion
- 2d Platoon Automotive Repair Company, 2d MT Battalion

REGIMENTAL COMBAT TEAM-8 (Assigned strength - 3738)

- 8th Marine Regiment
- Company B, 2d MT Battalion
- Company E, 2d Medical Battalion*
- Company C, 2d Engineer Battalion
- 2d Platoon Ordnance Company, 2d Service Battalion
- 3d Platoon Service Company, 2d Service Battalion
- 3d Platoon Automotive Repair Company, 2d MT Battalion
- Division Recon Company (less detachment)
- Detachment C, Division Signal Company
- Detachment D, Division Signal Company

OBSERVATION SQUADRON (VMO-2)

HARBOR GROUP

- 1st Sep Headquarters and Supply Company (Prov)
- 124th Port Company, USA
- 24th Depot Company

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*Majority were Navy Hospital Corpsmen

influx of some Army units (e.g., the 73d Field Hospital and two companies from the 264th Medical Battalion).

3.3.2 HIROSHIMA[3,4,5]

As stated earlier, Hiroshima (Figure 7) was not chosen to be a port of debarkation or the Headquarters for occupation troops in western Honshu. Therefore, the occupation of Hiroshima involved considerably fewer troops than were located at Nagasaki and required few, if any, troop billets within the city limits.

The occupation of western Honshu was assigned to the I and X Corps of the Sixth Army. Responsibility for the Kure-Hiroshima area was initially assigned to the 41st Division of the X Corps, and the occupation began with the landing of the 1st Battalion of the 162d Infantry Regiment (41st Division) at Hiro on 6 October, 1945. Hiro is located approximately 15 miles southeast of Hiroshima. Soon after landing the 162d Infantry secured the Kure Naval Yard. On 7 October, the remainder of the 162d Infantry landed and moved into the Kure Submarine Base (Kure is approximately 11 miles southeast of Hiroshima). On the same day (7 October 1945) the 186th Infantry Regiment debarked and bivouacked at Kaidaichi, a suburb of Hiroshima, about 5 miles southeast of the center of the city.

The 186th Infantry immediately began improvements to their camp and initiated reconnaissance patrols into their area of responsibility, which included the City of Hiroshima. The 186th Regiment remained in Kaidachi until the inactivation of the 41st Division in December 1945. Typical operations within the city of Hiroshima are not well documented; however, the following events are recorded:

22 October 1945	-	Checked Japanese supply dumps
26 October 1945	-	Checked Japanese supply dumps
2 November 1945	-	Sent reconnaissance party to Mitsubishi Heavy Industrial Corp. in Hiroshima to determine if heavy smelters were operational.
19 November 1945	-	Burned black powder on Hiroshima Parade Grounds.

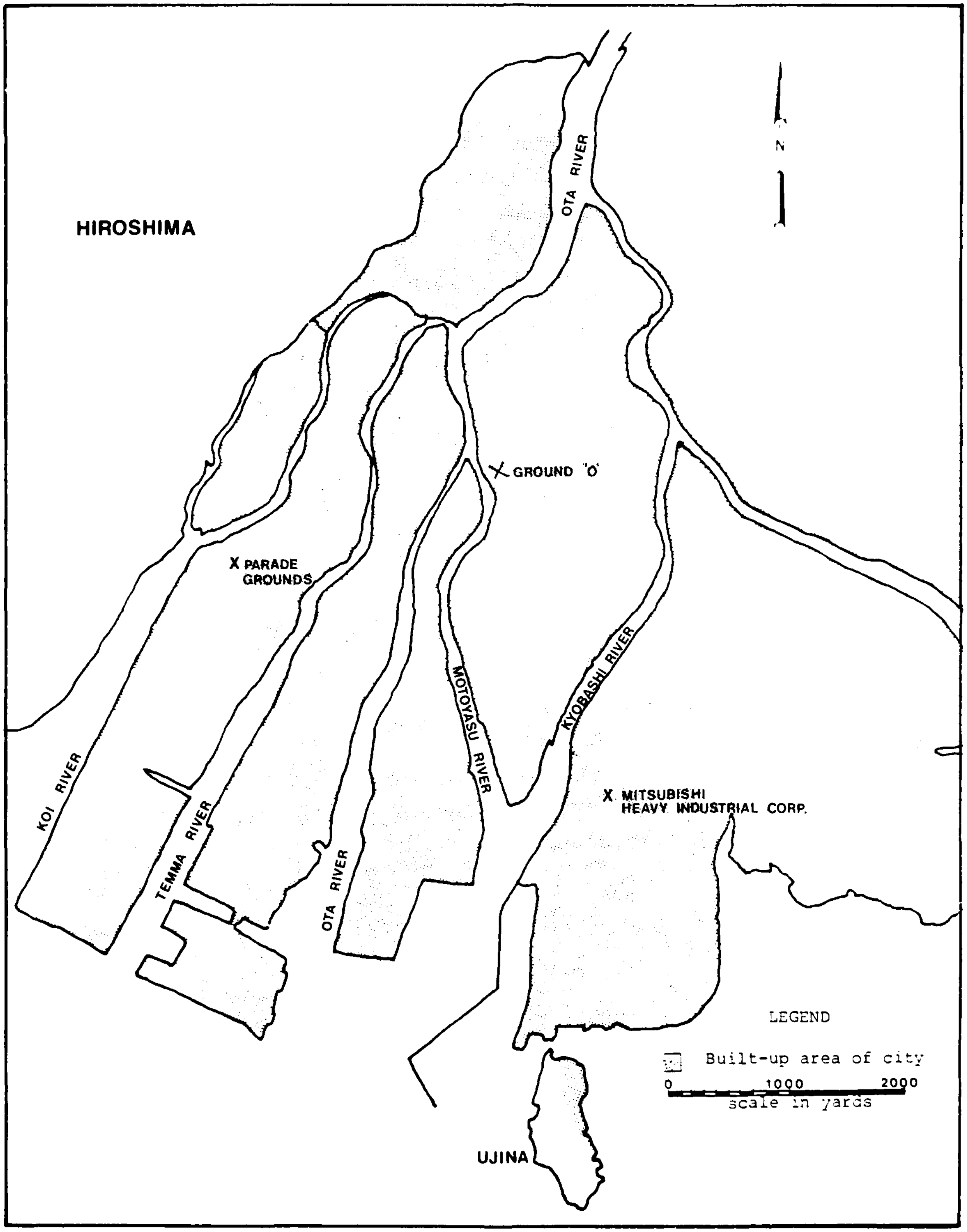

Figure 7. Hiroshima

27 November 1945 - Sent Patrol to Mitsubishi Heavy Industrial Corp. to check and inventory equipment. Destroyed Japanese equipment at demolition point in Hiroshima.

29 November 1945 - Burned guncotton on Hiroshima Parade Grounds.

The fact that these specific events are recorded in Reference 5 seems to indicate that daily operations in the city were not common.

Upon the deactivation of the 41st Division in December, the 24th Infantry Division, headquartered in Matsuyama, assumed control of Hiroshima Prefecture. The 34th Infantry regiment (24th Division) replaced the 186th and 162d Regiments of the 41st Division in the Hiroshima, Kaidachi, Kure, Hiro area on 1 December 1945 (approximate), when they established their headquarters at Hiro. The 34th Regiment was scattered over a very large area. The only unit in the immediate vicinity of Hiroshima was "G" company (approximately 160 men) of the 2d Battalion. G Company was quartered in Ujina, a small island in the delta area just south of Hiroshima.

The 34th Regiment moved its headquarters from Hiro to Himeji on 2 March 1946. On 6 March 1946, the 2d Battalion of the 34th Regiment including G Company that was stationed at Ujina was relieved of its responsibilities by the 67th Australian Infantry Battalion of the 34th Australian Infantry Brigade of the British Commonwealth Occupation Forces. Thus ended U.S. occupation in the Hiroshima area.

