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ANALYSIS OF RADIATION EXPOSURE FOR TASK FORCE BIG BANG, SHOT GALILEO

Exercise Desert Rock VII - VIII Operation Plumbbob

Science Applications, Inc.
8400 Westpark Drive
McLean, Virginia 22102

9 April 1980

Final Report for Period 27 February 1978-19 July 1979

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Fallout	Task Force BIG BANG	Resuspension
Desert Rock	HumRRO	Beta Dose
Radiation Exposure	Project 50.1	

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

The radiation doses to Task Force BIG BANG troops who participated in Shot GALILEO are determined and compared with film badge data gathered during Exercise Desert Rock VII-VIII. Fallout contours and decay rates are established and used to calculate total external beta and gamma doses, based on estimated stay time for various troop activities. Uncertainties are calculated for each parameter. Radiation dose from internal emitters, due to inhalation of resuspended contaminated particles, is calculated. Total

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20. ABSTRACT (Continued)

external gamma dose is estimated to be 1070-1780 mrem as compared with a mean film badge reading of 1900 mrem. 50-year bone dose, due to internal emitters, is estimated to be 10-25 mrem.

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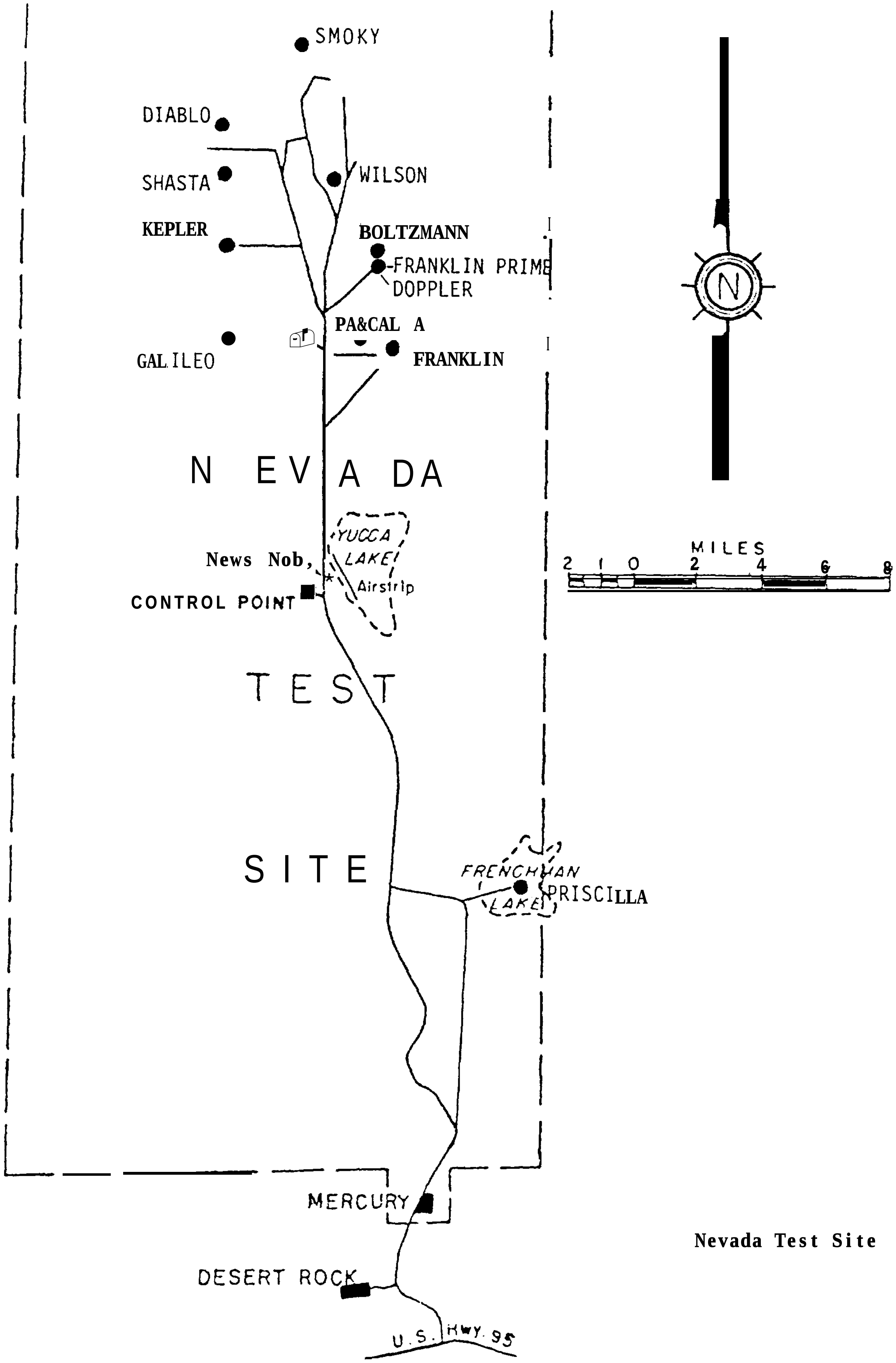

Nevada Test Site

Section 1

INTRODUCTION AND SUMMARY

This report focuses on the external and internal radiation doses to members of Task Force BIG BANG resulting from their activities at the Nevada Test Site during Operation Plumbbob in 1957. Task Force BIG BANG, a provisional company from the 82nd Airborne Division, participated in an exercise conducted by the Human Resources Research Office (HumRRO), Department of the Army, in conjunction with Shot GALILEO on 2 September 1957. The exercise and two rehearsals took place in an area that had been contaminated by fallout from several shots in the Plumbbob series prior to GALILEO, in particular Shot SMOKY, which occurred only 2 days earlier.

Task Force activities are traced from training in mid-August through the exercise on 2 September to provide the time-dependent position data required for the reconstruction of personnel dose. The application of decay rates to residual radiation intensity data (from SMOKY and other pertinent shots) permits the gamma intensity at any position and time to be determined. Radiation transport models for neutrons and gamma radiation are used to determine the initial radiation dose from GALILEO (fallout from GALILEO was not a factor due to prevailing wind conditions). The calculated external dose (in terms of the dose a film badge, as worn, would record) is compared with film badge records. An uncertainty analysis establishes confidence limits for the film badge gamma dose estimates. The dose from internal emitters is determined from reconstructed ground contamination levels, predicted radioisotopic composition of fallout, estimated resuspension of fallout particles and standard inhalation/dose models. Bone dose is emphasized because of the current interest in leukemia risk assessment.

Major findings presented in this report are:

- Virtually all external radiation dose received by Task Force BIG BANG resulted from operations in the SMOKY fallout field.

- Film badge gamma doses calculated for the task force ranged from 1070 to 1780 mrem, which is consistent with the mean film badge reading of 1900 mrem. Within 90 percent confidence limits, the calculated film badge dose range for all troops was 610 to 3420 mrem. All film badge readings were within this range.

- The calculated skin dose from external beta radiation was as high as 7 rem on the lower leg. Fewer than one percent of the beta particles penetrated to radiation-sensitive internal organs, however.

- Internal radiation dose resulted primarily from inhalation of resuspended fallout in the SMOKY and BOLTZMANN fields.

- The internal bone dose from alpha, beta and gamma radiation was approximately 10 to 25 mrem for a 50-year period. The dose from neutron-activated tower material was negligible.

The dose estimates for Task Force BIG BANG were derived, for the most part, from data provided in the references. Some troop activities, however, are uncorroborated and were therefore inferred from the limited data to establish a logical scenario.

Section 2

OPEKATIONS

2.1 GALILEO SHOT DATA

Date. 2 September 1957, 0540 hours (Scheduled date 1 September 1957)
Location. Area 1, Coordinates 797009, Nevada Test Site
Yield: 11 kt
HOB: 500' (steel tower)

2.2 PARTICIPANTS*

	Personnel
Task Force BIG BANG - Provisional Company, 82nd Airborne Division	167
Research team (civilian) - Human Resources Research Office (HumRRO)	10

2.3 TROOP PLAN

The participation of TF BIG BANG was not part of the original troop test plan. That plan called for Task Force WARRIOR, a different unit composed from the 1st Battle Group, 12th Infantry, to participate in both the Human Resources Research Office (HumRRO) sponsored test and the tactical exercise of infantry troop operations and maneuvers on an atomic battlefield. The objective

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* Note: As explained subsequently, not all these personnel participated in all activities, particularly the events on GALILEO shot day. Moreover, support personnel (e.g., rad-safe monitors from Camp Desert Rock) are not included in these figures.

of the HumRRO test was to determine whether any degradation of troop performance resulted from witnessing a nuclear shot for the first time.

Pre-shot performance standards were developed for the following activities, shown with their planned relationship to the shot for the tests:

a. Ability to disassemble and reassemble a rifle	immediately after the shot
b. Ability to clear a minefield	immediately after the rifle test
c. Ability to negotiate a combat course	on a later date in radiologically contaminated terrain

The shot chosen for the test was Shot SMOKY, scheduled for 19 August 1957. After several revisions, the general plan was for the test troops to observe their first nuclear detonation from trenches located 4500 yards from ground zero. Immediately after the shot, they were to exit the trenches and move to a cleared area for the rifle disassembly-reassembly test. From that point they would clear a dummy minefield by probing with bayonets. Finally, they would negotiate an infiltration course, perceived to be contaminated with fallout, and throw grenades at a target.

Because of a late July decision to permit Task Force WARRIOR to observe SHOT SHASTA, scheduled for 16 August, these troops could not be used for the HumRRO test without seriously affecting the entire research plan, the essence of which was to determine if performance was altered after witnessing a nuclear explosion for the first time. Therefore, the decision was made to employ a provisional company from the 82nd Airborne Division, scheduled to arrive at Camp Desert Rock on 30 July, for the HumRRO test. Subsequently, this provisional company was designated Task Force BIG BANG and was oriented solely to the HumRRO test to be conducted at shot SMOKY. Task Force WARRIOR continued to train for the SMOKY troop maneuver.

Task Force BIG BANG consisted of 167 men (7 officers + 160 enlisted men). Approximately 100 of the 160 enlisted men were equipped with rifles, the remainder carried carbines. Because about 100 troops were needed for the HumRRO experiment, those having rifles were selected. Some of the excess were used to assist the HumRRO research team in the experiment. There is little information available on what specific tasks the extra troops were assigned, but it is reasonable to assume that some were used as spares for the 100-man test group, while others would have been used to support the experiment in various ways.

The plans for the troop tests *were* revised considerably due to shot postponements. Because of the possibility of further postponements due to unfavorable winds, contingency plans were developed so that the experiment could be conducted before the 5 September troop departure deadline. One of these plans included participation in Shot GALILEO, scheduled for early September. New test areas were designated, but before construction could be initiated, the plan was terminated when it became evident that GALILEO was sensitive to the same adverse winds that were delaying SMOKY. It can be assumed that minor preparations would have been made, to include the designation of an observer area with a rifle disassembly-reassembly area and a vehicle parking area nearby. Because there would be no trenches, the GALILEO observer area would have been at least 4200 yards from ground zero, the minimum safe distance for troops in the open for that weapon yield (Reference 3).

During the SMOKY shot delays, the HumRRO research team observed Shot SHASTA, and at least one memeber of the team observed Shot DOPPLER on 23 August (Reference 2). When it was evident that SMOKY could not be fired on 28 August due to adverse weather, it was agreed that some (perhaps 67) of the task force who were not part of the HumRRO experiment could observe FRANKLIN PRIME on 30 August. The planned experiment, although delayed, would still retain its validity--the test troops would remain uninitiated to nuclear explosions.

On 30 August, planning continued for shot SMOKY to be fired the following day. The forecast winds were favorable from a public safety viewpoint, but the chances were extremely slim that the SMOKY trenches or research area could be occupied or used immediately thereafter due to fallout. Task Force BIG BANG, in order to be assured of observing a shot before departing, was scheduled to watch SMOKY from News Nob. The HumRRO test, its validity considerably jeopardized by not having uninitiated troops for the performance comparisons, could still be conducted two or three days later (in conjunction with a subsequent shot) at the original site when SMOKY contamination levels had sufficiently decayed.

As events ultimately proved, the concern that the test troops possibly would not see *a* shot was unnecessary. After the entire task force observed SHOT SMOKY on 31 August, GALILEO was rescheduled for 2 September and the HumRRO experiment was placed back on the GALILEO calendar. With insufficient time to construct trenches or clear test areas, it was decided that the troops would observe GALILEO in the open, approximately 4500 yards from ground zero. The rifle test would be conducted immediately thereafter in the same location. The infiltration course test would be conducted at the original SMOKY test area, contingent upon a favorable radiological survey of the area immediately beforehand. The minefield clearing exercise was scrubbed altogether. Thus, less than 24 hours before the shot, and with many of the test troops on weekend pass, the test plan was finalized to go with Shot GALILEO.

There has been some uncertainty regarding the actual locations of the SMOKY trenches, the HumRRO test area, and the point from which Task Force BIG BANG observed the GALILEC shot. The SMOKY trenches have been reported to be generally SSE of the SMOKY GZ at distances ranging from 3500 <u>meters</u> to 4750 <u>yards</u>. Op Order 17 (Reference 6) describes the trench area as being 4750 <u>yards</u> from GZ. This is verified by inspection of a detailed USGS topographic map (Oak Spring, 1:24,000), which shows a well-defined system of seven trenches, oriented precisely at right angles to the SMOKY shot point azimuth. The closest trench line is 4350 meters distant (or 4750 yards). This is considered to be the most reliable location (coordinates 849120) and will be used for the remainder of this analysis. Other descriptions of the trench area (References 3 and 4) coincide with this location if the distance from GZ is stated in meters rather than yards.

The HumRRO test area location is described in Reference 2 as being adjacent to the SMOKY trenches. Specifications call for a strip 200 yards wide by 1200 yards long, oriented approximately north-south (it was actually oriented toward GZ), with its eastern edge 50 yards from the trenches and its southern edge 4500 yards SSE of GZ. The rifle disassembly-reassembly test would be administered in the southern sector, the minefield would occupy the central area, and the infiltration course would be located at the northern edge, 3200 yards from GZ. If these distances were in meters rather than yards, all descriptions of the area would be compatible.

This area, as well as the SMOKY trench area, is shown in Figure 1. The infiltration course is at coordinates 840129, approximately 3200 meters from GZ.

The exact location where Task Force BIG BANG observed Shot GALILEO is not specified in any official report of Desert Rock operations. The HumRRO memorandum (Reference 2) states that the troops would be stationed in the open approximately 4500 yards from the tower. It is reasonable to assume that any observation point would be south of a line drawn generally east from GZ to allow a safe withdrawal route should the fallout drift unexpectedly toward the task force. Using this rationale, there are two general areas that are likely candidates. The first is the Tippipah Road/Mine Mountain area south of GZ, the second is a 2 km stretch of Mercury Highway east of GZ. Because the observation point would have been readily accessible to the infiltration course, which was to be used as soon as possible after the shot, the most likely location would have been along the Mercury Highway at or near the Buster-Jangle "Y", or "BJY" (Figure 2). This is 4500 meters from the tower.