Section 4
DOSE ESTIMATES

4.1 EXPOSURE SCENARIO

Section 3 outlined the general activities of the occupation troops, dates that major units were assigned in the Nagasaki and Hiroshima areas, and provided some details relative to specific locations of work areas and living quarters (billets). It is important to note that all known locations for headquarters, command posts, and billets were outside the radiologically contaminated areas. Since the contaminated areas within the built-up portions of each city fell well inside the outer perimeter of the area of near-total destruction (see Figures 1-4), it seems reasonable to assume that virtually all such facilities were located outside the contaminated areas and that exposure to radiation occurred only during periodic trips into these areas (official or unofficial). An exception would be the possible exposure resulting from the consumption of contaminated drinking water. Since details regarding specific activities and time spent within the contaminated areas are rare, the dose estimates are reasonable upper limits derived from a "worst case" scenario. The "worst case" scenario assumes that a hypothetical serviceman remains with his unit for the duration of the unit's entire occupation period, and during that time period, he spends 8 hours per day within the small area defined by the highest radiation intensity contour.

4.2 CALCULATIONS

Two distinct and separate contaminated areas are associated with each city; therefore, each contaminated area is considered separately. Obviously the results are not additive since the hypothetical serviceman cannot be present in each location at the same time. Since the fallout in Hiroshima was insignificant compared to that near Nagasaki and the Hiroshima occupation troops arrived later and stayed for a shorter time, ingestion and inhalation doses from the fallout field are calculated for Nagasaki only. The comparable doses at Hiroshima would be much smaller.

The methodology used for the calculations is straightforward. The dose received from exposure to the radiation sources outside the body (external emitters) is simply the time integral of the dose rate (which varies with radiological decay) over the exposure period. Calculation of the dose received from radionuclides inhaled or ingested is somewhat more complex.

4.2.1 Inhalation Dose

Since there were no air samples taken during troop activities in the contaminated areas, the inhalation dose is calculated indirectly from estimates of the amount of contamination in the soil at the time of occupation troop arrival. For the fallout fields, the surface activity ($\mu Ci/m^2$) is calculated from the gamma intensity (mR/hr) measured 1 meter above the ground using a ratio ($\mu Ci/m^2$ per mR/hr) determined in Reference 25 for similar conditions after a nuclear weapon test shot at the Nevada Test Site. The plutonium content of the soil around the Nishiyama Reservoir outside Nagasaki is estimated from soil sample data.[20] For the induced activity fields, the surface activity determined experimentally by Hashizume[15] and Arakawa[14] is used. Once the surface activity is known, and corrected for radiological decay, the airborne concentration is calculated by the application of a resuspension factor, which is the ratio of the amount of material in the air to that which is on the ground immediately below ($\mu Ci/m^3$ per $\mu Ci/m^2$). Numerous experiments have been conducted to study the resuspension of radioactive materials deposited on the ground under different conditions. Stewart[16] has tabulated resuspension factors that range from 1×10^{-3} to 1×10^{-11} m^{-1} depending on the conditions and the type of material studied. For this study, a high resuspension factor of 1×10^{-4} is selected for application in the induced activity fields around GZ since there is evidence of some mechanical dust-producing activities in these areas (e.g., clearing debris, construction of an airstrip). A value of 1×10^{-5} m^{-1} is chosen for the fallout fields. The amount of radioactive material inhaled is calculated by multiplying the airborne concentration ($\mu Ci/m^3$) by the breathing rate (m^3/hr) of a "standard man" and integrating over the duration of exposure (hr). From the amount of radioactive material inhaled, the 50 year dose-equivalent commitment (rem) to the body organ of interest is calculated by the application of an appropriate "dose conversion factor" (rem/μCi inhaled). The dose conversion factors, taken from references 22 and 23, are based on the latest lung model and metabolic data developed by the International Commission on Radiological Protection.

4.2.2 Ingestion Dose (Drinking Water)

The fallout field at Nagasaki centered around the Nishiyama Reservoir, one of four reservoirs that served the city. However, for this "worst case" calculation, it is assumed that only the Nishiyama Reservoir is used. The 50-year dose-equivalent commitment resulting from ingestion of water from the reservoir is calculated as follows: First, the concentration of radionuclide in the reservoir is calculated by multiplying the surface activity ($\mu Ci/m^2$) as determined for the inhalation dose, by the surface area of the reservoir (m^2) and dividing by its capacity (m^3). Because the runoff from the surrounding contaminated land area would have increased the concentration, this effect is considered by the application of an adjustment factor based on the size of the catchment area and a runoff coefficient. Assuming complete mixing (homogeneous mixture), the quantity of radioactive material ingested is calculated by integrating the product of the concentration ($\mu Ci/m^3$) and the average water intake of a "standard man" (m^3/day) over the duration of exposure (days). The 50-year dose to the organ of interest is then determined by the application of the appropriate "dose conversion factor" (rem/μCi ingested), as done for the inhalation dose calculations. The dose conversion factors for the ingestion calculation are also taken from references 22 and 23. See Appendix E.

4.3 UPPER LIMIT RESULTS

The NMRI survey was chosen as the basis for the calculations since the measurements were made at 1 meter above the ground and should be more representative of whole body exposure. The maximum recorded radiation intensities are used in the calculations.

The following exposure durations, taken from information in Section 3, are used in the calculations:

Nagasaki:

2d Marine Division - 16 Sept 1945 (D+38; H+912) to
2 July 1946 (D+327; H+7848)

Nishiyama:

2d Marine Division (RCT-2) - 24 Sept 1945 (D+46; H+1104) to
12 Nov 45 (D+95; H+2280)

2d Marine Division (Artillery Group) - 2 Nov 1945 (D+85; H+2040) to
26 June 46 (D+321; H+7704)

Hiroshima (all portions):

41st Division (186th Regiment) 7 Oct 1945 (D+62; H+1488) to
1 Dec 45 (D+117; H+2808)

24th Division (34th Regiment) 1 Dec 1945 (D+117; H+2808) to
2 Mar 46 (D+208; H+4992)

The upper limit dose estimates are given in Table 4. See Appendices A-E for details regarding each calculation.

TABLE 4

UPPER LIMIT DOSE ESTIMATES

	HIROSHIMA				NAGASAKI		
	GROUND ZERO		FALLOUT AREA		GROUND ZERO	NISHIYAMA AREA	
	41st DIV	24th DIV	41st DIV	24th DIV	2d DIV	2d DIV (RCT-2)	2d DIV (ARTY GROUP)
External Dose	0.030 rem	0.030 rem	0.019 rem	0.014 rem	0.081 rem	0.47 rem	0.63 rem
Inhalation Dose*							
Bone	0.004 rem	0.004 rem	--	--	0.018 rem	0.14 rem	0.58 rem
RBM**	***	***	--	--	***	0.033 rem	0.13 rem
Whole Body	0.003 rem	0.003 rem	--	--	0.014 rem	0.017 rem	0.068 rem
Ingestion Dose*							
Bone	--	--	--	--	0.09 rem	0.02 rem	0.07 rem
RBM**	--	--	--	--	0.05 rem	0.01 rem	0.04 rem
Whole Body	--	--	--	--	0.03 rem	0.01 rem	0.02 rem

* 50-year dose equivalent commitment
**RBM - Red Bone Marrow
***RBM dose factor for Sc-46 not available. RBM dose should be less than bone dose, but greater than whole body dose.

Section 5
DISCUSSION AND CONCLUSIONS

Whenever possible, a conservative approach leading to a "high-side" result was used in the calculations discussed in Section 4. For example, when compared to the wide range of resuspension factors reported by Stewart[16], the values chosen for the inhalation dose calculations ($K = 1 \times 10^{-4}$ for the induced activity; $K = 1 \times 10^{-5}$ for the fallout) are from the high end of the spectrum. The larger value was chosen for the induced activity fields around ground zero since there is evidence of some dust producing activities in these areas. For example, Reference 8 states that an air strip was constructed at Nagasaki approximately 900 feet from GZ. That operation (delayed by rain which would keep the dust down) took 12 days. A lower value was selected for the fallout field around the Nishiyama Reservoir near Nagasaki since the area is a watershed (normally moist) and no dust producing activity by the occupation troops was reported. In both cases, the resuspension factor used is considered to be conservative since they compare with high values observed in desert terrain[16]. Certainly southern Japan cannot be compared with desert terrain. For example, about 1.2 meters of rain fell in Nagasaki, during September and October, 1945.[26] Furthermore, the same resuspension factor was assumed to apply for the entire duration of occupation troop exposure. Several authors have reported rapid decay of resuspension factors with time after the contaminating event due to "weathering" processes[17,18].

The inhalation dose factors used in the internal dose calculations assume a resuspended particle size distribution having an activity median aerodynamic diameter of 1 micron. It is doubtful that contaminated dust resuspended by construction operations would be that small. Therefore, the dose factor used in these calculations should produce a conservative result.

Most of the assumptions made in the dose estimate for the ingestion of drinking water should also result in a conservative result. No attempt was made to separate the fission products into water soluble/insoluble fractions and eliminate the insoluble portion through sedimentation or filtration processes that likely took place. Also, the calculations do not take into account that there were at least 3 other reservoirs in the area and that local water was not declared safe for consumption (probably for bacteriological reasons) until 3 weeks after the troops arrived.[8] Drinking water was imported during the interim period.

Calculations relative to the neutron-induced activity fields are based on Arakawa's[14] and Hashizume's[15] determinations of the significant radionuclides present and their quantity. In each case, their findings were based on an estimate of the neutron fluence at ground level from the weapon (order of 10^{12} neutrons/cm^2), and laboratory neutron activation of actual soil and building materials taken from Nagasaki and Hiroshima. Quantitatively, their findings depend on indirect estimates of the neutron fluence based on the specific activity of Co-60 measured in various iron materials that were exposed to the neutrons from each weapon. Qualitatively, their findings were determined directly by gamma-ray spectroscopy of the laboratory neutron-activated samples. In Appendix A, only Sc-46 and Co-60 were considered to be significant for the external dose calculation. Other radionuclides (Na-24, Mn-56, and Cs-134) were identified by Arakawa and Hashizume; however, they were not considered in the calculation due to short half life (Na-24 and Mn-56) or small relative quantity (Cs-134). In Appendix C, the same two radionuclides (Sc-46 and Co-60) were considered in the inhalation dose calculation. A radiochemical separation of the neutron-activated samples showed small amounts of Fe-59, Zn-65, and K-40 that were masked by and counted as Na-24, Co-60 or Sc-46 during the gamma-ray spectroscopy analysis mentioned above. Since the inhalation dose factors for Fe-59 and Zn-65 are similar to those of Co-60 and Sc-46, their presence would not affect the overall result. The low decay rate and small amount of K-40 make it insignificant. The small relative abundance of Cs-134 (and similar dose factor) makes this isotope insignificant also. Pure beta emitters such as Ca-45 and P-32 that would not have been detected by gamma spectroscopy were also considered as potential contributors to the internal dose. None were present in sufficient quantity to affect the internal dose to the level of significance reported.

Finally, it must be emphasized that the dose estimates presented in Section 4 apply to an individual who stayed in an area of <u>maximum</u> contamination for eight hours per day for a long time period (2-10 months). In each case, these areas of maximum radiation intensity were quite small (approximately 0.1 km^2) and the contamination fell off rapidly with distance outward. Considering the results of the earliest survey (Manhattan District Survey, Figures 1 and 2) and the size of the built-up areas of each city[12], the extent of the contamination is shown below:

City	Built-up Area	Contaminated Area	
		Measurable	>0.1 mR/hr
Hiroshima	17.9 km^2	$\sim$8.9 km^2 (50%)	$\sim$0.16 km^2 (0.9%)
Nagasaki	10.4 km^2	$\sim$1.5 km^2 (14%)	<0.1 km^2 (1%)

Note that the fallout field at Nagasaki was outside the major built-up portion of the city.

As the above table indicates, the section of either city with a radiation level greater than 0.1 mR/hr (at the time of the surveys near the beginning of the occupation period) consisted of no more than 1 percent of the entire built-up area. Measurable contamination was recorded over only 50 percent of the Hiroshima built-up area and 14 percent of Nagasaki's. Thus, the upper limit estimates for the doses from induced activity given in Section 4.3 are high by at least a factor of two assuming random movement throughout the city.

With respect to the Nishiyama area, there is no record or rationale for stationing occupation units in the area of peak activity (which includes the reservoir itself) over the entire period assumed in the upper limit dose calculation. This area was mountainous, sparsely populated, and had few roads; therefore, it would have been of little interest other than for sightseeing. Patrols were probably conducted but with not nearly the exposure duration that has been assumed and almost certainly not with the same individuals on each patrol. In addition, as stated in Section 3.3.1, the responsibility of RCT-2, and later the Artillery Group, encompassed an area much larger (by at least an order of magnitude) than the area of contamination at Nishiyama. All of these aspects suggest that the upper limit estimates for RCT-2 and the Artillery Group given in Section 4.3 are probably too high by at least a factor of 10.

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APPENDIX A
CALCULATION OF DOSE FROM EXTERNAL EMITTERS
(INDUCED ACTIVITY)
HIROSHIMA AND NAGASAKI

Hiroshima:

Considering the weapon height of burst and the radiation patterns determined by measurements taken on 1-2 November 1945 (see Fig. 4), it can be safely assumed that the gamma radiation detected around GZ resulted from neutron-induced activity in the soil and building materials. In an effort to estimate the external dose to Hiroshima and Nagasaki residents from this induced activity, Hashizume, et al., made calculations based on data determined experimentally[15]. Samples of soil, roof-tile, brick, asphalt, concrete, and wood were collected from Hiroshima and Nagasaki, and analyzed by neutron activation. Using this analysis, Hashizume concluded that only Na-24, Mn-56, Sc-46, Co-60, and Cs-134 need be considered in his dose estimate.

Due to the short half-lives of Na-24 (15 hours) and Mn-56 (2.57 hours), these two isotopes become insignificant at the time of occupation troop arrival at Hiroshima (H+1488) and Nagasaki (H+912). Therefore, only the longer lived isotopes of Sc-46 (84 days), Co-60 (5.2 years) and Cs-134 (2 years) need be considered in this dose estimate for the occupation units.

Using the Hiroshima soil composition data obtained from the neutron activation analysis mentioned above and estimates of the thermal neutron fluence on the ground surface at Hiroshima resulting from the bomb, Hashizume determined the specific activities (μCi/g) of the soil and various building materials (immediately after detonation) shown below:

	Sc-46	Co-60	Cs-134
Soil	5×10^{-5}	0.5×10^{-5}	2×10^{-7}
Roof-tile	17×10^{-5}	1.3×10^{-5}	5×10^{-7}
Brick	11×10^{-5}	1.1×10^{-5}	2×10^{-7}
Concrete	9×10^{-5}	0.8×10^{-5}	4×10^{-7}
Average	10.5×10^{-5}	0.92×10^{-5}	3.25×10^{-7}

From the data presented above, it is evident that Sc-46 and Co-60 were the major contributors to the gamma radiation measurements made in the ground zero area at Hiroshima on 1-2 November 1945. Since Sc-46, and Co-60 both emit 2 gamma rays per disintegration with approximately the same average energy (Co-60 slightly higher), it can be assumed that the gamma intensity measured in air from each isotope follows the same ratio as their relative specific activities in the soil and building materials. Using the average specific activities, the ratio of Sc-46 to Co-60 at time t=0 would be:

$$\frac{10.5 \times 10^{-5}}{0.92 \times 10^{-5}} = 11.41 \text{ or } 92\% \text{ Sc-46; } 8\% \text{ Co-60}$$

For each significant radionuclide, the intensity at any time can be calculated from the following expression:

$$R_t = R_o e^{-\lambda t}$$

where R_t = Intensity at time t (mR/hr)

R_o = Intensity at time t = 0 (mR/hr)

λ = decay constant = $0.693/T_{1/2}$ in hours

t = time (hours).