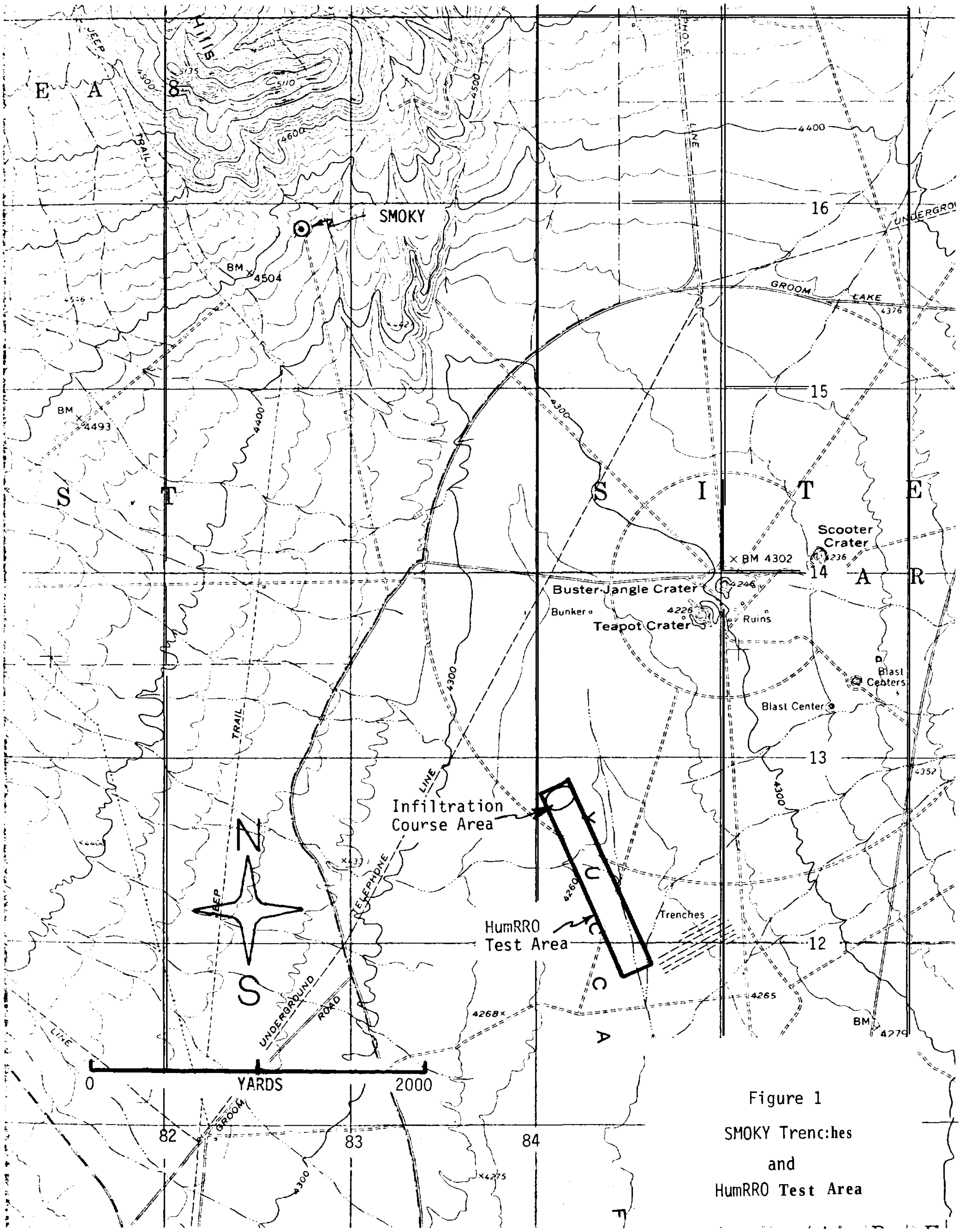

Figure 1

SMOKY Trenches

and

HumRRO Test Area

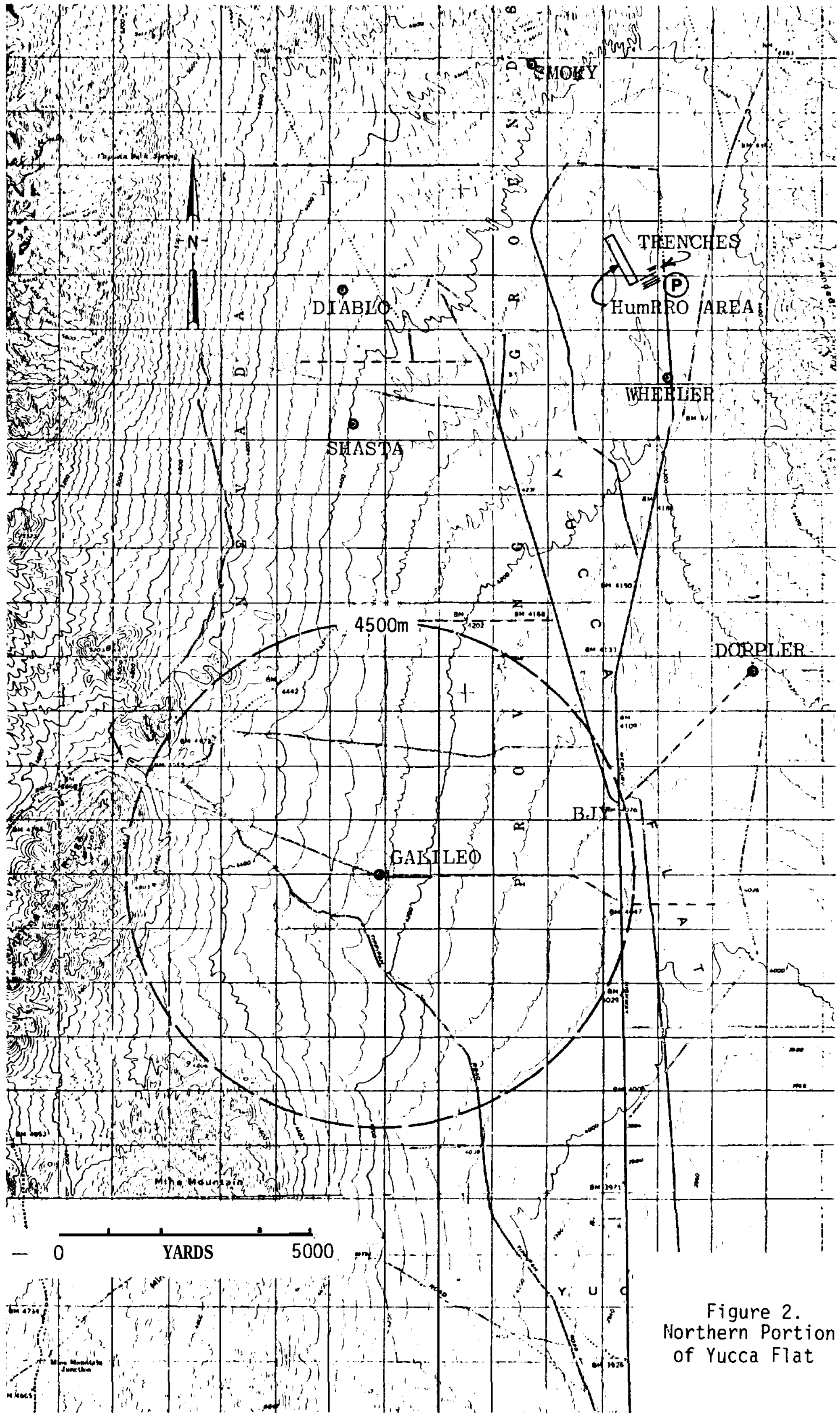

Figure 2.
Northern Portion
of Yucca Flat

The HumRRO memorandum (Reference 2) places the task force in the WHEELER area (see Figure 2) prior to its exercise at the SMOKY infiltration course. It is not likely that the task force observed Shot GALILEO from that location due to the rationale (safe withdrawal route) stated above and the fact that it is considerably further than 4500 yards from GZ. It is reasonable to assume that the task force may have rendezvoused in the WHEELER area with the Rad-Safe monitors who had surveyed the SMOKY infiltration course. Such a meeting would have saved time and provided a suitable location to brief the task force on the conditions at the SMOKY site. (NOTE: Shot WHEELER was fired on 6 September, after the task force had departed the test site.)

2.4 PRE-SHOT OPERATIONS

Task Force BIG BANG arrived at Camp Desert Rock at 12 August 1957. Preliminary training and briefings were conducted for the remainder of that week, in preparation for a final dry run on 18 August and shot participation the following day. When it was learned that SMOKY could not be scheduled sooner than 10 days after SHASTA, baseline testing was extended. This provided an opportunity to establish a better baseline, but increased the planning uncertainties which could have led to troop morale problems. On 23 August, the task force went to the forward area for the first time (Reference 2) to familiarize the troops with the test area. They located the SMOKY trenches, practiced the countdown, and conducted the rifle test, the minefield test, and the infiltration test. Figures 3 and 4 show the rifle test and the minefield test as conducted on that day. It should be noted that the test troops wore protective masks for the rifle test but not for the minefield or infiltration course test.

After a weekend pass, the task force returned to the forward area for baseline testing on 26 August. This would have been the final rehearsal, in anticipation of a 28 August SMOKY shot. The sequence of activities for both rehearsals is shown in Table 1.

When the 28 August SMOKY test was postponed, the opportunity arose for some of the task force, namely those troops who were not test subjects in the HumRRO experiment, to observe a shot. This would enhance the morale

Figure 3. Rehearsing the Rifle Test in the HumRRO Test Area 23 August 1957 (US Army Photograph)

Figure 4. Rehearsing the Minefield Test in the HumRRO Test Area 23 August 1957 (US Army Photograph)

TABLE 1

HUMRRO TEST REHEARSALS

Activity	Date	
	23 August	26 August
Depart Camp Desert Rock	0830"	0300*
Arrive SMOKY trench area	1100*	0445*
Orientation of trench area	1110	
Assign and enter trenches	1120	0525"
Don protective masks and practice countdown		0527*
Move to rifle test area	1140	0535*
Rifle test	1145	0540*
Move to minefield	1155	0550*
Mine clearing test	1205	0555*
Move to infiltration course	1215	0605
First group begins course	1230	0615*
Last group departs course	1330	0757*
Field mess at trench area	1345	0800
Load and return to Camp Desert Rock	1430	0845

* Reference 2. All other times are inferred from those referenced.

of approximately 70 men without affecting the HumRRO experimental objectives. Accordingly, most of the officers, the carbine-equipped troops, and the HumRRO team witnessed Shot FRANKLIN PRIME on 30 August, presumably from News Nob. The remainder of the troops continued to train and develop baseline data for participation in conjunction with a subsequent shot, as discussed previously. When the decision was made to fire SMOKY, it was believed that the test course would be contaminated and could not be used for several days after the shot. With little assurance that there would be another shot in which the task force could participate before returning home, the entire task force witnessed Shot SMOKY on 31 August from News Nob, 17 miles from ground zero. The test troops now having seen a nuclear burst, a significant parameter in the experiment was thereby negated. This seemed of little importance, however, because it was unlikely that the test troops would have an opportunity to observe a nuclear shot at or near the minimum safe distance and be tested immediately thereafter. The task force observed SMOKY, the test area was indeed contaminated by the fallout, and the troops were given the rest of the weekend off.

On 1 September (Sunday), the HumRRO experiment was placed back on the GALILEO calendar for an early 2 September (Monday) firing. There was a chance that the SMOKY fallout would have decayed sufficiently to permit some of the test to be performed. In the hope that part of the experiment could still be salvaged, the task force was reorganized around those present for duty, new baseline test measurements were established at the Desert Rock course, and a GALILEO observer area was designated and reconnoitered. Final plans were drawn up to depart Camp Desert Rock shortly after midnight, to observe the shot from the open area previously chosen, to conduct the rifle test immediately thereafter, and to be prepared to run the infiltration course test near the SMOKY trench area, contingent upon rad-safe clearance.

2.5 SHOT SCENARIO

Task Force BIG BANG, accompanied by the HumRRO team, departed Camp Desert Rock at 0130 hours on 2 September 1957. They arrived at the GALILEO observer area at 0245, where they remained until after the shot. At this point they were 4500 meters from ground zero. Neither the task force nor the team was at full strength. The HumRRO team had been reduced from ten to three by early departures from Nevada Test Site, TF BIG BANG was lacking personnel who failed to return from weekend pass (Reference 2). Of 110 BIG BANG' personnel whose film badge dose levels indicate that they participated in GALILEO, 80 were test troops, 6 were officers, and 7 were troop monitors (out of 9 originally chosen to assist the HumRRO team). The additional troops would have been required to replace the absent civilian and troop monitors.

GALILEO was detonated at 0540 hours, 2 September 1957. Task Force BIG BANG observed the shot in the open, south of BJY. The troops immediately began the rifle disassembly-reassembly test. They would have worn their protective masks as they had for the baseline tests (see Figure 3).

> NOTE: The GALILEO fallout was to the northwest*. However, the blast wave caused momentary winds of about 42 mph** at the observation area, and thus raised considerable dust. At 4500 meters from GZ, initial radiation was less than 10 mrem (see Section 3). Moreover, contamination from initial radiation (soil activation by neutrons) and, south of BJY, from the residual radiation of previous shots was negligible — on the order of a thousandth of the levels in the test area (which are discussed in Section 4.1).

After the rifle test, the rad-safe monitors and one member of the HumRRO team departed for the SMOKY tranch area in order to determine if the infiltration course residual radiation levels were low enough to permit troop entry. During this period, the troops breakfasted on assault rations and then moved by truck toward the trench area. By 0710 hours, the rad-safe monitors had returned from the SMOKY trench area, where the measured gamma intensity (not recorded) at the infiltration course was deemed to be safe for a one-hour stay time (Reference 2). They met the task force and briefed them on the site conditions. The task force was given clearance to remain at the infiltration course for one hour. They then proceeded to the SMOKY trench area, where they arrived at about 0740 at the parking area. After unloading, they formed up to proceed on foot to the infiltration course, about 1400 meters to the northwest.

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*Figure I-10
**Derived from Reference 7

At 0805, the first segment of the task force began the timed infiltration test. A diagram of the course is shown in Figure 5. All the troops were assembled near the start line, where they grouped in fours or fives, moved to the start line, and began the 80-yard course on signal from the HumRRO monitor. At the signal, each soldier would walk 10 yards, crawl under a barbed wire barrier, continue crawling for 15 yards and under a second barbed wire barrier. After clearing the second barrier, he would sprint about 6 yards to a foxhole and remain there for about 10 seconds. He would then sprint 8 more yards to a third barrier, crawl under it, and sprint another 15 yards to the "wall" (actually, a smooth wire barrier), where he would throw two practice grenades at a 4-foot square pit (see Figure 6), 12 yards away, give his name to the assistant monitor, and exit the course to the right. When the course was clear, the signal was given for the next group, waiting at the start line, to begin the timed course. Groups were started at about 3-minute intervals.

As each group completed the course, it withdrew to the truck parking area. The last group completed the course at 0855. By 0915, the last of the test troops and the monitors should have returned to the truck parking area. The trucks would have departed shortly thereafter for Camp Desert Rock, with a stop at the decontamination station near Yucca Pass, approximately 15 miles to the south. They would have arrived there at about 1000 hours. At this point, vehicles and personnel would be monitored and decontaminated, if necessary by brushing, washing, and confiscation/exchange. A 1030 departure would have placed Task Force BIG BANG at Camp Desert Rock by 1130. Film badges would be turned in upon departure for home station. No further activities in the forward area were required.

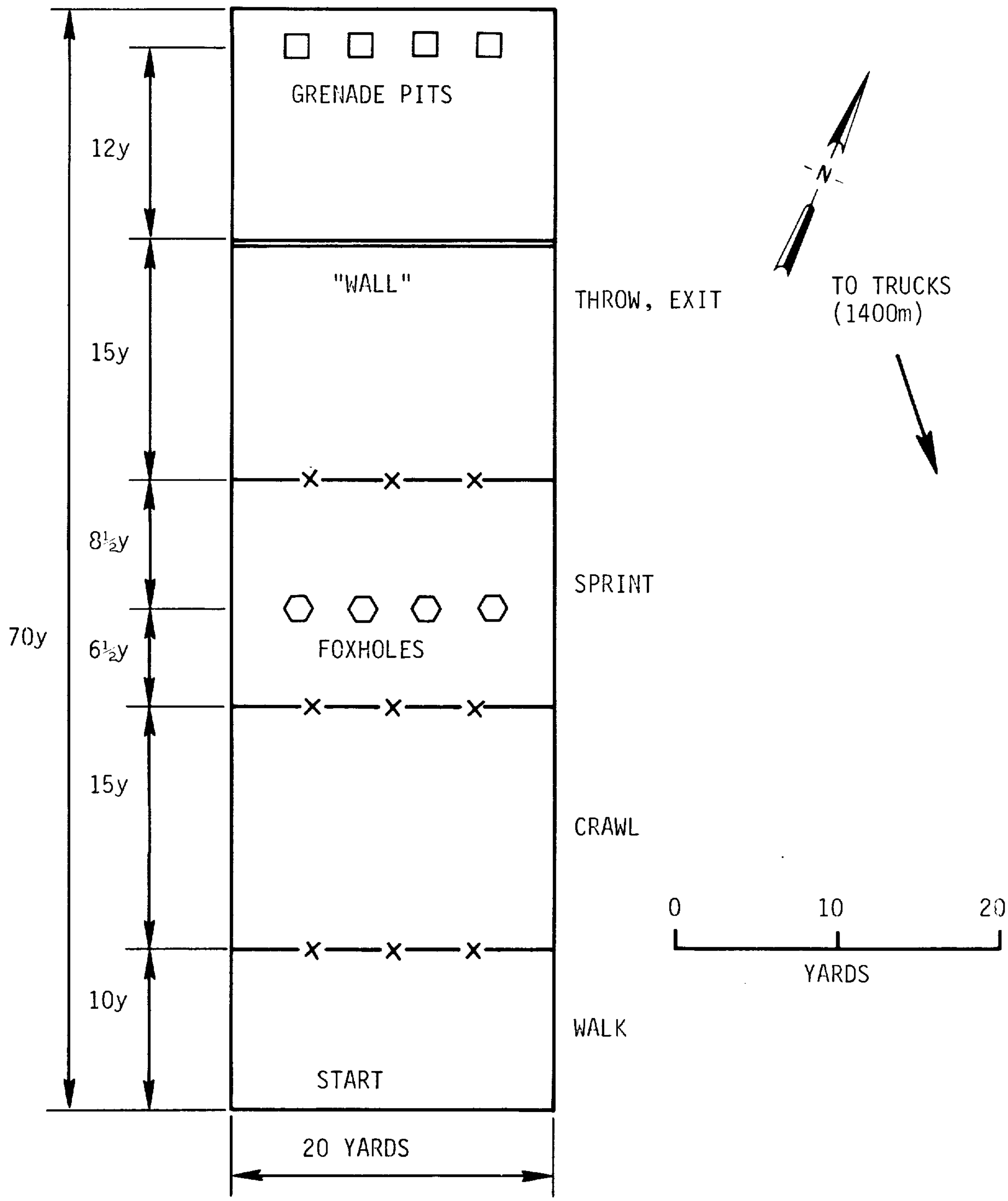

Figure 5. HumRRO Infiltration Course

Figure 6. Grenade Throw During the HumRRO Test, 2 September 1957 (US Army Photograph)

Inferred times for activities in the Smoky trench area are summarized as follows:

0740	-	Convoy arrives in parking area
0740-0745	-	Unload and assemble
0745-0800	-	Walk to infiltration course (1400 meters)
0800-0805	-	Break and final instructions
0805-0855*	-	Conduct exercise
0855-0900	-	Police area (look for lost film badges, etc.)
0900-0915	-	Return to truck parking area
0915-0920	-	Assemble and load
0920	-	Convoy departs

It should be noted that there is a strong likelihood that several film badges were lost by the troops who participated in this test. Depending on how and where the film badge was worn by each soldier, crawling, as well as other acts such as brushing off clothing, could have caused the film badge to slip off (Reference 3 makes a specific note of this characteristic). Even if some were noted as missing, it is not likely that time would have permitted more than a cursory search at the conclusion of the infiltration test.

* Reference 2

Section 3

INITIAL RADIATION

Task Force BIG BANG witnessed Shot GALILEO in the open from 4500 meters away. By using the computer codes ATR 4 and 4.1 (References 8 and 14), with the shot data of Reference 9, the initial dose from neutrons and gamma radiation is calculated to have been less than 10 mrem. Observers of Shots FRANKLIN PRIME and SMOKY from News Nob received no detectable initial radiation. Therefore, initial radiation may be discounted as a significant source of exposure to TF BIG BANG.

Section 4

RESIDUAL RADIATION

This section examines residual radiation from three aspects--external gamma radiation, external beta radiation (skin dose), and internal radiation from inhaled particles.

4.1 RESIDUAL GAMMA RADIATION EXPOSURE

Gamma doses are determined for Task Force BIG BANG, based on its activities in the fallout fields of several shots of Operation Plumbbob. Despite the penetrating ability of gamma rays from fission products, the human body affords some shielding, hence, the gamma dose to any organ depends on the geometry of the radiation source and the body position. In order that dose calculations may be compared to film badge readings, gamna doses are calculated for the surface of the chest, where a film badge is normally worn. The calculated film badge dose rate ($\dot{D}$) is related to the free-field gamma intensity (I) through the conversion factor developed in Reference 5. 1 mr/hr $\longrightarrow$ 0.7 mrem/hr. This conversion is applicable to an erect individual wearing a film badge on his chest, and standing in a uniform, plane fallout field. These conditions are met adequately in the GALILEO scenario except for the crawl in the infiltration course and other, briefer variations in posture. The calculated film badge dose is identical to the "film badge equivalent dose" of Reference 5.

The GALILEO fallout impacted on an area that stretched NNW from ground zero (see Figure I-10). Consequently, GALILEO contributed no residual radiation dose to the HumRRO exercise participants. Task Force BIG BANG and HumRRO personnel were exposed to residual radiation, however, from some of the earlier shots of Operation Plumbbob during their activities in Yucca Flat. The following activities are analyzed:

- Rehearsal in HumRRO area, 23 August
- Rehearsal in HumRRO area, 26 August
- Observation of Shot FRANKLIN PRIME, 30 August
- Observation of Shot SMOKY, 31 August
- Observation of Shot GALILEO, 2 September
- Conduct of exercise in HumRRO area, 2 September

A. The two on-site rehearsals of 23 and 26 August were conducted in the Smoky trench area and adjoining test area. From the fallout plots of Appendix I, it is determined that the following shots may have contributed residual radiation to the HumRRO activities:

BOLTZMANN	(28 May)
DIABLO	(15 July)
SHASTA	(18 August)

The loading area, trenches, minefield, and infiltration course of the HumRRO test area were all near the BOLTZMANN hotline.* Using the interpolation technique described in Appendix I, the intensity on the BOLTZMANN hotline in the test area is estimated to have been 300 mr/hr at twelve hours after the shot (H+12).

The HumRRO test area was near the edge of the fallout paths for both DIABLO and SHASTA (Figures I-4 and I-7). For these shots, the gamma intensity varied with position within the area. For both, the maximum intensity in the HumRRO test area was at the infiltration course, at about 20 mr/hr at H+12. This value, corrected for decay, will be taken conservatively as the intensity from each shot to which task force personnel were exposed.

H+12 intensities, I_{12}, for each shot are decayed to intensities on rehearsal dates through the factors, f, obtained from Table 11-6. The gamma film badge doses, D, accrued during rehearsals are reconstructed below:

---

*Line of highest radiation intensity along the fallout path.

23 August

Shot	I_{12} (mr/hr)	f	I (mr/hr)	$\dot{D}$(mrem/hr)	D(mrem)
BOLTZMANN	300	0.003	0.9	0.63	2.205
DIABLO	20	0.006	0.12	0.084	0.294
SHASTA	20	0.13	2.6	1.82	6.37
			26 August		
BOLTZMANN	300	0.003	0.9	0.63	2.52
DIABLO	20	0.005	0.1	0.07	0.28
SHASTA	20	0.068	1.36	0.952	3.808
				TOTAL	15

The above are based on stay times of 3.5 hours for the first rehearsal and 4 hours for the second (see Table 1).

B. Shots FRANKLIN PRIME and SMOKY were observed from News Nob. No residual radiation was present at this location.

c. TF BIG BANG and HumRRO personnel witnessed Shot GALILEO from the vicinity of the Mercury Highway, at or near BJY, where there was negligible residual radiation.

D. The activities in the SMOKY trench area resulted in substantial exposure to residual radiation from SMOKY. As was the case for the rehearsals in the BOLTZMANN fallout, the troops were within the highest recorded iso-intensity contour; therefore the technique described in Appendices I and III was used to estimate the radiation intensity. Using this technique and Figure I-9, the SMOKY residual radiation intensity (H+12 values) in the area ranged from 2200 mr/hr at the parking area to 6100 mr/hr at the infiltration course. The fallout fields from Shots BOLTZMANN, DIABLO, and SHASTA also contributed to the exposure during this exercise, as for the rehearsals. The H+12 intensities are converted to those encountered during this exercise, using the decay factors for BOLTZMANN, DIABLO, and SHASTA obtained detonated only two days before the exercise, the decay data included in Table II-4 are required for suitable accuracy. The following chart shows the reconstruction of the film badge dose for 2 September.

		I_{12} (mr/hr)	f	I (mr/hr)	$\dot{D}$(mrem/hr)	D(mrem)
BOLTZMANN		300	0.003	0.9	0.63	1
DIABLO		20	0.005	0.1	0.07	< 1
SHASTA		20	0.025	0.5	0.35	1
SMOKY	parking area	2200	0.30	660	462	477 - 77
	infiltration course	6100		1830	1281	171 - 1281
	average during march	3800		1140	798	399
					TOTAL	1050 - 1760

The range of doses is based on times given in the shot scenario (Section 2.5). Of the 100 minutes Task Force BIG BANG spent in the SMOKY trench/infiltration course area, 30 minutes were spent marching, 8 to 60 minutes were spent at the infiltration course (depending on how long the test troops waited for their turn to run the course), and the remaining time was spent at the parking area.

During the infiltration course exercise, the troops spent approximately 60 seconds crawling on the ground and an additional 10-12 seconds in a foxhole (Reference 2). Using the ANISN radiation transport code (Reference 12), an adjustment factor (1.1) is obtained to convert the gamma radiation intensity at 3 feet above an infinite plane source to a surface level intensity. From this small factor it is evident that the increase in gamma radiation intensity that results from decreasing the distance to the plane source directly under the detector (subject) is practically offset by a decrease in the area that contributes radiation. In consideration of the short time (about one minute) spent on the ground during the test, the adjustment to the gamma dose is negligible.

4.2 EXTERNAL BETA RADIATION EXPOSURE

For the average-energy beta particles from the SMOKY fallout in which Task Force BIG BANG operated, maximum ranges of 1 meter in air and 0.13 cm in tissue suggest a beta radiation hazard limited to skin on the lower portion of the body. However, because of the wide range of beta energies from the fission products, the actual beta spectrum encountered on 2 September is used to calculate personnel doses. Although there was no reported erythema (skin redness), the common visible symptoms of a beta burn, the exposure of the lower legs (above the boot tops) and the chest (film badge) during the stay in the contaminated area, as well as the direct contact with the soil during the infiltration course test, is considered. From Appendix IV, it is evident that the surface contamination at the infiltration course during the rehearsals was insignificant when compared with the level on 2 September (0.256 Ci/m^2). Therefore, only the exposure during the test itself is considered.

The beta dose from skin contact is computed with the aid of the H+51 hour beta spectrum (Reference 13) and energy deposition-with-depth data (Reference 28). The spectrally-averaged deposition value is 2.0 MeV/cm per normally-incident beta. For a surface collection of isotropic point sources, the geometry is such that the <u>average</u> energy deposition with depth per beta emitted has the same value near the skin surface as per normally-incident beta. For a one-minute contact time, the beta dose to the skin surface is estimated as follows:

$$\text{Dose(rem)} = \frac{\left(0.256\ \frac{\text{Ci}}{\text{m}^2}\right)\left(2.22 \times 10^{12}\ \frac{\text{dis}}{\text{min-Ci}}\right)\left(2.0\ \frac{\text{MeV}}{\text{dis-cm}}\right)\left(1\ \text{min}\right)}{\left(1.0\ \frac{\text{g}}{\text{cm}^3}\right)\left(6.25 \times 10^{7}\ \frac{\text{MeV}}{\text{g-rad}}\right)\left(1\ \frac{\text{rad}}{\text{rem}}\right)\left(10^{4}\ \frac{\text{cm}^2}{\text{m}^2}\right)} = 1.8\ \text{rem}$$

Beta skin doses to the lower leg and chest are computed for the 100-minute duration of the task force's activities in the SMOKY fallout field. Because a boot provides quite effective shielding from beta, the greatest beta dose to an erect individual would have been just above the boot.

The following method for calculating beta particle transport from the ground to the skin provides an upper limit to the beta dose:

1. The ground surface source of beta radiation is divided into half-annuli (rings), each characterized by its average distance from the skin under consideration (the half is that portion of the ground visible from the skin, assumed vertically oriented).

2. The betas do not originate precisely from the ground surface because of ground roughness. Attenuation of betas emitted at small angles to the surface is particularly significant. A uniform distribution to a depth of 1 mm is assumed for the beta source. The annuli are therefore partitioned into layers.

3. The orientation of the skin surface relative to the beta source influences the calculated dose. Therefore, each annular layer is further partitioned into sectors.

4. The straight-line distances through the soil, air, clothing, and the dead outer layer of skin, as weighted by the density of each, are combined to form an equivalent distance in tissue. Added to this is the straight-line distance into live tissue to any desired depth. The total equivalent tissue distance is used in conjunction with the energy deposition data of Reference 28 to calculate the contribution from each sector of each annular layer to tissue dose at the desired depth.

These calculations show that only betas of above average energy (0.42 MeV) contributed to the skin dose. Betas from less than two meters distant contributed most of the dose. For the lower leg, the calculated beta skin dose is 6 rem, for the chest, 3 rem. The beta dose calculated for the film badge (unshielded by clothing) is 4 rem.

The estimated beta dose to surface skin is greater than the estimated gamma film badge dose, but its biological effect is far less. Some high energy beta particles do penetrate the skin, but dose levels decrease sharply with depth. For example, the estimated dose for the genetic material nearest to the surface of the young-adult gonad is 0.4 rem. The skin itself is generally less susceptible to radiation damage than are internal organs. Consequently, the estimated external beta dose is not significant when compared to the external gamma dose to the whole body. This fact is reflected by radiation standards which permit a much greater skin-only dose than whole body dose.

4.3 INTERNAL RADIATION EXPOSURE

Section 4.1 outlined Task Force BIG BANG activities in areas contaminated by radioactive fallout. The two on-site rehersals conducted on 23 and 26 August took place in the HumRRO test area near the SMOKY trenches. At that time the area was contaminated by fallout from shots BOLTZMANN (28 May), DIABLO (15 July) and SHASTA (18 August). On 2 September, after observing shot GALILEO, the task force returned to the same area to conduct a portion of the HumRRO exercise on the infiltration course. By then, the area had received additional fallout from shot SMOKY fired only 2 days earlier (31 August).

With the exception of the rifle disassembly/reassembly portion of HumRRO exercise, respiratory protection was likely not worn by task force personnel during their test activities (see Figure 3, 4, and 6). Therefore, inhalation of resuspended radioactive material is considered in the overall dose reconstruction.

Unfortunately, there are no measurements of body burdens, bioassays, or air sampling data that can be used to estimate the radiation dose to BIG BANG personnel resulting from internal emitters. However, the internal dose* can be calculated from estimates of ground contamination levels using the following basic methodology:

- The concentration of radioactive materials in the air is determined by multiplying the ground contamination level by an appropriate resuspension factor**.

- The amount of radioactive material inhaled is determined by multiplying the airborne concentration by the breathing rate and the duration of exposure.

- The radiation dose to an internal organ of interest (bone, lung, liver, etc.) for a specified time period is determined by multiplying the amount of radioactive material inhaled by an appropriate dose factor**.

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* The term "dose" is used in this section instead of the more precise term "committed dose equivalent" as defined by the International Commission of Radiological Units and Measurements (ICRU).

** These terms are explained later in the text.

Because fallout consists of a mixture of radioactive materials, this process must be performed for each radionuclide. The total dose to a particular organ is given by the following expression:

$$D_j = GC \times K \times BR \times T \times \sum_i P_i \, DF_{ij}$$

where:

D_j = Dose (rem) to organ j
GC = Ground Contamination (Ci/m^2)
K = Resuspension Factor (Ci/m^3 per Ci/m^2, or m^{-1})
BR = Breathing Rate (m^3/hr)
T = Duration of Exposure (hr)
P_i = Activity fraction of isotope i
DF_{ij} = Dose Factor (rem/Ci) for organ j resulting from an intake of isotope i

Ground Contamination. There is no data that directly quantifies the amount and constituents of the surface contamination at the time and location of BIG BANG activities. However, these parameters can be related to the gamma intensities determined in Section 4.1. See Appendix IV.

Resuspension Factor.* Radioactive particles deposited on the ground or other surfaces are not an inhalation hazard unless they become airborne through some resuspension process such as wind action or mechanical disturbance. The degree of resuspension depends on many factors which include:

- the activity causing resuspension (wind action, pedestrian traffic, heavy equipment operation, etc.)

- nature of the surface (rough, vegetation, wet or dry)

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* The resuspension factor (K) is the ratio of the concentration of resuspended material in the air (e.g., Ci/m^3) to the amount of that material on the surface (e.g., Ci/m^2). The factor as used hereafter has the dimension of m^{-1}.

- particle characteristics (size, composition)
- location of measurement (height above ground, relationship to source)
- time after deposition (weathering, small particle depletion, etc.)