From Figure 4, the highest intensity contour in the neutron-activation field around GZ was 0.069 mR/hr on 1 November 1946, (D+87; H+2088). The contribution to this intensity from Sc-46 and Co-60 would be:

$$R_t = A\, R_o e^{-\lambda_1 t} + B\, R_o e^{-\lambda_2 t} = 0.069 \text{ mR/hr}$$

where λ_1 = decay constant for Sc-46 = 0.693/2016 hr = 0.0003438 hr^{-1}

λ_2 = decay constant for Co-60 = 0.693/45552 hr = 0.0000152 hr^{-1}

A = fraction* of Sc-46

B = fraction* of Co-60

Therefore:

$$R_o = \frac{R_t}{A\,e^{-\lambda_1 t} + B\,e^{-\lambda_2 t}}$$

$$R_o = \frac{0.069}{(0.92)e^{-(0.0003438)(2088)} + (0.08)e^{-(0.0000152)(2088)}}$$

$$R_o = 0.13 \text{ mR/hr}$$

Assuming that exposure to 1 roentgen results in a dose of 1 rem, the dose (D) received from each significant radionuclide from time (t_i) to time (t_f) can be calculated from the following expression:

$$D = \int_{t_i}^{t_f} R_o e^{-\lambda t} dt = \frac{R_o}{\lambda}\left(e^{-\lambda t_i} - e^{-\lambda t_f}\right)$$

Therefore, at Hiroshima, the dose received by a hypothetical serviceman from the 41st Division from Sc-46 over the period 7 October 1945 (H+1488) to 1 December 1945 (H+2808) is calculated as follows:

$$D = \frac{AR_o}{\lambda_1}\left(e^{-\lambda_1 t_i} - e^{-\lambda_1 t_f}\right)$$

$$= \frac{(0.92)(0.13)}{0.0003438}\left(e^{-(0.0003438)(1488)} - e^{-(0.0003438)(2808)}\right)$$

$$= 76 \text{ mrem} = 0.076 \text{ rem}$$

The dose from Co-60 would be:

$$D = \frac{BR_o}{\lambda_2}\left(e^{-\lambda_2 t_i} - e^{\lambda_2 t_f}\right)$$

$$= \frac{(0.08)(0.13)}{0.0000152}\left(e^{-(0.0000152)(1488)} - e^{-(0.0000152)(2808)}\right)$$

$$= 13 \text{ mrem} = 0.013 \text{ rem}$$

Assuming an 8 hour per day exposure, the total dose would be:

$$D = \frac{76 + 13}{3} \approx 30 \text{ mrem or } 0.03 \text{ rem}$$

The dose received by a hypothetical serviceman from the 24th Division from 1 December 1945 (H+2808) to 2 March 1946 (H+4992) would be:

From Sc-46:

$$D = \frac{AR_o}{\lambda_1}(e^{-\lambda_1 t_i} - e^{\lambda_1 t_f})$$

$$= \frac{(0.92)(0.13)}{0.0003438}(e^{-(0.0003438)(2808)} - e^{-(0.0003438)(4992)})$$

$$= 70 \text{ mrem}$$

From Co-60:

$$D = \frac{BR_o}{\lambda_2}(e^{-\lambda_2 t_i} - e^{-\lambda_2 t_f})$$

$$= \frac{(0.08)(0.13)}{0.0000152}(e^{-(0.0000152)(2808)} - e^{-(0.0000152)(4992)})$$

$$= 21 \text{ mrem}$$

Assuming an 8 hour per day exposure, the total dose would be:

$$D = \frac{70+21}{3} \approx 30 \text{ mrem or } 0.03 \text{ rem}$$

Nagasaki:

Using a similar approach, Arakawa[14] estimated the specific activity of Sc-46 and Co-60 (at time of burst) in the Nagasaki soil to be:

Sc-46 - 16.7×10^{-5} μCi/g (average)
Co-60 - 1.1×10^{-5} μCi/g

Using the same methodology used in the Hiroshima calculation and the measurements made at GZ in Nagasaki (0.069 mR/hr on 21 October or H+1512, the midtime of the NMRI Survey):

$$R_o = \frac{R_t}{Ae^{-\lambda_1 t} + Be^{-\lambda_2 t}}$$

$$= \frac{0.069}{(0.938)e^{-(0.0003438)(1512)} + (0.062)e^{-(0.0000152)(1512)}}$$

$$= 0.11 \text{ mR/hr}$$

Therefore, at Nagasaki, the dose received from Sc-46 over the period 16 September 1945 (H+912) to 2 July, 1946 (H+7848) is calculated as follows:

$$D = \frac{AR_o}{\lambda_1}(e^{-\lambda_1 t_i} - e^{\lambda_1 t_f})$$

$$= \frac{(0.938)(0.11)}{0.0003438}(e^{-(0.0003438)(912)} - e^{-(0.0003438)(7848)})$$

$$= 199 \text{ mrem}$$

The dose from Co-60 over the same period:

$$D = \frac{BR_o}{\lambda_2}(e^{-\lambda_2 t_i} - e^{-\lambda_2 t_f})$$

$$= \frac{(0.062)(0.11)}{0.0000152}(e^{-(.0000152)(912)} - e^{-(0.0000152)(7848)})$$

$$= 44 \text{ mrem}$$

The total dose considering an 8 hour/day exposure:

$$D = \frac{199+44}{3} = 81 \text{ mrem or } 0.081 \text{ rem}$$

APPENDIX B
CALCULATION OF DOSE FROM EXTERNAL EMITTERS (FISSION PRODUCTS)
HIROSHIMA AND NAGASAKI/NISHIYAMA

According to Glasstone[1], the gamma intensity from early fallout decays with time after the detonation (up to 4000 hours) according to $t^{-1.2}$, where t equals the time after detonation in hours. Between 4000 hours and 7700 hours (extent of time of interest for this study), the decay is approximately $t^{-2.2}$. Therefore, the intensity (R_t) in mR/hr at any time (t) in hours can be calculated from the following expression:

$$R_t = R_1 t^{-1.2}, \; t < 4000$$

$$R_t = R_1 (4000)^{-1.2} \left(\frac{t}{4000}\right)^{-2.2}, \; t > 4000$$

where R_1 = Reference time (H+1) intensity (mR/hr)

Since exposure to 1 roentgen of gamma radiation results in a dose of 1 rem, the dose (D) in rems resulting from an exposure from time (t_i) to a later time (t_f) can be calculated by integrating the above expression as follows:

$$D = \int_{t_i}^{t_f} R_1 t^{-1.2}\, dt = 5R_1 (t_i^{-0.2} - t_f^{-0.2}), \text{ for } t_f < 4000$$

$$D = \int_{t_i}^{4000} R_1 t^{-1.2} dt + \int_{4000}^{t_f} R_1 (4000)^{-1.2} \left(\frac{t}{4000}\right)^{-2.2} dt$$

$$= R_1 \left[5(t_i^{-.2} - 4000^{-.2}) + \frac{4000}{1.2} (4000^{-1.2} - t_f^{-1.2}) \right], \text{ for } t_f > 4000$$

In order to reflect an 8 hour per day exposure during the period, the above equation is divided by 24/8 or 3.