Numerous experiments have been conducted to study this phenomenon and develop representative resuspension factors for various conditions. Stewart (Reference 15) has tabulated resuspension factors that range from 10^{-3} to 10^{-11}, depending on the conditions and the type of material studied.

Surface winds were calm during the exercise on the HumRRO course on 2 September (Reference 10); therefore, any resuspension resulted solely from the troop activities. The potential for the inhalation of mechanically resuspended material began with the truck ride into the area. Surveys made during a weapons safety experiment measured resuspension factors which averaged 2×10^{-5} in the rear of a Land Rover vehicle in motion (Reference 15). While in the contaminated area, resuspension resulted from walking to and from the infiltration course, waiting in the area prior to running the course, and the actual running of the course (which included about one minute of crawling time). Obviously, resuspension reached its peak during the time on the infiltration course. In connection with other safety experiments, Stewart (Reference 15) reports plutonium resuspension factors for similar arid terrain that ranged from 3×10^{-4} to 1.5×10^{-6} resulting from dust raised by pedestrians. These measurements were made approximately 1 foot above the ground and the resuspended particles were characterized as mainly having diameters of 20-60 microns; fewer than 1 percent were smaller than 10 microns (aerodynamic diameter)*. At elevations higher than one foot above the ground, these measured resuspension factors should be considerably lower. For example, in another experiment reported by Stewart, the resuspension factor measured at 2 feet above the ground was more than an order of magnitude less than the value determined one foot above the surface.

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* Diameter of a spherical particle (density = 1 g/cm^3) with the same settling velocity as the particle in question. For example, a 10 μm unit density sphere would behave as a 6 μm particle of sand or a 3 μm PuO_2 particle.

On the basis of the data discussed above, the following resuspension factors are chosen to represent the conditions during the HumRRO exercise on 2 September:

Activity	$K(m^{-1})$
Infiltration course run	10-4
All other activities	10-5

Wind-driven resuspension must be considered for the rehearsals. Disagreements in reference material regarding the functional dependence in the resuspension factor on wind speed (u) and time (t) after fallout deposition prevents conclusive estimates from being made. Reported dependences on wind speed include $K \sim u^2$ (Reference 18), $K \sim u^3$ (Reference 15), and K uncorrelated to u (Reference 15). Time dependences include $K \sim e^{-\lambda t}$ (Reference 17) and K-e-A&Reference 18). Differences in particle size distribution limit the comparability of reported experiments to each other and to the HumRRO environments.

Larson's data (Reference 11) on airborne and ground activity concentrations for SMOKY fallout 99 miles from GZ, at 3 to 20 days after the shot, are used to deduce resuspension factors. These range from 10^{-8} to 10^{-6}. Daily-averaged winds ranged from about 1 to 10 mph. For the HumRRO rehearsals, the various fallout fields were 5 to 90 days old. Surface wind speed during the 23 August rehearsal was 4 to 8 mph, while the only datum on 26 August (at a time subsequent to the rehearsal) indicated gusts to 23 mph (Reference 16). These conditions are considered sufficiently comparable to those of the Larson data, so that with any reasonable application of the various wind speed and time dependence models, the wind-driven resuspension factor is unlikely to have been greater than order 10^{-5} during the HumRRO rehearsals. Therefore, the resuspension factors chosen for mechanical disturbances are used for the rehearsals as well as the exercise.

Breathing Rate. The Task Group on Lung Dynamics of the International Commission on Radiological Protection (ICRP) has applied three different ventilatory states to their lung model. These states are typifed by breathing rates of 0.67, 1.3 and 1.9 m^3/hr (Reference 19). The mid-range value is representative of a moderate activity state, the highest value represents strenuous activity. For purposes of this analysis, the high value is chosen to represent the time on the infiltration course. The mid-range value is applied to the remainder of the time.

Exposure Duration. The task force spent 3.5 and 4 hours at the HumRRO test area during the two rehearsals (23 August and 26 August), respectively. Travel to and from the area was over approximately 4 kilometers of roadway that had been contaminated by BOLTZMANN and WILSON fallout (Figures I-1 and I-3). Considering the short distance, and that fallout deposited on the road more than two months earlier would likely have been swept away by prior traffic, transit time is not included in the exposure duration for the rehearsals. On 2 September, the task force traveled approximately 8 kilometers (15 minutes) through the two-day-old SMOKY fallout field to get to the test area, where they spent one hour and forty minutes conducting the infiltration course portion of the HumRRO exercise. During both rehearsals and the final exercise, each test participant spent approximately 3 minutes per run on the infiltration course, this included about one minute of crawling time and 10-12 seconds in a foxhole. It is assumed that, during the rehearsals, each troop ran the course twice.

Protective masks were worn during the rifle disassembly/reassembly exercise. The amount of time that the masks were worn during the rehearsals is unknown, however, the actual test took less than 3 minutes. Considering this short time, credit for respiratory protection is not included in the total exposure times, which are summarized below:

23 August - 3.5 hours (includes 6 minutes on infiltration course)
26 August - 4 hours (includes 6 minutes on infiltration course)
2 September - 2.2 hours (includes 3 minutes on infiltration course)

Dose Factor. Radioactive material that has been inhaled or ingested will be absorbed, metabolized, and distributed to body tissues according to its chemical and physical properties. While the material is in the body, it irradiates the organ of residence, near-by organs, or even the whole body, depending on the type and energy of its emissions. Various models have been developed to portray the biological pathways and retention/excretion of inhaled and/or ingested material. Based on these models, internal radiation doses to selected organs of interest have been calculated for unit quantity intakes (inhalation and ingestion) of most radionuclides, for periods of up to 50 years subsequent to the intake. Dose is thus related to the amount of radioactive material inhaled or ingested through "dose conversion factors" or simply "dose factors" (e.g.,, rem/Ci inhaled).

Dose factors have been tabulated in References 20-24 and vary according to the biologic retention models employed and the selection of other parameters. Reference 24 contains the most current data, however, the authors consider the information preliminary and do not recommend it for uncritical adoption for all radiological applications at this time. Therefore, the dose factors tabulated in Reference 23 are used in this analysis. It should be mentioned that these dose factors are based on a one-year chronic intake rather than an acute intake such as that experienced by Task Force BIG BANG. However, the authors state that these dose factors can be applied to an acute intake with an error of 5 percent or less. The inhalation dose factors included in Reference 23 are based on the lung model as presented in ICRP Publication 2 (1959) (Reference 25). This model assumes that 25 percent of the inhaled material (readily soluble) is immediately exhaled, 50 percent is deposited in the upper respiratory passages and subsequently swallowed, and 25 percent is deposited in the lower portions of the lung and eventually taken up by body fluids. Only one-eighth of the insoluble materials inhaled is taken up by body fluids. These retention values are nearly the same as those characterized for the inhalation of an aerosol having a particle size distibution with an activity median aerodynamic diameter (AMAD) of 1 micron* (Reference 26).

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* Half of the airborne radioactivity is associated with particle sizes greater than 1 micron aerodynamic diameter. For loynormal activity distributions, the model is nearly constant over a wide range of geometric standard deviation, therefore, this parameter is commonly unspecified.

The particle size distribution of resuspended material subject to inhalation by BIG BANG troops is unknown, however, there is evidence to suggest that it would be dominated by large particles. For example, Larson (Reference 11) records the following data relative to the particle size of fallout from SMOKY:

Distance From GZ (miles)	Percent of Total Activity for Particles of Diameter <44 Microns
15U	52
100	38
50	19
25	15
4.6	2.9

An even lower percentage of activity would be expected on small particles in the HumRRO exercise area, 2.1 miles from GZ.

In order to consider the uncertainties with respect to the particle size distribution of the resuspended material, two calculations are made which cover lower and upper bounds of reasonable sizes:

- The first calculation assumes an aerosol having an activity median aerodynamics diameter (AMAD) of approximately one micron. This is accomplished by utilization of the inhalation dose factors listed in Reference 23. (See discussion on page 38.) This follows the recommendation of the International Commission on Radiological Protection (ICRP) to assume an AMAD of one micron when the actual particle size distribution is unknown. (Reference 26).

- The second calculation assumes an aerosol having an AMAD greater than 20 microns. According to the ICRP (Reference 26), complete nasopharyngeal (upper respiratory system) deposition can be assumed for unusual particle size distribution having AMADs greater than 20 microns. Particles deposited in this region are rapidly cleaned and normally swallowed, thus the intake pathway becomes ingestion. Therefore, the application of <u>ingestion</u> dose factors to the amount of material <u>inhaled</u> assumes an aerosol with an AMAD of greater than 2U microns.

As stated earlier, inhalation and ingestion dose factors are available for several body organs. In this assessment, emphasis is placed on the bone dose since the bone contains blood-forming marrow and accumulates several long-lived radionuclides (e.g., Sr^{90}).

Appendix IV indicates that 49 radionuclides represent in excess of 98% of the total beta/gamma activity present in fallout fields relevant to Task Force BIG BANG. The alpha activity results from 3 alpha emitters. Composite 50-year bone dose factors, $\sum(P_i \times DF_i)$, for the 49 beta/gamma emitters and 3 alpha emitters at each time of interest are shown below. The dose factors for the alpha emitters are scaled to relate directly to the inhaled beta/gamma activity to prevent disclosure of classified information, as mentioned in Appendix IV.

COMPOSITE 50-YEAR BONE DOSE FACTORS
(mrem per Ci of beta activity inhaled/ingested)

		INHALATION		INGESTION	
SHOT	DATE	ALPHA	BETA/ GAMMA	ALPHA	BETA/ GAMMA
SMOKY	2 SEP	1.15+5*	1.30+6	2.85+1	1.20+6
SHASTA	23 AUG	1.41+7	4.16+6	3.49+3	2.97+6
	26 AUG	1.89+7	6.22+6	4.68+3	3.95+6
	2 SEP	4.44+7	1.17+7	1.10+4	5.85+6
DIABLO	23 AUG	1.28+8	2.72+7	3.17+4	8.80+6
	26 AUG	1.38+8	2.90+7	3.42+4	9.00+6
	2 SEP	1.65+8	3.30+7	4.08+4	9.30+6
BOLTZMANN	23 AUG	3.64+8	5.52+7	9.03+4	1.06+7
	26 AUG	3.78+8	5.67+7	9.38+4	1.07+7
	2 SEP	4.12+8	6.10+7	1.02+5	1.08+7

* Read as 1.15×10^5.

Results. The calculated 50-year bone dose resulting from the inhalation of resuspended radioactive fallout is tabulated in Table 2. The results are tabulated according to the following categories:

- Troop activity (infiltration course vs. all others)
- Type of emitter inhaled (alpha vs. beta/gamma)
- Particle size of resuspended material (> 20 μm vs 1 μm AMAD)

Entries in Table 2 are calculated as in the following example: The 50-year bone dose from SMOKY beta/gamma emitters inhaled during the infiltration course run, for a resuspended particle AMAD of 1 μm, is:

$$D = 0.256\ Ci/m^2 \times 10^{-4}/m \times 1.9\ m^3/hr \times 0.05\ hr \times 1.3 \times 10^6\ mrem/Ci = 3.16\ mrem$$

The calculated 50-year bone dose to Task Force BIG BANG personnel resulting from inhalation of resuspended fallout from four Plumbbob shots is quite low. Considering the two extremes relative to the particle size distribution of the resuspended material (1 micron vs. greater than 20 microns AMAD), the range in the calculated 50-year dose is 8.8 to 23 millirem. Considering the close proximity of BIG BANG activities to shot ground zeros and the measured particle size data previously discussed, the actual dose should be close to the low end of the calculated range.

Upon observation of these results, several points deserve discussion.

- The bone dose from the alpha emitters is nil when a particle size distribution of AMAD greater than 20 microns is assumed. This is due to the extremely low absorption of the radionuclides involved from the gastrointestinal tract to the blood (that transports them to the bone). This absorption process is much more efficient (several orders of magnitude) for smaller particles that are deposited in the pulmonary region of the lung.

- The BOLTZMANN alpha activity in the fallout (assume AMAD = 1 μm) contributes significantly more to the bone dose than the more recent SMOKY fallout. This is due to differences in the composition of the fissionable material.

TABLE 2 ESTIMATED 50-YEAR BONE DOSE

		DOSE (mrem)									
		INFILTRATION COURSE RUN				OTHER ACTIVITIES					
		ALPHA		BETA/GAMMA		ALPHA		BETA/GAMMA		TOTAL	
EVENT	SOURCE	>20 μm*	1 μm*	>20 μm*	1 μm*	>20 μm*	1 μm*	>20 μm*	1 μm*	>20 μm*	1 μm*
REHEARSAL 23 AUG	SHASTA	< .001	0.09	0.02	0.03	< .001	0.20	0.04	0.06	0.06	0.37
	DIABLO	< .001	0.05	0.004	0.01	< .001	0.12	0.01	0.03	0.01	0.21
	BOLTZMANN	< .001	1.15	0.03	0.17	< .001	2.67	0.08	0.41	0.11	4.40
REHEARSAL 26 AUG	SHASTA	< .001	0.06	0.111	0.02	< .001	0.15	0.02	0.05	0.04	0.28
	DIABLO	< .001	0.05	0.003	0.01	< .001	0.12	0.01	0.03	0.01	0.21
	BOLTZMANN	< .001	1.19	0.03	0.17	< .001	3.18	0.09	0.47	0.12	5.01
EXERCISE 2 SEP	SHASTA	< .001	0.03	0.004	0.01	< .001	0.06	0.01	0.02	0.01	0.12
	DIABLO	< .001	0.03	0.002	0.01	< .001	0.06	0.004	0.01	0.006	0.11
	BOLTZMANN	< .001	0.65	0.02	0.10	< .001	1.44	0.04	0.22	0.06	2.41
	SMOKY	< .001	0.28	2.92	3.16	< .001	0.52	5.40	5.85	8.32	9.80
TOTALS		< .01	3.6	3.0	3.7	< .01	8.5	5.7	7.2	8.8	23

* Activity Median Aerodynamic Diameter (AMAD)

Note: The results for the 2 September exercise represents the dose estimates for the late finishers of the infiltration course run. Estimates for the early finishers are approximately 2 mrem lower.

- As indicated in the basic methodology for this calculation, several parameters are involved. Of these parameters, the resuspension factor has the greatest potential for significant variation from the values used in this calculation. It should be noted that the values used were from the high end of the range reported in the scientific literature; however, even if the assumed values were low by two orders of magnitude, the calculated 50-year dose would still be less than 3 rem.

Section 5

UNCERTAINTY ANALYSIS AND DETERMINATION OF TOTAL FILM BADGE GAMMA DOSE

Because virtually all of the external gamma dose accrued by TF BIG BANG and HumRRO personnel was due to their activities in the SMOKY fallout field, only the uncertainties pertinent to these need be considered. The methodology of Reference 5 is used with the analysis of Appendices I and III to determine error bands. Estimated error factors associated with 90 percent confidence limits for each uncertainty parameter are displayed below:

Source of Error		SMOKY Fallout Field, 2 Sept
Fallout plot intensities		1.46
Fallout plot interpolation	infiltration course	1.64
	parking area	1.35
Mean troop position		1.1
Decay rate		1.3
Duration of activity		1.1
COMBINED ERROR FACTOR	infiltration course	1.99
	parking area	1.76

These error factors are applied to the dose accrued at each location, with interpolated values along the marching path. The range of film badge doses calculated for TF BIG BANG personnel in the SMOKY fallout field is thus 1050 $^{+850}_{-470}$ mrem to 1760 $^{+1650}_{-850}$ mrem (all with 90 percent confidence). Total film badge dose, including the contributions from the rehearsals and the observation of GALILEO, is only 20 mrem greater.

Quantitative error estimates are not feasible for the external beta and internal radiation dose calculations. In each case, however, it is clear that one parameter dominates the uncertainties: the fallout depth distribution for external beta, and the resuspension factor for internal radiations. If the fallout were concentrated at 1 mm depth rather than uniformly distributed within the top millimeter, for example, the beta skin dose would be reduced about 70 percent. For internal dose calculations, the results are directly proportional to the resuspension factor used.

Section 6

FILM BADGE DOSIMETRY

6.1 FILM BADGE DATA

Personnel of Task Force BIG BANG were each issued one film badge to cover the entire period of their stay at NTS. Film badges were of the type described in Reference 5, Appendix III. There were 161 individuals with undamaged badges for the period 13 August to 3 September 1957. The original film badge records do not list subunit affiliation for the exercise, but the HumRRO report (Reference 2) identifies some of the troops used as monitors. On the basis of currently available data, it does not appear possible to differentiate among platoons. That the readings are widely distributed is evidence of distinct troop components, however.

Figure 7 depicts the film badge gamma readings for Task Force BIG BANG. Two clusters are evident in this plot. About one-third of the personnel received no more than 295 mrem. They apparently did not attend the exercise, as their doses are inconsistent with entry into the SMOKY fallout field. All others received at least 860 mrem. A comparison of gamma and beta doses for Task Force BIG BANG is displayed in Figure 8. There is only a weak positive correlation between beta and gamma readings. The highest beta readings cannot necessarily be attributed to those involved in the crawling exercise; several monitors and officers had relatively high readings. Although the one-minute crawl was a significant contributor to the beta dose, body position during the rest of the exercise may have been more influential. While the troops were waiting their turns to run the infiltration course, they may have rested in a variety of postures. A posture that would place the film badge near the ground would have increased the beta reading, owing to the short range of most beta particles.

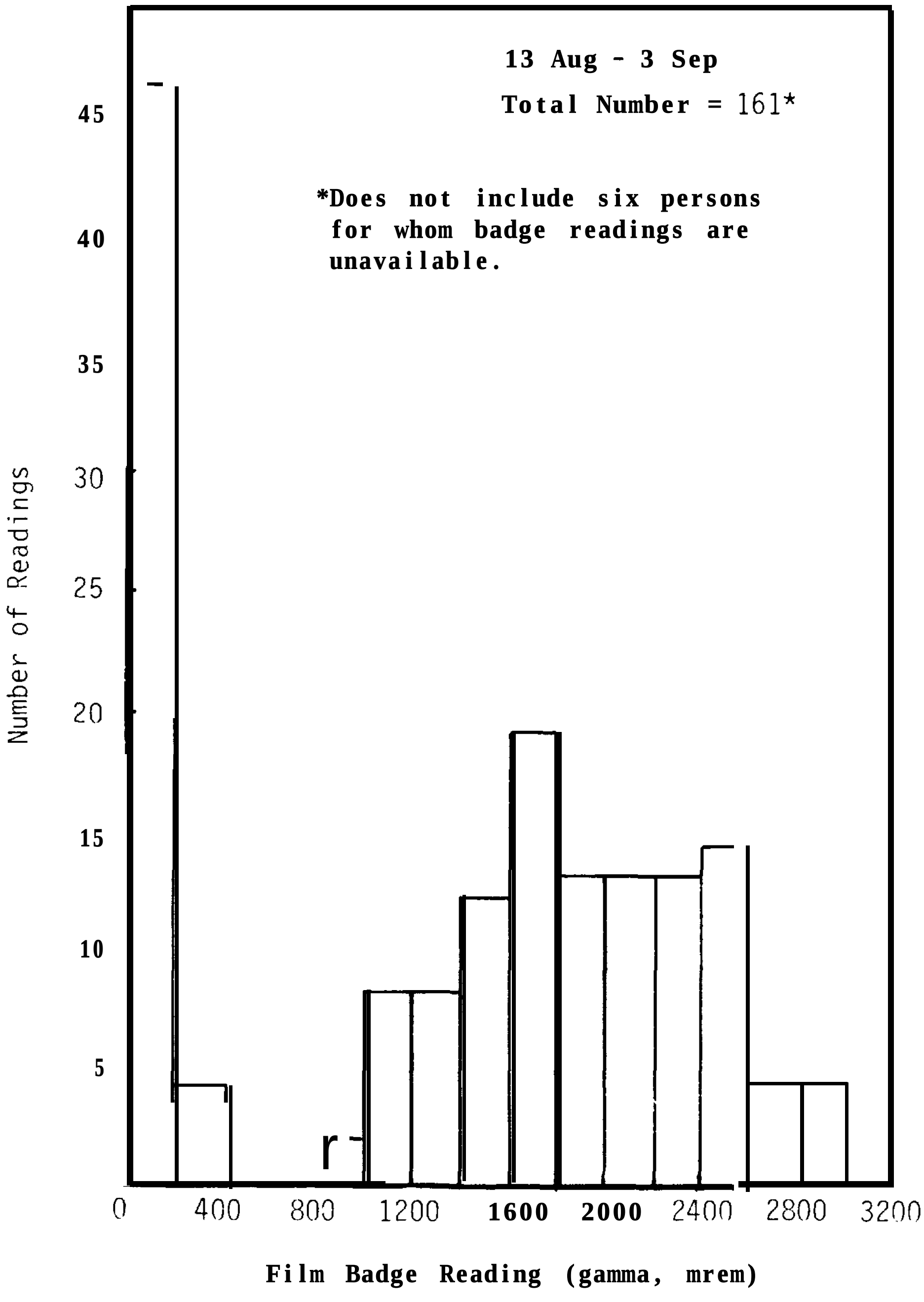

Figure 7. Distribution of Film Badge Readings, Task Force BIG BANG

	0–200	200–400	400–600	600–800	800–1000	1000–1200	1200–1400	1400–1600	1600–1800	1800–2000	2000–2200	2200–2400	2400–2600	2600–2800	2800–3000
1000–1100	TOTAL NUMBER = 161*							1					1		
900–1000											1		1		1
800–900								1			1				
700–800									2	2		1			
600–700								1			2	1			1
500–600									1				2		
400–500									5	1	1	1	3		
300–400										1	1	4	2	1	
200–300							1	1	3	1	2	2	1	1	1
100–200								1	1	5	3	2	2		
0–100	47	4			2	8	7	7	7	3	2	2	2	2	1

Gamma Reading (mrem)

* Does not include six persons for whom badge readings are unavailable.

Figure 8. Cross Plot of Gamma and Beta Film Badge Readings

Most of the low-dose readings fall into two groups centered about 0 and 150 mrem. Along with the 10 zero readings, there are 5 reports of 12 to 20 mrem. These numbers are not considered meaningful since the threshold of reliable film badge readings is at least 25 mrem.

Most of the remaining low-dose readings are within 150 $\pm$ 30 mrem. Personnel who accrued these doses must have attended some undocumented activity in the time frame of the rehearsals. This interpretation is supported by the 119 mrem reading of a HumRRO team member who departed prior to the exercise; the reading cannot be reasonably correlated with the 15 mrem calculated for the rehearsals.

Of those personnel participating in the exercise, the monitors *received* the highest exposures. This seems reasonable since the monitors, in the performance of their duties, may have stayed longer on the infiltration course than any of the test troops. Nine of the ten known participating military and civilian monitors recorded from 2500 to 3200 mrem, whereas only one of the test troops exceeded 2600 mrem.

The mean gamma dose of the troops participating in the exercise was 1900 mrem, with a standard deviation of 490 mrem. There are too few data points to ascribe statistical significance to the distribution in Figure 7. It is not clear from the plot whether the high-dose data tend toward a single Gaussian distribution or the superposition of several such distributions, as the troop activity scenario would suggest.

Those troops who can be inferred to have remained together should have similar readings. For example, the four lieutenants all accrued between 2380 and 2480 mrem. Aside from the monitors, it is difficult to make similar deductions from rank in other cases, however.

6.2 COMPARISON OF DOSE CALCULATIONS WITH FILM BADGE DATA

Figure 9 displays a comparison of the distribution of film badge gamma readings with the calculated distribution of film badge doses for the test troops. An adaptation of each was necessary for the direct comparison:

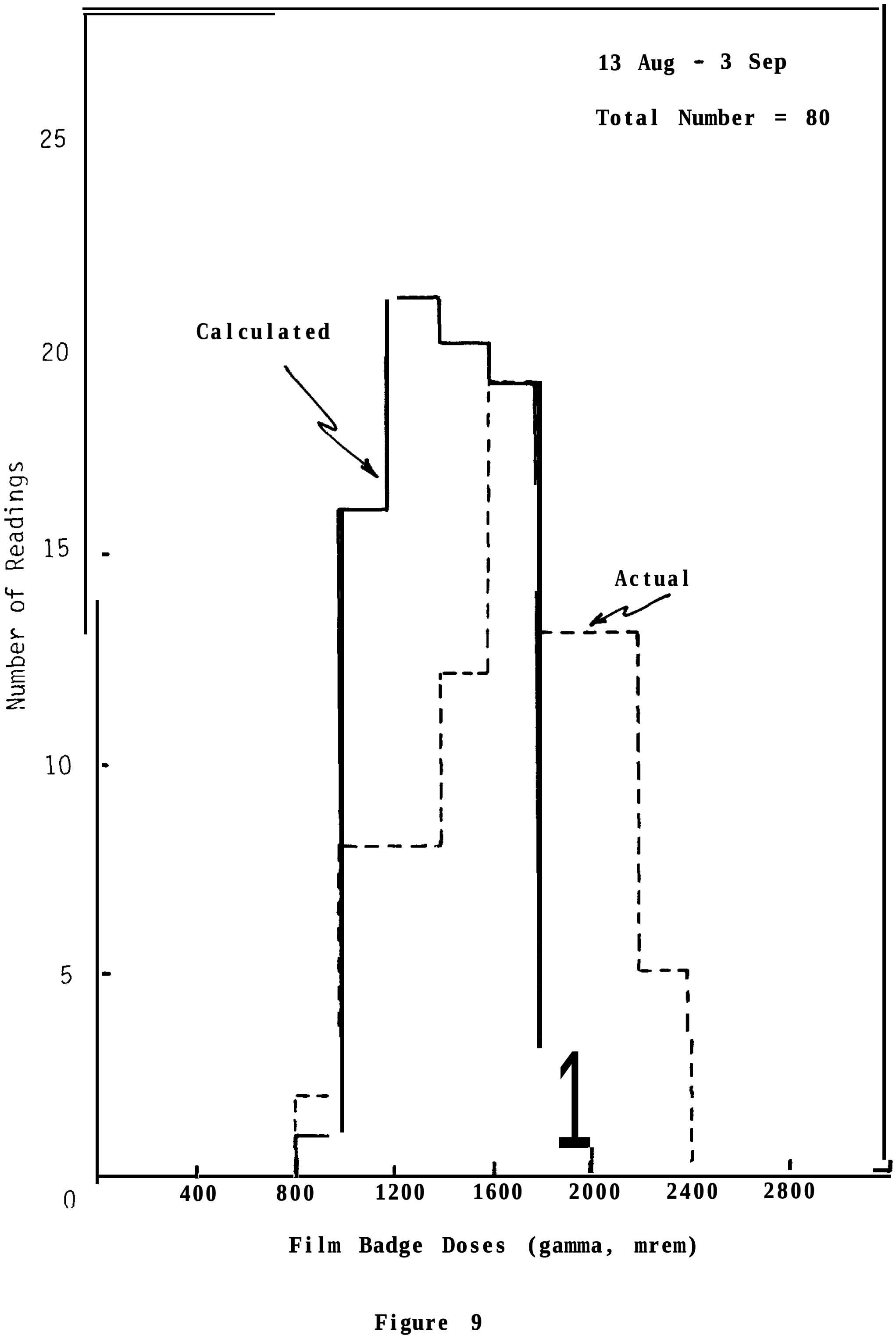

Figure 9

Distribution of Calculated and
Actual Film Badge Doses

(1) a standard deviation of 7 percent* was assigned to the reading for each group of test participants, and (2) the officers, identified monitors, and those (presumed to be monitors' assistants) with the 17 next highest doses were not included, so that the 80 remaining readings are presumed to be those of the test troops. The figure demonstrates that the scenario of troop activities implies a dose distribution similar to that found for TF BIG BANG film badges.

A statistical comparison of the calculated gamma film badge doses and the film badge readings is displayed in Table 3. Of those troops who were tested in the HumRRO exercise, the earliest finishers of the infiltration course are estimated to have accrued 1070 mrem, while the latest finishers' estimate is 1780 mrem. These compare favorably with the overall TF BIG BANG average film badge reading of 1900 mrem and the 1630 mrem average reading of deduced test troops. For the monitors, the calculated dose of 1780 mrem compares to the actual median film badge reading of 2830 mrem. The latter is well within the confidence limits of the former.

The calculated film badge beta dose (the skin dose to the chest area) is greater than the film badge beta readings, perhaps because the fallout was distributed to depths greater than one millimeter. The low or zero readings likely resulted from the film badges being tucked into pockets to preclude their loss, leading to additional shielding, particularly if the beta window were facing inward toward the body. In this case, the calculated beta dose to the film is 0.3 rem for the one millimeter depth distribution.

* 7 percent was the smallest standard deviation in film badge readings for any cohesive unit during Desert Rock VII-VIII and pertained to readings of a magnitude similar to that for TF BIG BANG.

TABLE 3

COMPARISON OF CALCULATED FILM BADGE DOSES
WITH FILM BADGE DATA FOR
TASK FORCE BIG BANG TROOPS*

Group	Calculated Film Badge Dose** (mrem)	Film Badge Readings (mrem)	
		lowest	860
Earliest Finishers	1070^{+850}_{-470}		
		mean, test troops	1630
Average Finishers	1430^{+1220}_{-650}		
		mean, all troops	1900
Latest Finishers, Officers, Monitors	1780^{+1650}_{-850}	median, officers	2390
		median, monitors	2830
		highest	2980

* Period: 13 August - 3 September 1957; personnel present at HumRRO exercise only

** With 90 percent confidence limits

Section 7

CONCLUSIONS

Of the several shots during Operation Plumbbob that contributed to the residual radiation exposure of Task Force BIG BANG, only Shot SMOKY was of any significance. Although the HumRRO exercise was conducted in conjunction with Shot GALILEO, no residual and negligible initial radiation from GALILEO was encountered by the troops. Exposure to gamma radiation in the SMOKY fallout field resulted in film badge readings from about 1 rem to 3 rem. The data indicate that film badge records are in substantial agreement with equivalent values inferred from radiation field measurements and troop movement records. Reasonable judgments concerning troop motion within the SMOKY fallout field yield a satisfactory explanation for the range of the film badge readings.

The dose to personnel from inhaled radioactivity was small in comparison to the external gamma dose. For the bone, the calculated 50-year dose is less than 25 mrem. The internal exposure resulted from both fissioned and unfissioned bomb debris, which emitted alpha, beta, and gamma radiation. Neutron-activated shot tower material contributed negligibly to the internal dose.

Section 8

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APPENDIX I

FALLOUT PLOTS

(Except for the GALILEO map, this appendix is taken from Reference 5 and is included here for reader convenience.)

Because the radiation dose accrued by individuals at the Nevada Test Site in 1957 was caused, to a significant extent, by the exposure to fallout from several shots, it is imperative that all Plumbbob shots be examined and, where appropriate, the fallout plotted. Table I-1 lists the shots that were examined and identifies those for which fallout plots are produced in the figures following. For those not plotted, the reason is primarily that the height of burst was sufficient for that yield to reduce local fallout, beyond the immediate area around ground zero, to insignificant levels. This is verified through inspection of post-shot rad-safe surveys by Reynolds Electrical Engineering Company (REECO) and the Civil Effects Group (CETG), Program 37 (References 1 and 11).

The fallout plots shown in Figures I-1 through I-10 were derived from the information contained in the above references. Plots of actual radiation levels, measured at specific times after each shot, were normalized to H+12 hours by using the decay schemes described in Appendix II. A single composite fallout plot was obtained from the survey data through averaging the normalized values. The REECO dose rate plots were not used in their entirety; only actual data points were considered (where the REECO iso-intensity contours intersect roads). Because the roads depicted in the REECO plots were sufficiently straight, sets of collinear data values were obtained which could be processed mathematically.