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Hiroshima Calculation:

From Figure 4, the maximum intensity in the downwind fallout field (west of Koi River) was 0.042 mR/hr on 1 November 1945 (D+87; H+2088). Therefore:

$$R_1 = \frac{R_t}{t^{-1.2}} = \frac{0.042}{2088^{-1.2}} \simeq 405 \text{ mR/hr}$$

The dose received by a hypothetical serviceman from the 41st Division (186th Regiment) from 7 October 1945 (D+62; H+1488) to 1 December 1945 (D+117; H+2808) would be:

$$D = \frac{5(405)(1488^{-0.2} - 2808^{-0.2})}{3}$$

$$= 19 \text{ mrem or } 0.019 \text{ rem}$$

The dose received by a hypothetical serviceman from the 24th Division (34th Regiment) from 1 December 1945 (D+117; H+2808) to 2 March 1946 (D+208; H+4992) would be:

$$D = \frac{405}{3}\left[5(2808^{-.2} - 4000^{-.2}) + \frac{4000}{1.2}(4000^{-1.2} - 4992^{-1.2})\right]$$

$$\simeq 14 \text{ mrem or } 0.014 \text{ rem}$$

Nagasaki/Nishiyama Calculation:

From Figure 3, the highest intensity in the downwind fallout field around the Nishiyama Reservoir was 1.080 mR/hr on 21 October 1945 (mid-time of survey; D+73; H+1752).

$$R_1 = \frac{R_t}{t^{-1.2}} = \frac{1.080}{1752^{-1.2}} \simeq 8427 \text{ mR/hr}$$

The dose received by a hypothetical serviceman from the 2d Marine Division (RCT-2) from 24 September 1945 (D+46; H+1104) to 12 November 1945 (D+95; H+2280) would be:

$$D = \frac{5(8427)(1104^{-0.2} - 2280^{-0.2})}{3}$$

$$\simeq 470 \text{ mrem or } 0.47 \text{ rem}$$

The dose received by a hypothetical serviceman from the 2d Marine Division (Artillery Group) from 2 November 1945 (D+85; H+2040) to 26 June, 1946 (D+321; H+7704) would be:

$$D = \frac{8427}{3}\left[5(2040^{-.2} - 4000^{-.2}) + \frac{4000}{1.2}(4000^{-1.2} - 7704^{-1.2})\right]$$

$$\simeq 630 \text{ mrem or } 0.63 \text{ rem}$$

APPENDIX C
CALCULATION OF DOSE FROM INTERNAL EMITTERS
(INHALED INDUCED ACTIVITY)
HIROSHIMA AND NAGASAKI

In Appendix A it was determined that Sc-46 and Co-60 were the only isotopes of significance remaining in the GZ area at the time of occupation troop entry into Hiroshima and Nagasaki. Average specific activities (μCi/g) for soil and building materials determined by Arakawa[14] and Hashizume, et al.,[15] at time zero (immediately after detonation) are shown below:

	Sc-46	Co-60
Hiroshima	10.5×10^{-5}	0.92×10^{-5}
Nagasaki*	16.7×10^{-5}	1.1×10^{-5}

Assuming a composite (soil and building materials) density of 2.0 grams per cubic centimeter, the concentration (μCi/cm^3) of these materials are shown below

	Sc-46	Co-60
Hiroshima	21.0×10^{-5}	1.84×10^{-5}
Nagasaki	33.4×10^{-5}	2.2×10^{-5}

Assuming that the top centimeter of soil and/or crushed building material is available for resuspension, a conservative value (10^{-4}m^{-1}) for a resuspension factor and a breathing rate of 1.3 m^3/hr, the quantity (μCi) of each radionuclide inhaled during the entire occupation period is calculated as follows:

*Soil only

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$$Q = \frac{SA_o \times K \times BR}{3} \int_{t_i}^{t_f} e^{-\lambda t} dt$$

$$Q = \frac{SA_o \times K \times BR}{3\lambda} (e^{-\lambda t_i} - e^{-\lambda t_f})$$

where
Q = Quantity inhaled (μCi)
SA_o = Surface activity at time zero ($\mu Ci/m^2$)
K = Resuspension factor (m^{-1})
BR = Breathing Rate (m^3/hr)
t_i = Time of entry (hr)
t_f = Time of departure (hr)
λ = Decay constant
3 = Exposure Factor (8 hour/day exposure)

Results:

For Hiroshima:

	41st Division (t_i=1488; t_f=2808)	24th Division (t_i=2808; t_f=4992)
	Q	Q
	Sc-46 = 0.058 μ Ci	Sc-46 = 0.053 μ Ci
	Co-60 = 0.010 μ Ci	Co-60 = 0.017 μ Ci

For Nagasaki: (t_i=912; t_f=7848)

Sc-46 = 0.28 μCi
Co-60 = 0.062 μCi

Using 50-year dose commitment factors from references 21 and 22, the dose to the bone and to the whole body is calculated as follows:

D = Q x DF (for organ of interest)

where
D = 50-year dose commitment (rem)
Q = Quantity inhaled (μCi)
DF = Dose Factor (rem/μCi inhaled)

For Hiroshima (41st Division)

From Sc-46:

Whole body dose $= 0.058 \times 3.11 \times 10^{-2} = 1.8 \times 10^{-3}$ rem

Bone dose $= 0.058 \times 5.51 \times 10^{-2} = 3.2 \times 10^{-3}$ rem

From Co-60:

Whole body dose $= 0.010 \times 8.20 \times 10^{-2} = 0.8 \times 10^{-3}$ rem

Bone dose $= 0.010 \times 5.06 \times 10^{-2} = 0.5 \times 10^{-3}$ rem

Totals:

Whole body dose $= 2.6 \times 10^{-3}$ rem

Bone dose $= 3.7 \times 10^{-3}$ rem

For Hiroshima (24th Division)

From Sc-46:

Whole body dose $= 1.7 \times 10^{-3}$ rem

Bone dose $= 2.9 \times 10^{-3}$ rem

From Co-60:

Whole body dose $= 1.4 \times 10^{-3}$ rem

Bone dose $= 0.9 \times 10^{-3}$ rem

Totals:

Whole body dose $= 3.1 \times 10^{-3}$ rem

Bone dose $= 3.8 \times 10^{-3}$ rem

For Nagasaki

From Sc-46:

Whole body dose $= 0.9 \times 10^{-2}$ rem

Bone dose $= 1.5 \times 10^{-2}$ rem

From Co-60:

Whole body dose $= 5.1 \times 10^{-3}$ rem

Bone dose $= 3.1 \times 10^{-3}$ rem

Totals:

Whole body dose $= 1.4 \times 10^{-2}$ rem

Bone dose $= 1.8 \times 10^{-2}$ rem

APPENDIX D

CALCULATION OF DOSE FROM INTERNAL EMITTERS (INHALED FISSION PRODUCTS AND UNFISSIONED PLUTONIUM) NAGASAKI (NISHIYAMA)

FISSION PRODUCTS:

In Figure 3, the maximum radiation intensity recorded in the fallout field around the Nishiyama Reservoir was 1.080 mR/hr on 21 October, 1945, (midtime of the NMRI survey). Assuming the intensity decays according to $t^{-1.2}$, this level would be approximately 1.9 mR/hr on 24 September, 1945, the earliest date that RCT-2 could send patrols into the area.