Because gamma radiation intensity tended to vary exponentially with distance, the data were fit to an exponential form. The simplest, after taking logarithms, is

$$\log I = ax + b$$

TABLE I-1

OPERATION PLUMBBOB FALLOUT DETERMINATION
28 MAY TO 2 SEPTEMBER 1957

SHOT	YIELD	DATE & TIME	BURST HEIGHT	AREA	COORD	FALLOUT
BOLTZMANN	12KT	28 May, 0455	500' Tower	7	867056	Fig. II-1
FRANKLIN	140T	2 Jun, 0455	300' Tower	3	870004	Fig. II-2
LASSEN	.5T	5 Jun, 0455	500' Balloon	9b	852100	Insig.
WILSON	10KT	18 Jun, 0455	500' Balloon	9b	852100	Fig. II-3
PRISCILLA	37KT	24 Jun, 0630	700' Balloon	FF	956729	Offsite East
HOOD	74KT	5 Jul, 0440	1500' Balloon	9b	852100	Insig.
DIABLO	17KT	15 Jul, 0430	500' Tower	2b	792118	Fig. II-4
KEPLER	10KT	24 Jul, 0450	500' Tower	4	797057	Fig. II-5
OWENS	9.7KT	25 Jul, 0630	500' Balloon	9b	852100	Insig.
PASCAL "A"	S(N)	26 Jul, 0100	Underground	3j	858009	Fig. II-6
STOKES	19KT	7 Aug, 0525	1500' Balloon	7b	867047	Insig.
SHASTA	17KT	18 Aug, 0500	500' Tower	2a	794093	Fig. II-7
DOPPLER	11KT	23 Aug, 0530	1500' Balloon	7b	867047	Insig.
FRANKLIN PRIME	4.7KT	30 Aug, 0540	750' Balloon	7b	867047	Fig. II-8
SMOKY	44KT	31 Aug, 0530	700' Tower	8(2c)	828159	Fig. II-9
GALILEO	11KT	2 Sep, 0540	500' Tower	1	797009	Fig. II-10

S(N) - Safety shot with some nuclear yield

A least squares linear regression was performed on log I. The locations of I=10, 100, and 1000 mr/hr were obtained according to the fit. Usually, the data, when normalized to H+12, spanned these values. If not, no extrapolation was performed.

The log-linear fit is clearly inappropriate across GZ or the hotline. A higher order fit, akin to a Gaussian, was tried in order to permit a functional maximum:

$$\log I = ax^2 + bx + c$$

While this form was useful in obtaining gamma intensity on hotlines, it underestimated GZ values. When used on data not crossing GZ, there was a tendency toward unrestrained exponential growth (i.e., positive a), just as for the log-linear fit. So long as the data lines did not cross GZ or the hotline, the difference in 10, 100, and 1000 mr/hr locations from the first order to second order fit was well within the standard deviation of the data. For these reasons, the log-linear fit was used to construct composite plots.

The consistency of the data was assessed from log I(x). The standard deviation, σ, of log I from the best linear fit was computed along all lines used. A markedly similar scatter in the data was observed not only from line to line, but also from shot to shot. For all lines used on all plots, the error factor, defined as $10^{1.65\sigma/\sqrt{n-1}}$, where n is the number of data points along a line, averages 1.46. Its own standard deviation is 0.05. The consistency of the error factor supports the dismissal of isolated data far outside reasonable confidence limits.

Thus, all the composite plots may be regarded as depicting gamma intensity along the roads within a factor of 1.46, with 90 percent reliability. Where the contours have been interpolated between roads, the error factor would be slightly greater. The on-site composite plots were reasonably consistent with the off-site surveys from Program 37 (Reference 11). For most shots, interpolation was necessary in the gap between the composite contours obtained from on-site surveys and off-site surveys. In those cases, azimuthal consistency as well as magnitude determined the overall correlation. Where the contours have been interpolated (dashed lines), the error factor grows considerably, particularly where contours are closely spaced.

In general, available data was used or interpolated for all areas of interest. One obvious exception is evident for SMOKY, where the upwind radiation intensity is crucial to determine the dose received by Task Force WARRIOR and supporting elements operating in the upwind area. The steep terrain obviously prevented post-shot ground or aerial rad-safe surveys immediately upwind. The upwind contours were therefore estimated as being virtually circular, under the conservative assumption that upwind fallout would have carried no farther from ground zero than crosswind fallout, particularly in the fact of rising terrain. In this case, as well as others, both estimated and interpolated contours are dotted.

It should be noted that the fallout plots shown in the figures differ from earlier estimates of fallout, such as that provided by the DASA 1251 report (Reference 10). Because the plots are all derived from the same data (References 1 and 11), some explanation for the difference is in order. First, presumed actual survey points along roads were used as data points rather than the entire sketched contours. Second, DASA 1251 ascribed more reliability to the contours than could have possibly existed. For instance, the northwest quadrant of SMOKY fallout should be considered highly suspect simply on the basis that the steep terrain would have precluded surveys in that area. Third, the influence of previous shots on subsequent surveys was not considered. This is particularly evident for SMOKY, where the REECO surveys *were* biased by the northerly SHASTA fallout of two weeks previous and DIABLO fallout of seven weeks previous. Thus, any composite SMOKY fallout plot, using REECO data, would reflect higher intensities on the western side than actually resulted from shot SMOKY itself. Finally, the DASA 1251 fallout contours were normalized (to H+1) using a decay rate of $t^{-1.2}$. The plots contained herein are normalized to H+12 through the use of actual shot decay rates where available from Program 37. Where the actual data are not available, the composite Plumbbob decay is used. In either case, significant variations from the traditional $t^{-1.2}$ 'rule" are evident. This is discussed in Appendix II where actual decay rates and schemes used to derive the composite plots are described in greater detail.

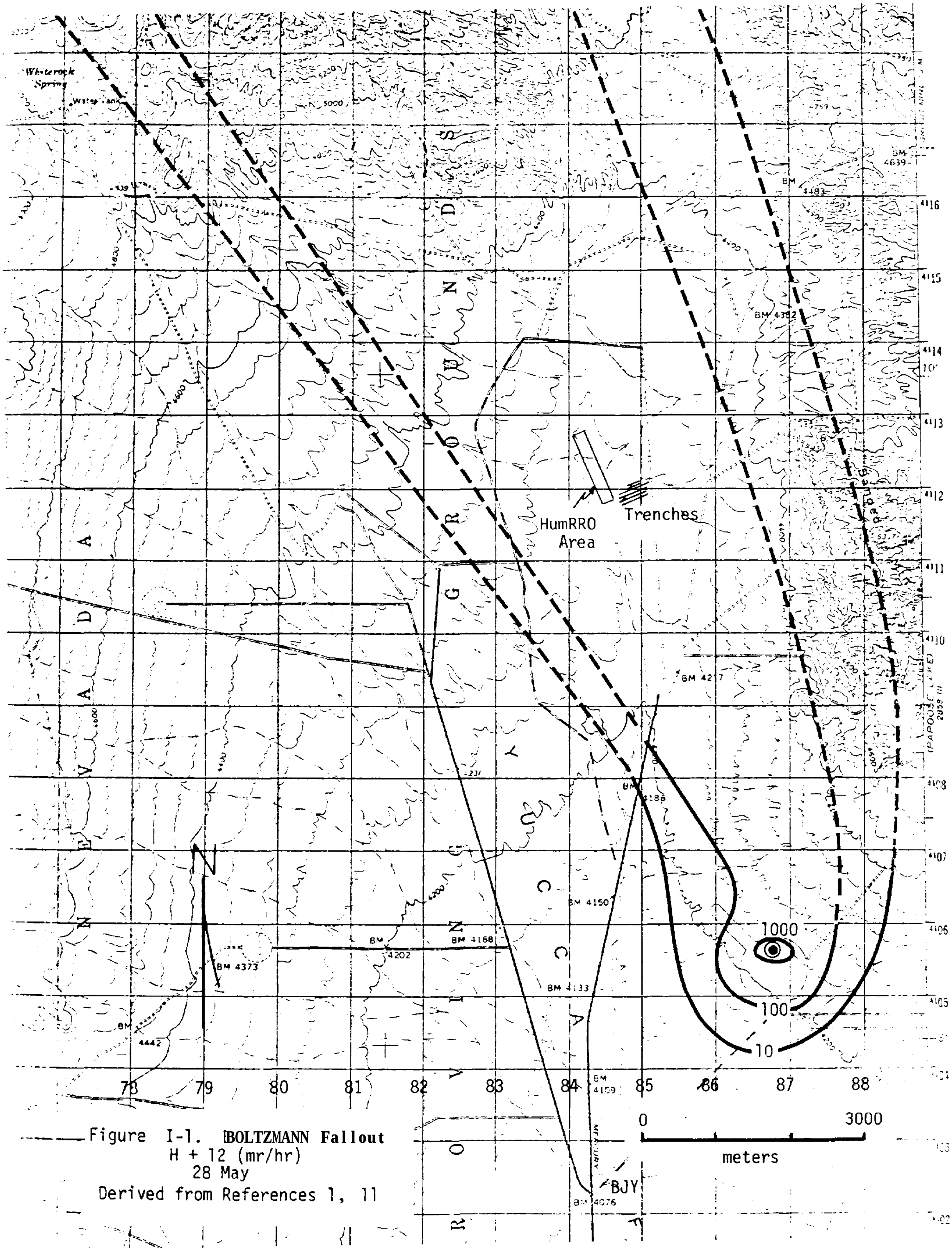

Figure I-1. BOLTZMANN Fallout
H + 12 (mr/hr)
28 May
Derived from References 1, 11

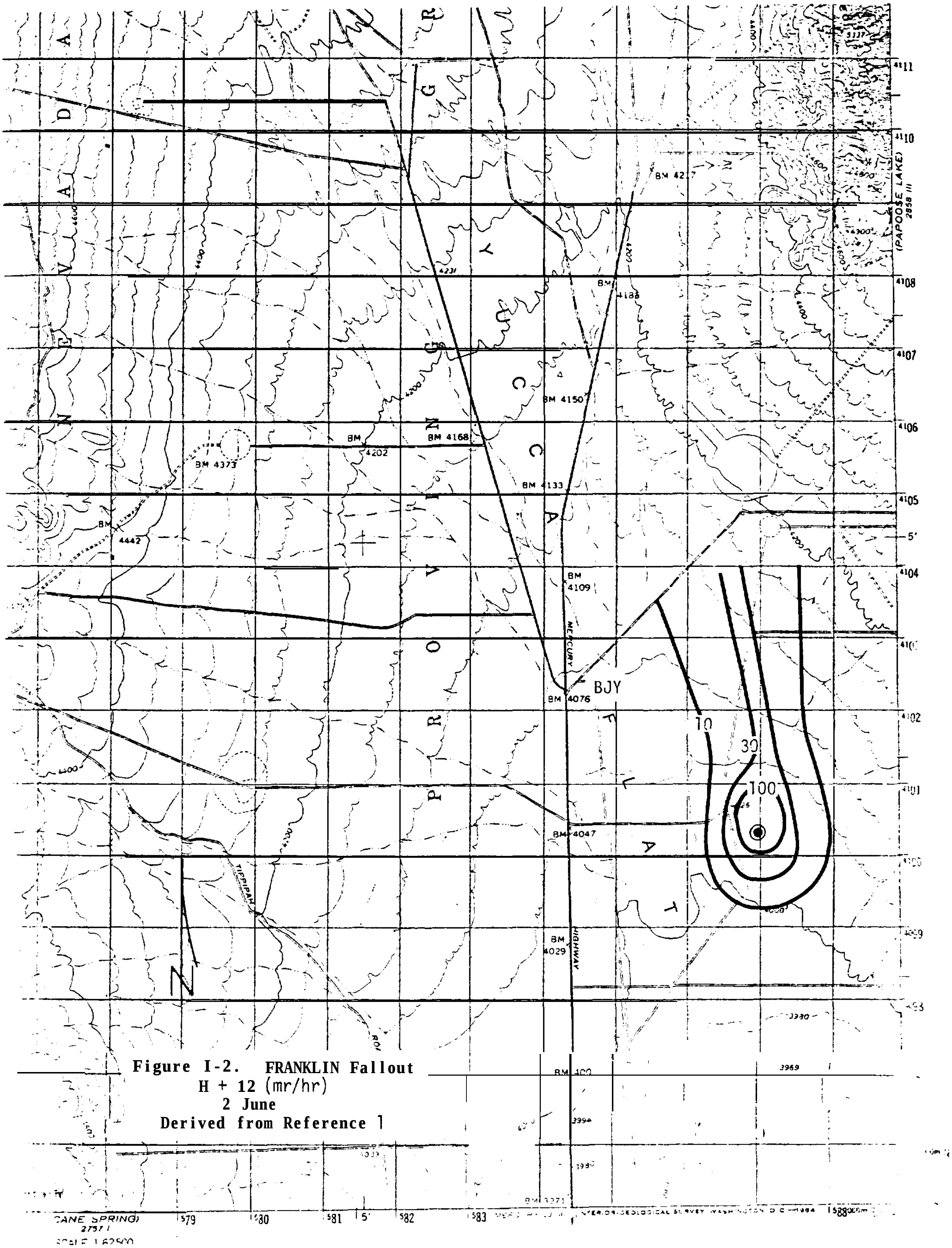

Figure I-2. FRANKLIN Fallout
H + 12 (mr/hr)
2 June
Derived from Reference 1

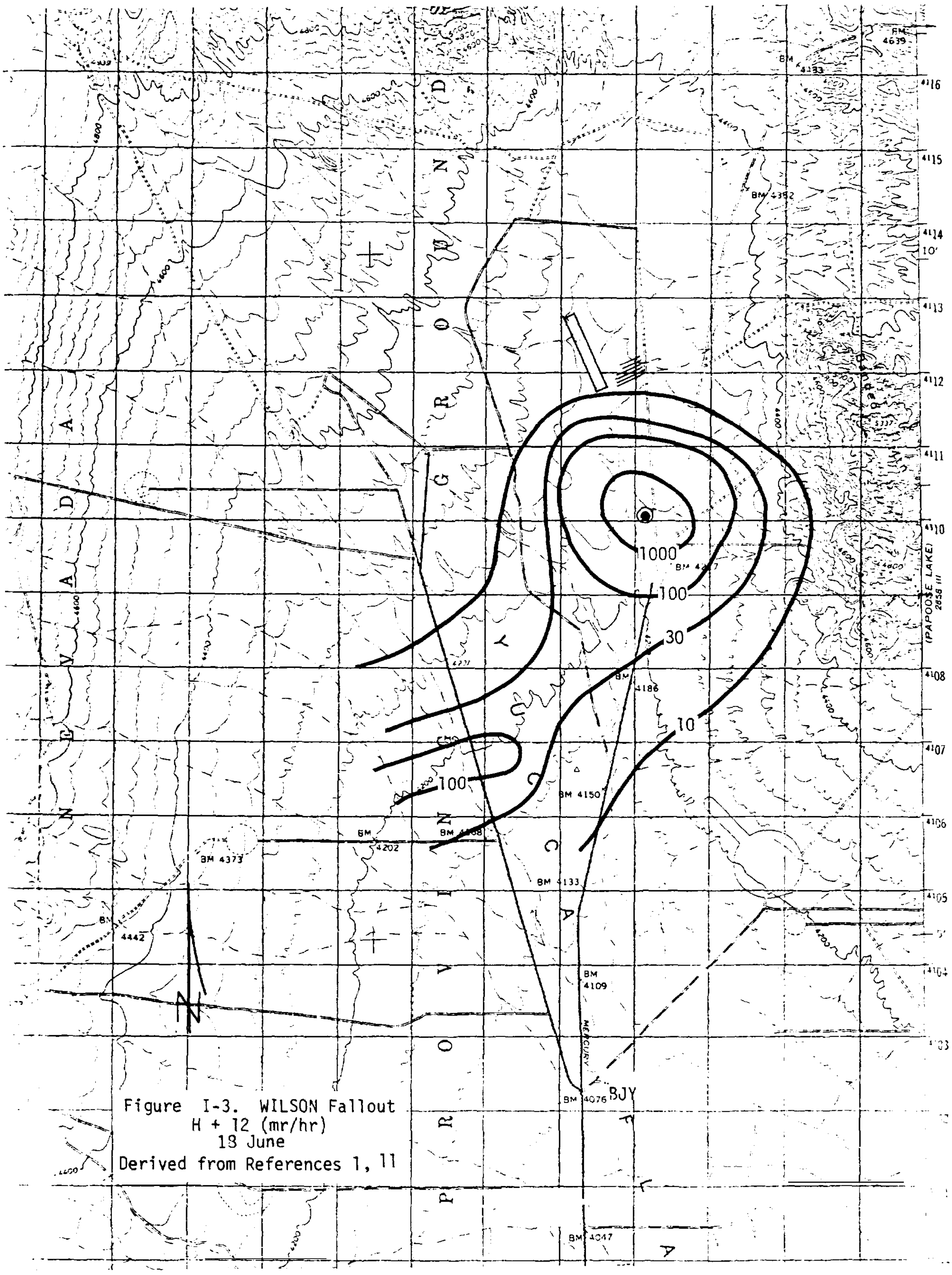

Figure I-3. WILSON Fallout
H + 12 (mr/hr)
18 June
Derived from References 1, 11

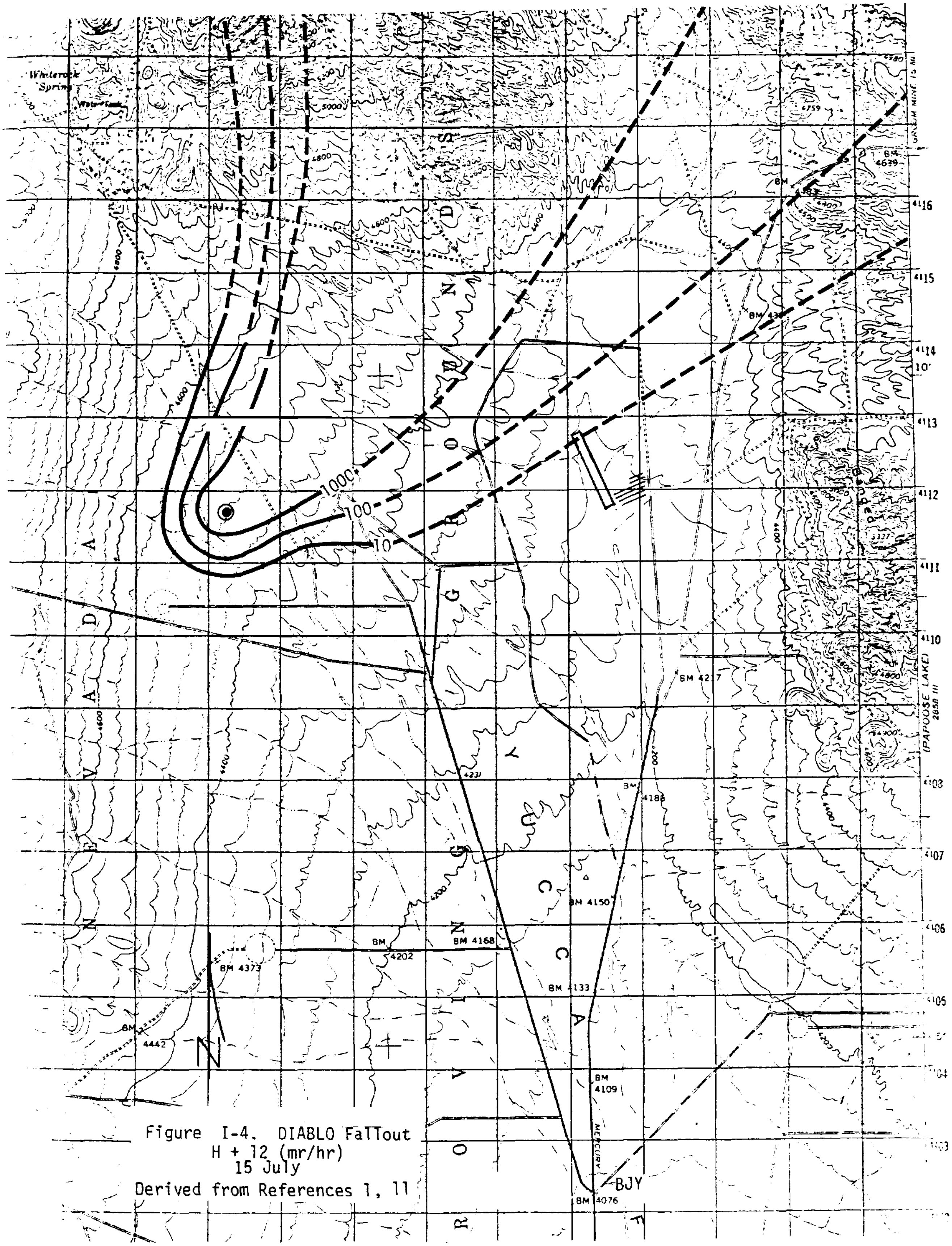

Figure I-4. DIABLO Fallout
H + 12 (mr/hr)
15 July
Derived from References 1, 11

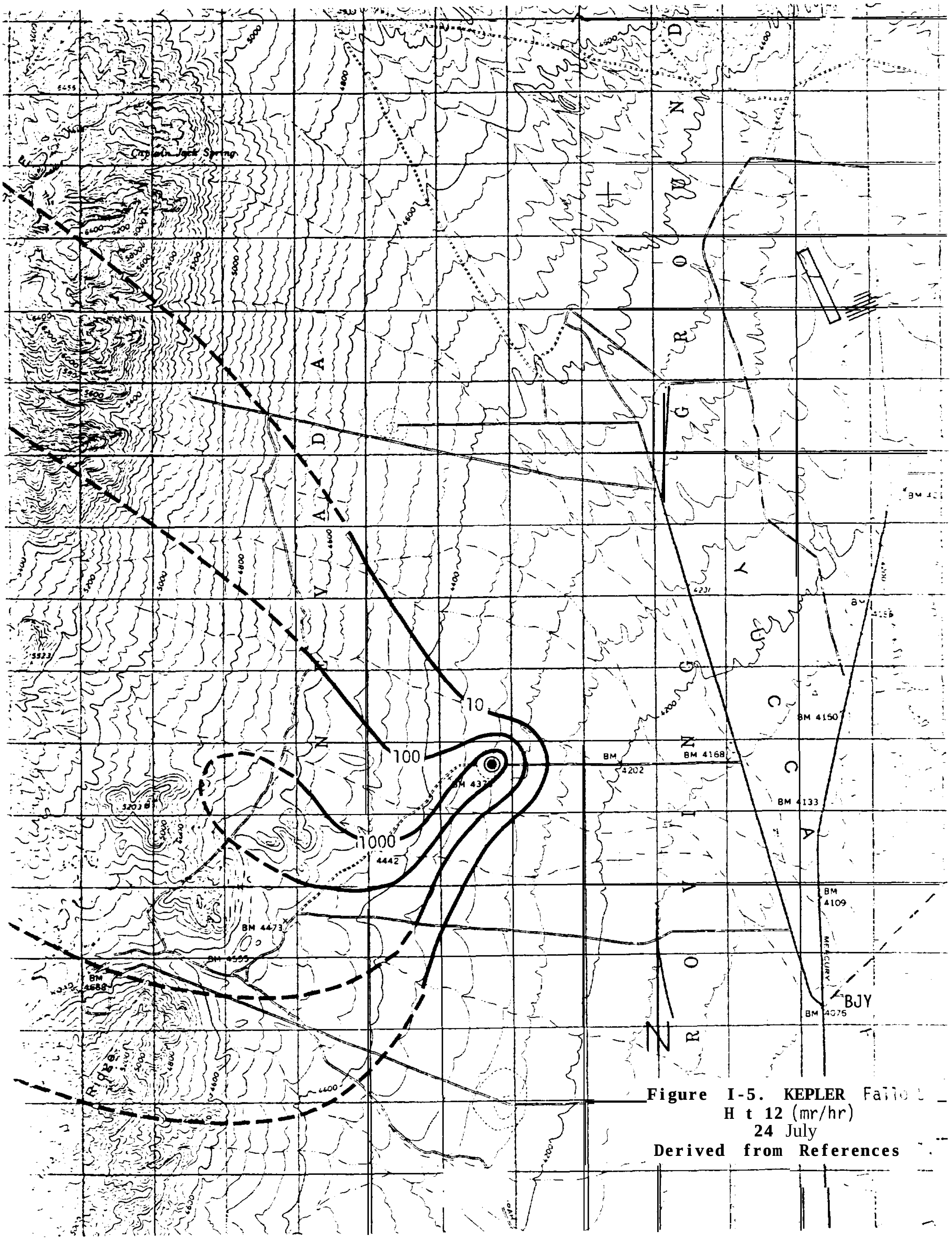

Figure I-5. KEPLER Fallout
H t 12 (mr/hr)
24 July
Derived from References

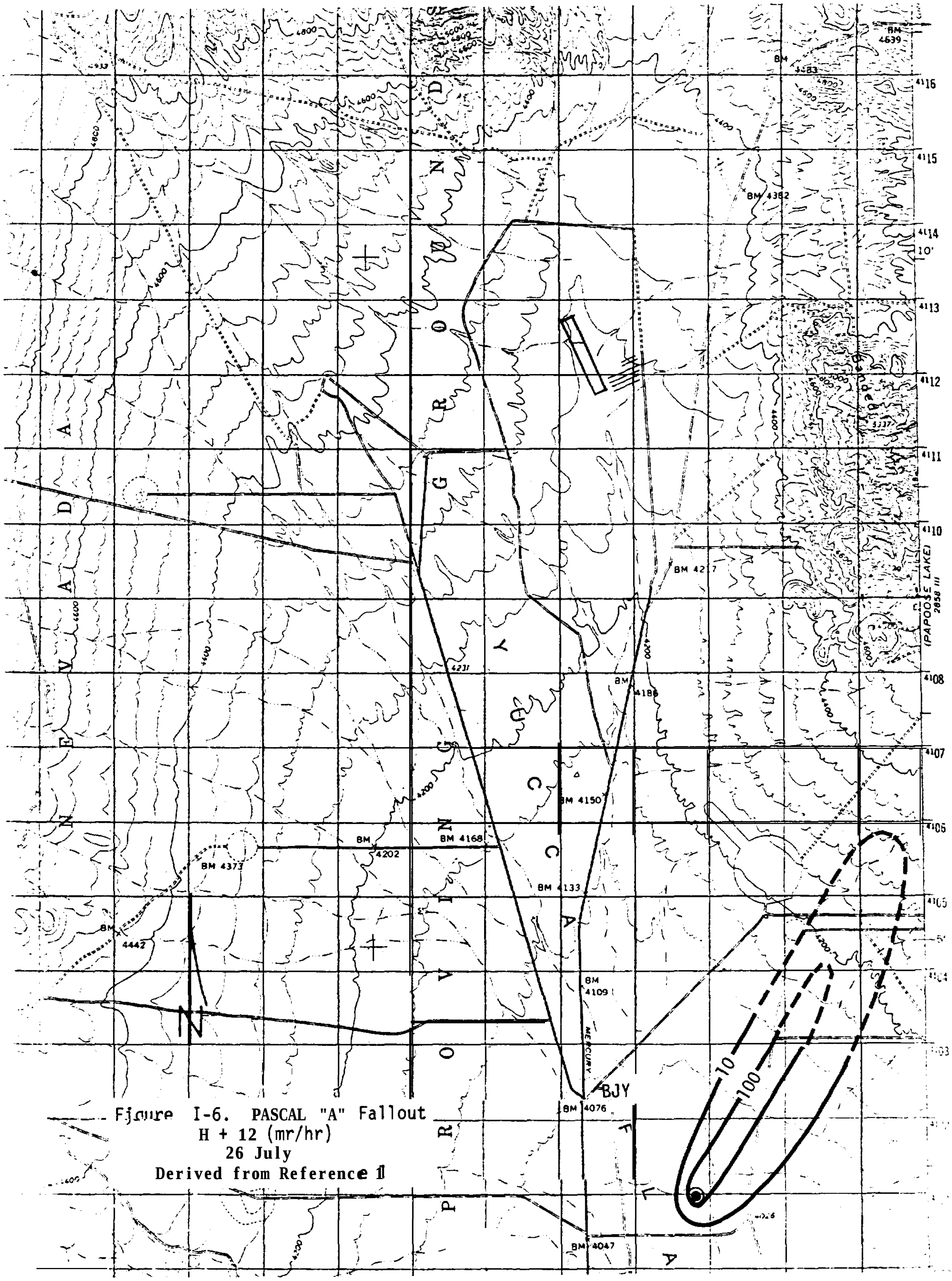

Figure I-6. PASCAL "A" Fallout
H + 12 (mr/hr)
26 July
Derived from Reference 1

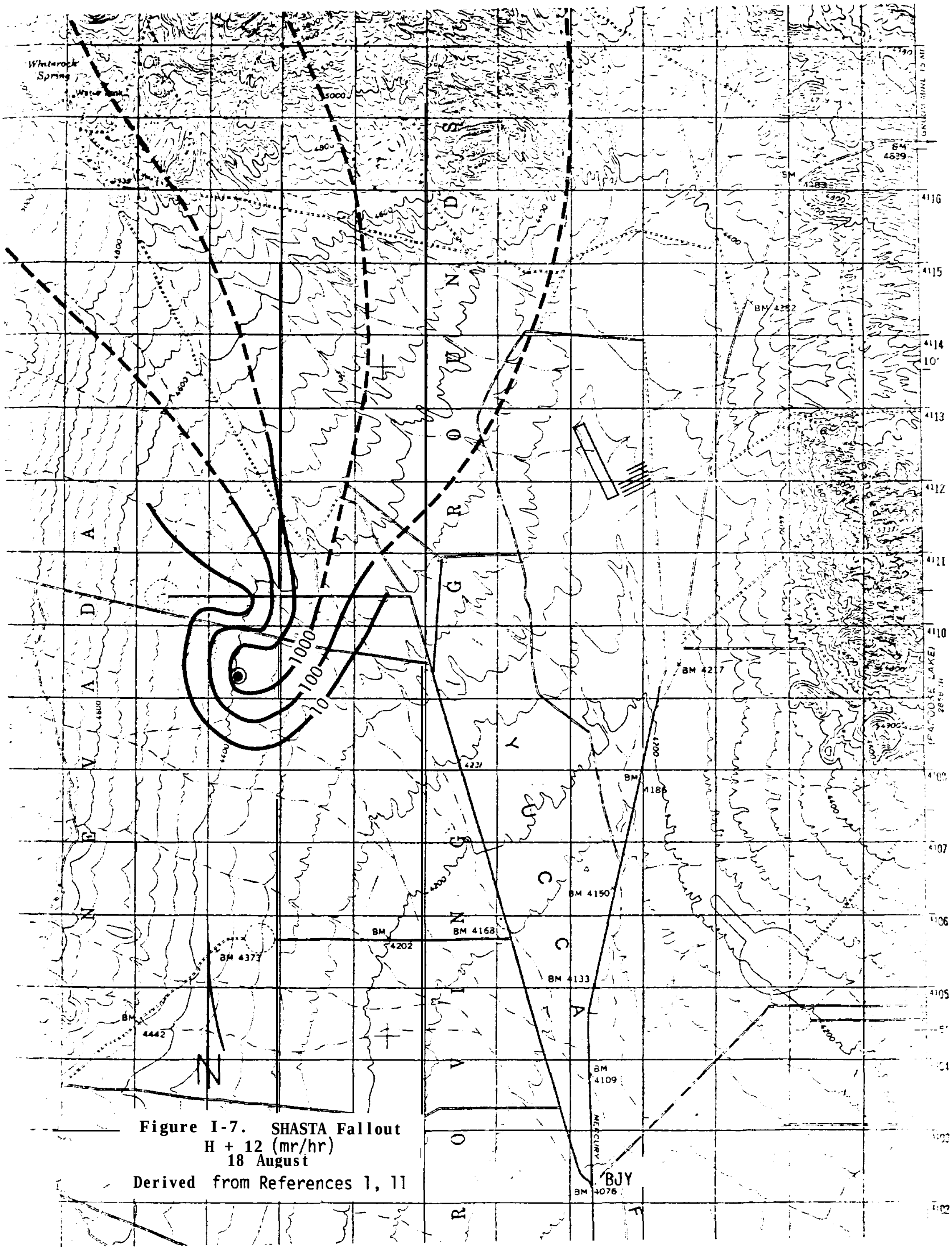

Figure I-7. SHASTA Fallout
H + 12 (mr/hr)
18 August

Derived from References 1, 11

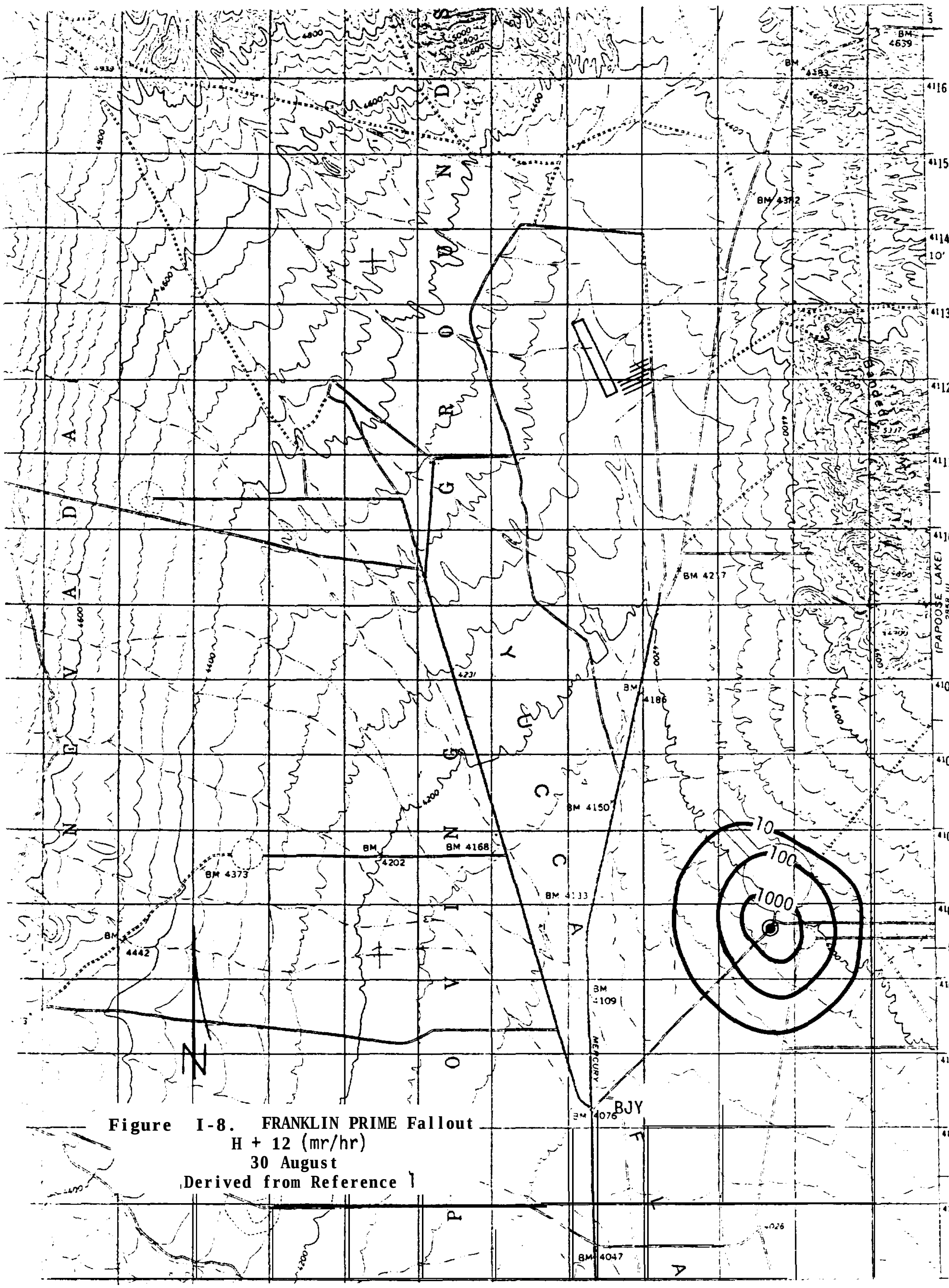

Figure I-8. FRANKLIN PRIME Fallout
H + 12 (mr/hr)
30 August
Derived from Reference 1

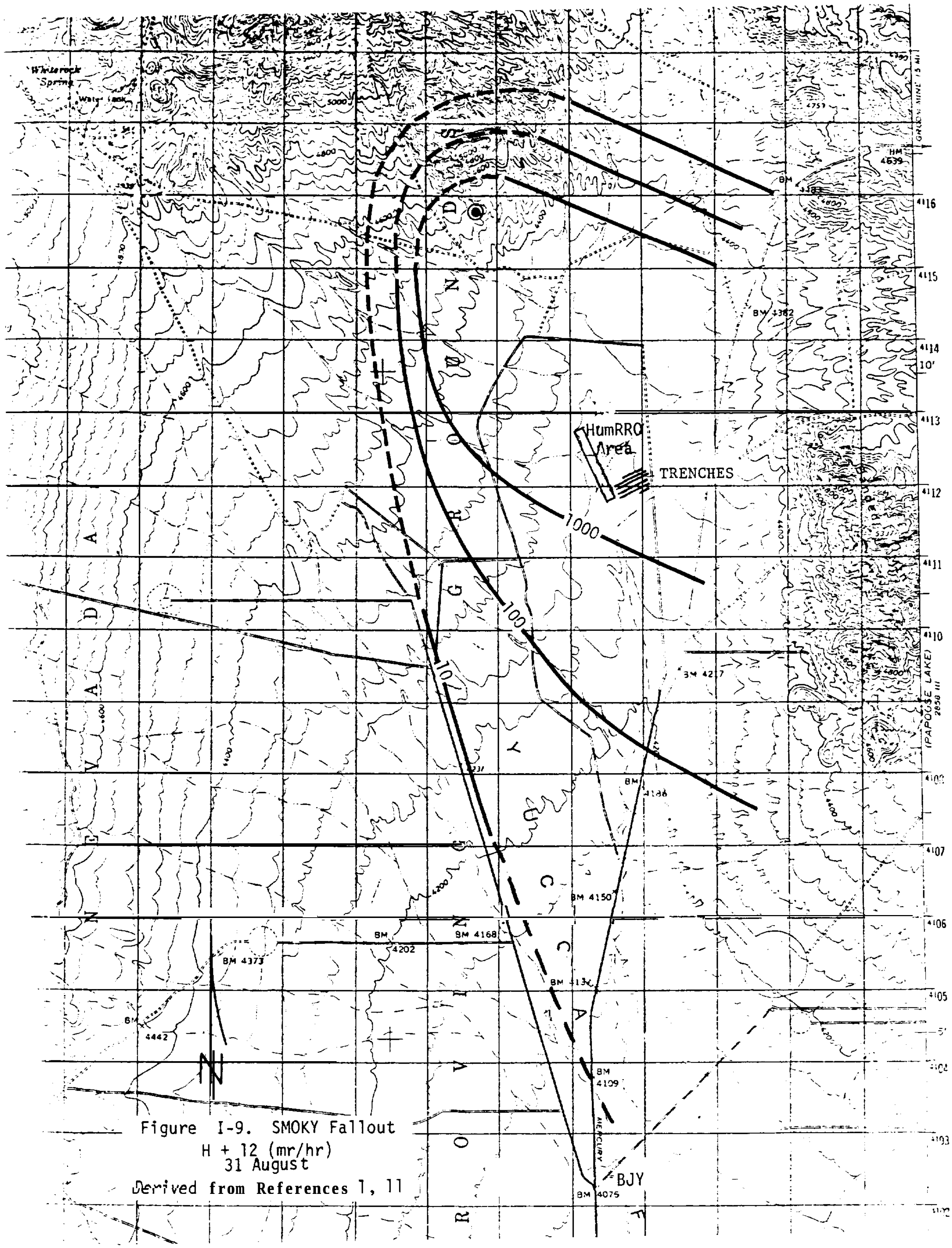

Figure I-9. SMOKY Fallout
H + 12 (mr/hr)
31 August
Derived from References 1, 11

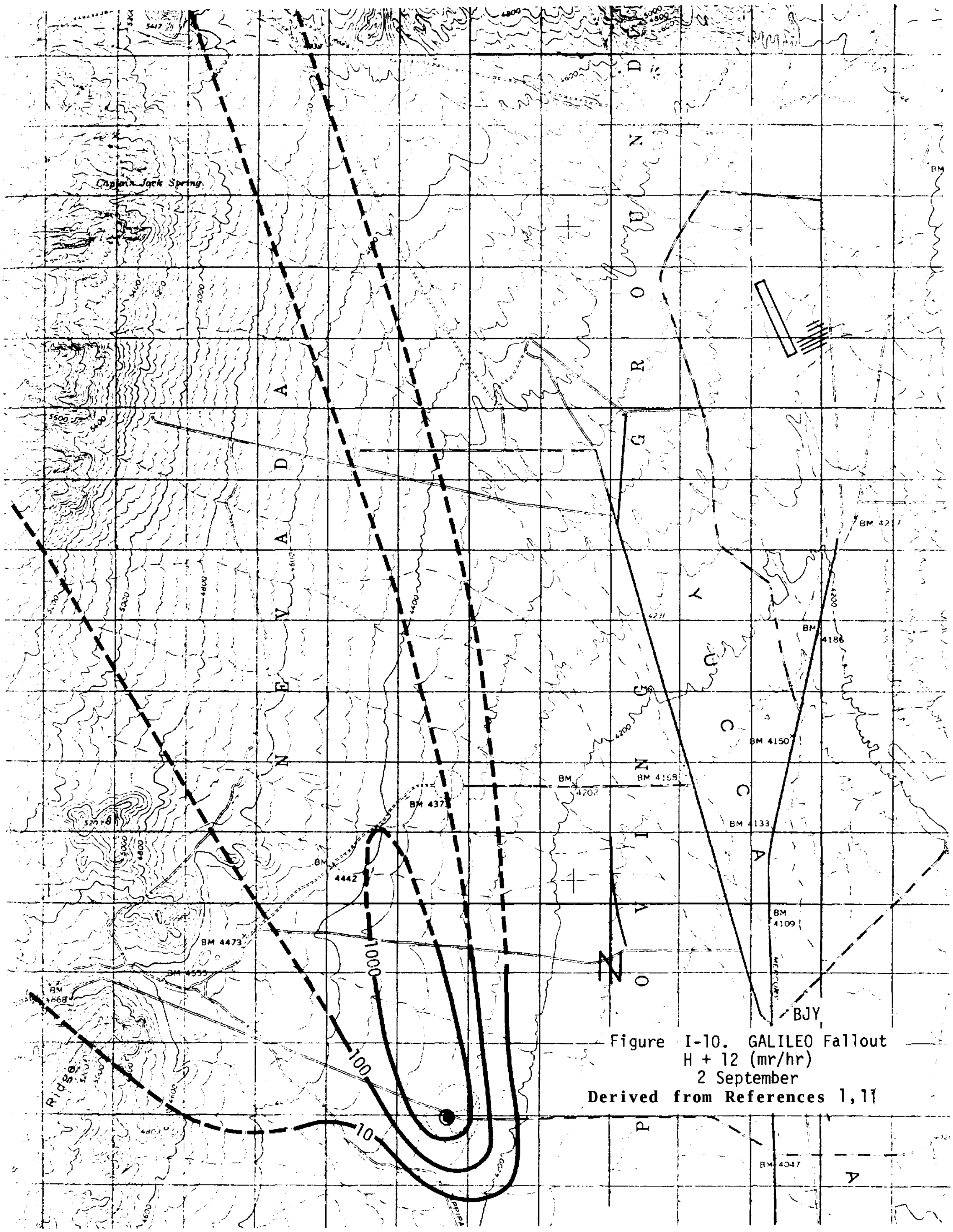

Figure I-10. GALILEO Fallout
H + 12 (mr/hr)
2 September
Derived from References 1,11

APPENDIX II

FALLOUT DECAY

(Except for the additional decay factors through the GALILEO shot date, this appendix is taken from Reference 5 and is included here for reader convenience.)

The decay of fallout contamination was examined in detail for two specific reasons. First the rate was used to normalize all survey data to H+12. From these reduced data, the fallout plots shown in Appendix I were constructed. Second, precise decay rates were needed to facilitate evaluation of the actual intensity of each fallout field at various times after the shot when troop units were operating therein.

Several decay curves were examined, particularly the actual decay rates for specific shots as measured by Program 37 (Reference 11) whenever they were available. For the other shots where no decay data was available, the Plumbbob composite decay, as compiled by Program 37, was examined. It was noted that these decay rates vary considerably from the traditional $t^{-1.2}$ "rule". They also vary from the decay rate used in the DELFIC code (DoD Standard fallout model), which determines a composite decay from the decay of each fission product. While DELFIC agrees quite well with the $t^{-1.2}$ "rule", it does not consider the case of tower shots where substantial amounts of extraneous neutron-activated material, such as iron, are added to the radionuclide inventory. Also DELFIC does not consider fractionation, any one of several processes apart from radioactive decay which results in non-uniform composition of fallout material. For example, delayed fallout generally contains relatively more Sr^{90} and Cs^{137}, which have gaseous precursors, than does early fallout.

The actual decay rates were used for Shots BOLTZMANN, DIABLO, SHASTA, and SMOKY. These are shown in Tables II-1 through 11-4. For all other shots, the overall Plumbbob composite decay was used, as shown in Table 11-5.

TABLE II-1

BOLTZMANN FALLOUT DECAY

H+ (hours)	Decay Rate, x*
<2	Plumbbob Composite
2-3	-0.65
3-5	-0.89
5-8	-1.00
8-13	-1.33
13-900	Plumbbob Composite
900-1400	-1.17
1400-4000	-1.20

*as used in the expression, t^x