The gamma radiation intensity (mR/hr) measured at one meter above the ground was related to the surface activity ($\mu Ci/m^2$) for the fallout from three nuclear weapons test shots at the Nevada Test Site.[25] For Shot Diablo, the ratio of the surface activity ($\mu Ci/m^2$) to the gamma intensity (mR/hr) was 179 to 1, forty-nine days after the detonation. Since the Diablo device and the Nagasaki weapon both used plutonium as the fissionable material and the time interval after the detonation is nearly the same (49 days vs. 46 days), this ratio can be used to estimate the surface activity at Nishiyama on 24 September 1945, as follows:

$$1.9 \text{ mR/hr} \times 179\ (\mu Ci/m^2)/(mR/hr) \approx 340\ \mu Ci/m^2$$

Using activity fractions of the fission product inventory at 1100 hours obtained from ORIGEN[24], the surface activity of each significant isotope at the earliest time of troop entry (24 September 1945, H+1104 hours) is calculated below:

$$SA_i = SA_t \times f_i$$

where SA_i = Surface activity of isotope i ($\mu Ci/m^2$)
SA_t = Total surface activity (340 $\mu Ci/m^2$)
f_i = Activity fraction of isotope i

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ISOTOPE	f	SA_i ($\mu Ci/m^2$)
Sr-89	0.0358	12.22
Sr-90	0.0004	0.13
Y-90	0.0004	0.13
Y-91	0.0466	15.89
Zr-95	0.0840	28.66
Nb-95	0.0621	21.19
Ru-103	0.1433	48.89
Ru-106	0.0212	7.23
Rh-103m	0.1433	48.89
Rh-106	0.0212	7.23
Te-127m	0.0012	0.41
Te-127	0.0012	0.41
Te-129m	0.0078	2.66
Te-129	0.0049	1.67
I-131	0.0185	6.31
Cs-136	0.0019	0.64
Cs-137	0.0011	0.37
Ba-137m	0.0010	0.35
Ba-140	0.0653	22.29
La-140	0.0749	25.55
Ce-141	0.1219	41.59
Ce-144	0.0216	7.37
Pr-143	0.0648	22.11
Pr-144	0.0216	7.37
Nd-147	0.0197	6.72

The amount of each significant radionuclide inhaled during the occupation period is calculated using the following expression:

$$Q = \frac{SA_o \times K \times BR}{3} \int_{t_i}^{t_f} e^{-\lambda t} \, dt$$

$$Q = \frac{SA_o \times K \times BR}{3\lambda} \left(e^{-\lambda t_i} - e^{-\lambda t_f} \right)$$

when:
- Q = Amount inhaled (μCi)
- SA_o = Surface activity at time zero ($\mu Ci/m^2$)
- K = Resuspension Factor (m^{-1})
- BR = Breathing Rate (m^3/hr)
- t_i = Time of entry (hr)
- t_f = Time of departure (hr)
- λ = Radiological Decay Constant (hr^{-1})
- 3 = Exposure Factor (8 hours/day exposure)

Using this equation, the amount of each isotope inhaled during the occupation period is shown below:

ISOTOPE	Q(μCi inhaled) RCT-2	Q(μCi inhaled) Artillery Group
Sr-89	4.59E-02	5.52E-02
Sr-90	6.67E-04	3.19E-03
Y-90	6.67E-04	3.19E-03
Y-91	6.16E-02	8.30E-02
Zr-95	1.14E-01	1.72E-01
Nb-95	8.43E-02	1.26E-01
Ru-103	1.67E-01	1.44E-01
Ru-106	3.52E-02	1.40E-01
Rh-103m	1.67E-01	1.44E-01
Rh-106	3.52E-02	1.40E-01
Sn-123	5.86E-04	1.44E-03
Sn-125	1.80E-04	1.05E-05
Te-127m	1.78E-03	4.02E-03
Te-127	1.79E-03	4.02E-03
Te-129m	8.58E-03	6.11E-03
Te-129	5.39E-03	3.83E-03
I-131	7.50E-03	2.65E-04
Cs-136	1.19E-02	1.84E-04
Cs-137	1.88E-03	8.98E-03
Ba-137m	1.77E-03	8.41E-03
Ba-140	3.97E-02	5.15E-03
La-140	4.56E-02	5.91E-03
Ce-141	1.31E-01	8.77E-02
Ce-144	3.54E-02	1.25E-01
Pr-143	4.14E-02	6.16E-03
Pr-144	3.54E-02	1.25E-01
Nd-147	1.06E-02	9.57E-04

The 50-year dose-equivalent commitment to the bone, red bone marrow (RBM) and the whole body resulting from the inhalation of these isotopes is calculated as follows:

$$D = Q \times DF \text{ (for organ of interest)}$$

where: D = Dose (rem)

Q = Quantity inhaled (μCi)

DF* = Dose Conversion factor (rem/μCi inhaled)

*Dose factors from References 22 and 23.

FOR RCT-2:

ISOTOPE	Q	DF (bone)	D (bone)	DF (RBM)	D (RBM)	DF (Whole Body)	D (Whole Body)
Sr-89	4.59E-02	3.38E-02	1.55E-03	1.33E-02	0.61E-03	4.76E-03	0.21E-03
Sr-90	6.67E-04	3.00	2.00E-03	1.10	0.74E-03	0.24	0.16E-03
Y-90	6.67E-04	1.95E-03	*	8.39E-04	*	9.62E-04	*
Y-91	6.16E-02	2.25E-02	1.38E-03	8.51E-03	0.52E-03	5.67E-03	0.35E-03
Zr-95	1.14E-01	9.15E-03	1.05E-03	5.46E-03	0.62E-03	5.55E-03	0.63E-03
Nb-95	8.43E-02	1.22E-03	0.11E-03	1.61E-03	0.13E-03	1.94E-03	0.17E-03
Ru-103	1.67E-01	9.12E-04	1.55E-03	1.25E-03	0.21E-03	1.98E-03	0.37E-03
Ru-106	3.52E-02	8.76E-03	0.31E-03	9.37E-03	0.33E-03	6.18E-02	0.21E-03
Rh-103m	1.67E-01	2.05E-08	*	2.28E-08	*	9.89E-07	*
Rh-106	3.52E-02	1.14E-08	*	1.43E-08	*	3.44E-07	*
Te-127m	1.78E-03	2.25E-03	*	2.52E-03	*	3.20E-03	*
Te-127	1.79E-03	8.87E-06	*	4.09E-05	*	5.13E-05	*
Te-129m	8.58E-03	3.51E-04	*	8.27E-04	*	5.54E-04	*
Te-129	5.39E-03	2.25E-06	*	6.31E-06	*	1.80E-05	*
I-131	7.50E-03	2.38E-04	*	2.02E-04	*	6.13E-04	*
Cs-136	1.19E-02	6.70E-03	0.08E-03	7.91E-03	0.10E-03	6.00E-03	0.07E-03
Cs-137	1.88E-03	4.54E-02	0.08E-03	4.91E-02	0.10E-03	3.26E-02	0.06E-03
Ba-137m	1.77E-03	1.70E-07	*	2.22E-07	*	3.21E-07	*
Ba-140	3.97E-02	5.72E-03	0.23E-03	3.61E-03	0.14E-03	2.08E-03	0.08E-03
La-140	4.56E-02	8.00E-04	0.04E-03	8.52E-04	0.04E-03	1.05E-03	0.05E-03
Ce-141	1.31E-01	1.55E-02	2.03E-03	4.07E-03	0.54E-03	3.27E-03	0.05E-03
Ce-144	3.54E-02	0.91	32.21E-03	0.35	12.46E-03	0.17	6.03E-03
Pr-143	4.14E-02	1.10E-02	0.45E-03	3.36E-03	0.14E-03	2.14E-03	0.08E-03
Pr-144	3.54E-02	1.03E-05	*	4.27E-06	*	9.75E-06	*
Nd-147	1.06E-02	9.80E-03	0.11E-03	2.75E-03	0.02E-03	2.14E-03	0.02E-03
Totals			~43E-03 or 0.043 rem		~17E-03 or 0.017 rem		~9E-03 or 0.009 rem

*Less than 1E-05

NOTE: Read 4.59E-02 as 4.59 x 10^{-2}

FOR THE ARTILLERY GROUP:

ISOTOPE	Q	DF (bone)	D (bone)	DF (RBM)	D (RBM)	DF (Whole Body)	D (Whole Body)
Sr-89	5.52E-02	3.38E-02	1.86E-03	1.33E-02	0.73E-03	4.76E-03	0.26E-03
Sr-90	3.19E-03	3.00	9.56E-03	1.10	3.51E-03	0.24	0.76E-03
Y-90	3.19E-03	1.95E-03	*	8.39E-04	*	9.62E-04	*
Y-91	8.30E-02	2.25E-02	1.87E-03	8.51E-03	0.70E-03	5.67E-03	0.47E-03
Zr-95	1.72E-01	9.15E-03	1.57E-03	5.46E-03	0.94E-03	5.55E-03	0.95E-03
Nb-95	1.26E-01	1.22E-03	0.16E-03	1.61E-03	0.20E-03	1.94E-03	0.25E-03
Ru-103	1.44E-01	9.12E-04	0.13E-03	1.25E-03	0.18E-03	1.98E-03	0.29E-03
Ru-106	1.40E-01	8.76E-03	1.26E-03	9.37E-03	1.35E-03	6.18E-02	0.89E-03
Rh-103m	1.44E-01	2.05E-08	*	2.28E-08	*	9.89E-07	*
Rh-106	1.40E-01	1.14E-08	*	1.43E-08	*	3.44E-07	*
Te-127m	4.02E-03	2.25E-03	*	2.52E-03	*	3.20E-03	*
Te-127	4.02E-03	8.87E-06	*	4.09E-05	*	5.13E-05	*
Te-129m	6.11E-03	3.51E-04	*	8.27E-04	*	5.54E-04	*
Te-129	3.83E-03	2.25E-06	*	6.31E-06	*	1.80E-05	*
I-131	2.65E-04	2.38E-04	*	2.02E-04	*	6.13E-04	*
Cs-136	1.84E-04	6.70E-03	*	7.91E-03	*	6.00E-03	*
Cs-137	8.98E-03	4.54E-02	0.41E-03	4.91E-02	0.44E-03	3.26E-02	0.30E-03
Ba-137m	8.41E-03	1.70E-07	*	2.22E-07	*	3.21E-07	*
Ba-140	5.15E-03	5.72E-03	0.04E-03	3.61E-03	0.02E-03	2.08E-03	0.01E-03
La-140	5.91E-03	8.00E-04	*	8.52E-04	*	1.05E-03	*
Ce-141	8.77E-02	1.55E-02	1.36E-03	2.03E-03	0.36E-03	3.27E-03	0.29E-03
Ce-144	1.25E-01	0.91	114.00E-03	0.35	43.84E-03	0.17	21.30E-03
Pr143	6.16E-03	1.10E-02	0.07E-03	3.36E-03	0.02E-03	2.14E-03	0.01E-03
Pr-144	1.25E-01	1.03E-05	*	4.27E-06	*	9.75E-06	*
Nd-147	9.57E-04	9.80E-03	*	2.75E-03	*	2.14E-03	*
Totals			~132E-03 or 0.132 rem		~52E-03 or 0.052 rem		~26E-03 or 0.026 rem

*Less than 1E-05

PLUTONIUM-239:

The weapon dropped on Nagasaki was a Pu-239 device; therefore some unfissioned plutonium would be expected in the fallout around the Nishiyama Reservoir, and above-background levels of Pu-239 have been detected in that area. Soil samples (10 cm deep) taken in relatively undisturbed areas (grasslands and graveyards) in 1969, expressed in terms of surface activity, ranged from 0.015 $\mu Ci/m^2$ to 0.038 $\mu Ci/m^2$ with an average of 0.024 $\mu Ci/m^2$.[20] These samples were taken in the general area of the maximum radiation intensity recorded in Figures 1 and 3 . Soil samples taken in nearby areas that were not contaminated by fallout from the bomb ranged from 0.001 to 0.006 $\mu Ci/m^2$ with an average of 0.004 $\mu Ci/m^2$. Using the latter results as a background level, the residual Pu-239 surface contamination from the bomb (24 years later) was about 0.02 $\mu Ci/m^2$ in the area of maximum fallout contamination. Due to the extremely long radiological half life of Pu-239 (24,000 years), radiological decay since 1945 would be insignificant; therefore any difference in the surface contamination between 1945 and 1969 would result from environmental factors. Plutonium-oxide, the most likely chemical form of the unfissioned plutonium, has been shown to be persistent in soil.

Soil samples (30 cm deep) taken in the same general area in 1970 and analyzed for Cs-137, averaged 0.8 $\mu Ci/m^2$ while similar background samples averaged 0.5 $\mu Ci/m^2$.[19] Subtracting background and back-calculating for radiological decay results in a level of 0.53 $\mu Ci/m^2$ in 1945. This agrees fairly well with the calculated value of 0.37 $\mu Ci/m^2$, especially since the exact location of these samples relative to the location of the maximum radiation intensity (1.08 mR/hr) used to calculate the surface activity is unknown. Such agreement implies that the Cs-137 contamination in undisturbed soils has not been significantly altered by environmental factors. Therefore, assuming Cs-137 and Pu-239 behave similarly, the Pu-239 soil sample data mentioned above can be used (unadjusted) to estimate the inhalation dose as follows:

$$D_i = SA \times K \times BR \times T \times DF_i$$

where D_i = 50 year dose-equivalent commitment for organ i

SA* = Surface Activity ($\mu Ci/m^2$)

K = Resuspension factor (m^{-1})

BR = Breathing rate (m^3/hr)

T = Duration of exposure (hr)

DF_i = Dose Conversion Factor (rem/μCi inhaled) for organ i

<u>For the RCT-2:</u> (t_i = 1104 hours; t_f = 2280 hours)

$$\text{Bone Dose} = 0.02 \times 10^{-5} \times 1.3 \times \frac{1176}{3} \times 9.12 \times 10^2 = 0.093 \text{ rem}$$

$$\text{RBM Dose} = 0.02 \times 10^{-5} \times 1.3 \times \frac{1176}{3} \times 1.54 \times 10^2 = 0.016 \text{ rem}$$

$$\text{Whole Body Dose} = 0.02 \times 10^{-5} \times 1.3 \times \frac{1176}{3} \times 86 = 0.008 \text{ rem}$$

<u>For the Artillery Group:</u> (t_i = 2040 hours; t_f = 7704 hours)

$$\text{Bone Dose} = 0.02 \times 10^{-5} \times 1.3 \times \frac{5664}{3} \times 9.12 \times 10^2 = 0.447 \text{ rem}$$

$$\text{RBM Dose} = 0.02 \times 10^{-5} \times 1.3 \times \frac{5664}{3} \times 1.54 \times 10^2 = 0.076 \text{ rem}$$

$$\text{Whole Body Dose} = 0.02 \times 10^{-5} \times 1.3 \times \frac{5664}{3} \times 86 = 0.042 \text{ rem}$$

<u>TOTALS (Fission Products + Pu-239)</u>

For RCT-2:

Bone Dose = 0.043 + 0.093 = 0.136 rem

RBM Dose = 0.017 + 0.016 = 0.033 rem

Whole Body Dose = 0.009 + 0.008 = 0.017 rem

For the Artillery Group:

Bone Dose = 0.132 + 0.447 = 0.579 rem

RBM Dose = 0.052 + 0.076 = 0.128 rem

Whole Body Dose = 0.026 + 0.042 = 0.068 rem

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*Radiological decay is insignificant during occupation period.

APPENDIX E

CALCULATION OF DOSE FROM INTERNAL EMITTERS (INGESTED FISSION PRODUCTS AND UNFISSIONED PLUTONIUM IN DRINKING WATER) NAGASAKI

The maximum fallout measured in the Nagasaki area centered around the Nishiyama reservoir, one of four reservoirs that served the city. In Appendix D, the surface activity ($\mu Ci/m^2$) of each significant radionuclide at the point of maximum intensity in the fallout field was calculated for the time of occupation troop arrival. Assuming the same surface activity on the reservoir and subsequently mixed uniformly throughout (no settling or filtration of insoluble components) the concentration (C_o) of each radionuclide in the reservoir would be:

$$C_o(\mu Ci/m^3) = \frac{SA(\mu Ci/m^2) \times \text{Surface Area of Reservoir } (m^2)}{\text{Capacity of Reservoir } (m^3)}$$

According to reference 13, the surface area of the reservoir (full) is $1.39 \times 10^5 m^2$, and its effective capacity is 3.88×10^8 gal or $1.47 \times 10^6 m^3$.

In order to consider the contribution from the surface activity that may have washed into the reservoir from the adjacent watershed, the concentration is adjusted by the ratio of the size of the catchment area ($4.59 \times 10^6 m^2$)[8] to that of surface area of the reservoir and the use of runoff coefficient for similar terrain (0.35). Since the size of the catchment area is slightly larger than that defined by the 0.555 mR/hr contour in Figure 3, which is approximately half the activity level assumed above for direct deposition on the reservoir, the adjustment factor (A) is divided by 2 as follows:

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$$A = \frac{\text{Catchment Area } (m^2) \times 0.35}{\text{Area of Reservoir } (m^2) \times 2}$$

$$= \frac{4.59 \times 10^6 \times 0.35}{1.39 \times 10^5 \times 2}$$

$$= 5.78$$

Assuming a water consumption rate of 2 liters ($2 \times 10^{-3} m^3$) per day, the activity of each radionuclide ingested during the occupation period is calculated from the following expression:

$$Q = DR \times A \times C_o \int_o^{t_f} e^{-\lambda t} dt$$

$$= \frac{DR \times A \times C_o}{\lambda} (1 - e^{-\lambda t_f})$$

where
- Q = Activity ingested (μCi)
- DR = Drinking rate (m^3/day)
- A = Adjustment factor
- C_o = Activity concentration at time of arrival
- λ = Radiological Decay Constant (days^{-1})
- t_f = Duration of exposure (days)

After the quantity of each radionuclide ingested has been determined, the 50-year dose commitment resulting therefrom is calculated as follows:

$$D = Q \times DF \text{ (organ of interest)}$$

where:
- D = 50-year dose commitment (rem)
- Q = Quantity ingested (μCi)
- DF = Dose Factor (rem/μCi ingested)

For the 2d Marine Division (t_1 327 - 38 289 days):

ISOTOPE	SA	C_0	Q	DF (Bone)	D (Bone)	DF (RBM)	D (RBM)	DF (Whole Body)	D (Whole Body)
Sr-89	12.22	1.16	9.64E-01	1.33E-02	1.28E-02	5.23E-03	0.50E-02	1.80E-03	0.17E-02
Sr-90	0.13	0.012	4.02E-02	1.2	4.82E-02	0.43	1.73E-02	9.45E-02	0.38E-02
Y-90	0.13	0.012	4.02E-02	1.61E-06	*	6.94E-07	*	5.07E-04	*
Y-91	15.89	1.50	1.42	2.45E-05	*	1.15E-05	*	4.37E-04	0.06E-02
Zr-95	28.66	2.71	2.82	3.53E-04	0.09E-02	6.62E-04	0.19E-02	5.45E-04	0.15E-02
Nb-95	21.19	2.00	2.08	3.51E-04	0.07E-02	6.74E-04	0.14E-02	5.04E-04	0.10E-02
Ru-103	48.89	4.62	3.05	3.75E-04	0.11E-02	6.52E-04	0.20E-02	5.29E-04	0.16E-02
Ru-106	7.23	0.68	1.75	8.12E-03	1.42E-02	8.31E-03	1.45E-02	5.94E-03	1.04E-02
Rh-103m	48.89	4.62	3.04	2.30E-08	*	4.05E-08	*	8.96E-07	*
Rh-106	7.23	0.68	1.75	1.07E-08	*	1.86E-08	*	1.89E-07	*
Te-127m	0.41	0.039	5.83E-02	2.44E-03	0.01E-02	2.59E-03	0.02E-02	7.60E-04	*
Te-127	0.41	0.039	5.83E-02	1.60E-05	*	7.48E-05	*	5.34E-05	*
Te-129m	2.66	0.25	1.43E-01	1.89E-03	0.03E-02	1.34E-03	0.02E-02	1.29E-03	0.02E-02
Te-129	1.67	0.16	8.85E-02	2.15E-06	*	6.64E-06	*	1.73E-05	*
I-131	6.31	0.60	7.95E-02	3.59E-04	*	2.94E-04	*	9.08E-04	*
Cs-136	0.64	0.06	1.38E-02	1.01E-02	0.01E-02	1.20E-02	0.02E-02	9.05E-03	0.01E-02
Cs-137	0.37	0.035	1.16E-01	6.82E-02	0.79E-02	7.38E-02	0.86E-02	4.91E-02	0.57E-02
Ba-137m	0.35	0.033	1.16E-01	1.61E-07	*	2.93E-07	*	5.12E-07	*
Ba-140	22.29	2.11	4.49E-01	1.36E-03	0.06E-02	1.34E-03	0.06E-02	1.11E-03	0.05E-02
La-140	25.55	2.42	5.14E-01	3.52E-04	0.02E-02	1.02E-03	0.05E-02	1.04E-03	0.05E-02
Ce-141	41.59	3.93	2.14	4.06E-05	*	1.22E-04	0.03E-02	1.72E-04	0.04E-02
Ce-144	7.37	0.70	1.66	2.10E-04	0.03E-02	1.37E-04	0.02E-02	1.00E-03	0.16E-02
Pr-143	22.11	2.09	4.73E-01	2.31E-06	*	7.08E-07	*	2.16E-04	0.01E-02
Pr-144	7.37	0.70	1.66	5.61E-08	*	1.19E-07	*	6.84E-06	*
Nd-147	6.72	0.64	1.13E-01	5.71E-05	*	1.81E-04	*	2.69E-04	*
Pu-239	0.02	0.002	6.32E-03	5.7E-01	0.36E-02	9.55E-02	0.06E-02	4.82E-02	0.03E-02
Totals					<0.09 rem		<0.05 rem		<0.03 rem

*Less than 1E-04

Similarly for the other major units with different periods of exposure, the doses are as follows:

<u>For the RCT-2</u> ($t_f = 95 - 46 = 49$ days):

D (Bone)	D (RBM)	D (Whole Body)
$\sim$0.02 rem	$\sim$0.01 rem	$\sim$0.01 rem

<u>For the Artillery Group</u> ($t_f = 321 - 85 = 236$ days):

D (Bone)	D (RBM)	D (Whole Body)
$\sim$0.07 rem	$\sim$0.04 rem	$\sim$0.02 rem

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13 April 1981

NATD

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SEE DISTRIBUTION

1. The Defense Nuclear Agency, as the Department of Defense (DoD) executive agency for matters relating to low-level ionizing radiation, is conducting an extensive review of radiation exposures to military personnel who have participated in all aspects of the United States nuclear weapons development programs. This program, termed the Nuclear Test Personnel Review (NTPR), was begun in 1977 in response to concern over possible health risks as a result of very low level radiation exposures.

2. Similar concerns have been expressed with regard to U. S. veterans who were involved in the 1945-1946 occupation of Hiroshima and Nagasaki, Japan. DNA has expended a large research effort to recover from records and historical documents all available data pertaining to the occupation of these cities and the possible radiation exposures of these troops.

3. The enclosed report by Science Applications Inc., written under contract to DNA, provides estimates of upper limits of the radiation doses that would have been possible for members of the occupation forces to have received. These dose reconstructions are based upon: (1) patterns of residual activity measured, documented and published shortly after the bombings, by both U. S. and Japanese investigators, (2) extensive review and analysis of this residual activation in the ensuing decades, (3) the documented history of the occupation, including arrival and departure dates for each Army and Marine Corps unit which operated in the vicinity of the cities, and (4) current dose calculation methodologies.

4. DNA believes this report accurately represents a conservative approach to dose estimation, and that the upper limits estimated are reasonable and appropriate. Your review of this report is invited.

Harry A. Griffith

HARRY A. GRIFFITH
Lieutentant General, USA
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