Source: Reference 11

Conversion of REECO Survey Data*to H+12

Survey	H+	Factor
Initial (0551)	0.927	.030
H+8 (1319)	8.4	622
D+1 (0648)	25.9	i.93
D+3 (0550)	72.9	4.46
D+7 (1352)	177	11.3

* Reference 1

TABLE II-2

DIABLO FALLOUT DECAY

H+ (hours)	Decay Rate, x*
1-2	Plumbbob Composite
2-5	-1.30
5-6	-1.71
6-15	-1.13
15-25	-0.50
25-30	-2.38
30-80	Plumbbob Composite
80-180	-1.06
180-300	-1.84
300-400	-1.64
400-600	-1.33
600-2300	-1.21

*as used in the expression, t^x

Source: Reference 11

Conversion of REECO Survey Data* to H+12

Survey	H+	Factor
Initial (0551)	1.35	,043
H+7 (1118)	6.8	.526
D+1 (0645)	26.25	1.87
D+2 (0652)	50.4	3.74
D+3 (0642)	74.2	5.45
D+4 (0755)	99.4	7.33

* Reference 1

TABLE II-3

SHASTA FALLOUT DECAY

H+(hours)	Decay Rate, x*
<3	Plumbbob Composite
3-5	-1.21
5-8	-0.92
8-10	-0.65
10-70	-0.76
70-180	-1.21
180-400	-1.67
400-1500	-1.28
1500-3000	-1.19

*as used in the expression, t^x

Source: Reference 11

Conversion of REECO Survey Data* to H+12

Survey	H+	Factor
Initial (0740)	2.7	0.21
H+6 (1124)	6.4	0.61
D+1 (0729)	26.5	1.83
D+2 (0650)	49.8	2.95
D+3 (3625)	73.4	4.05

* Reference 1

TABLE II-4

SMOKY FALLOUT DECAY

H+ (hours)	Decay Rate, x*
6-8	-1.34
8-19	-0.74
19-42	-0.83
42-85	-0.95
85-650	Plumbbob Composite**
650-800	-2.39
800-900	-1.23
900-1400	-1.00
1400-3000	-1.17

*as used in the expression, t^x

**The reference does not portray Plumbbob Composite decay in this interval.

Source: Reference 11

Conversion of REECO Survey Data* to H+12

Survey	H+	Factor
H+8 (1309)	7.65	.698
D+1 (0628)	24.97	1.76
D+3 (1415)	80.75	5.02
D+5 (1318)	127.8	8.95

* Reference 1

TABLE II-5

PLUMBBOB COMPOSITE FALLOUT DECAY

H+ (hours)	Decay Rate, x*
<2	-2.18
2-3	-0.70
3-6	-1.30
6-14	-1.03
14-50	-0.78
50-100	-0.90
100-180	-1.20
180-400	-1.58
400-600	-1.29
600-1600	-1.34
1600-3000	-1.45
3000-4000	-1.68
4000-5000	-1.76

*as used in the expression t^x

Source: Reference 11

Although the differences in decay rates are not significant for some time intervals, it should be noted that the actual decay rates are generally more consistent with each other than with $t^{-1.2}$. Figure II-1 is a plot of each specific decay for the shots named, together with the Plumbbob composite, compared with the traditional decay, all normalized to H+12 hours.

Thus, to find the intensity at a time H+t, given the intensity at time H+t_0, the following expression is used:

$$\frac{I_t}{I_{t_0}} = \left(\frac{t}{t_0}\right)^x$$

where x is the slope of the decay curve, obtained from Tables II-1 through 11-5, for successive time intervals. In this manner, all radiological survey data were normalized to H+12 hours to aid in deriving the fallout plots shown in Appendix I. The iso-intensity contours so reconstructed were then used for all subsequent analyses of personnel exposures. The analyses required that the actual fallout intensities be determined at various times after each shot for specific troop locations. Table II-6 shows the factors used in the analyses. These factors were derived from the above expression to aid in converting H+12 intensities to any subsequent time. For precise conversions, particularly within one or two days after a given event, the above expression should be used.

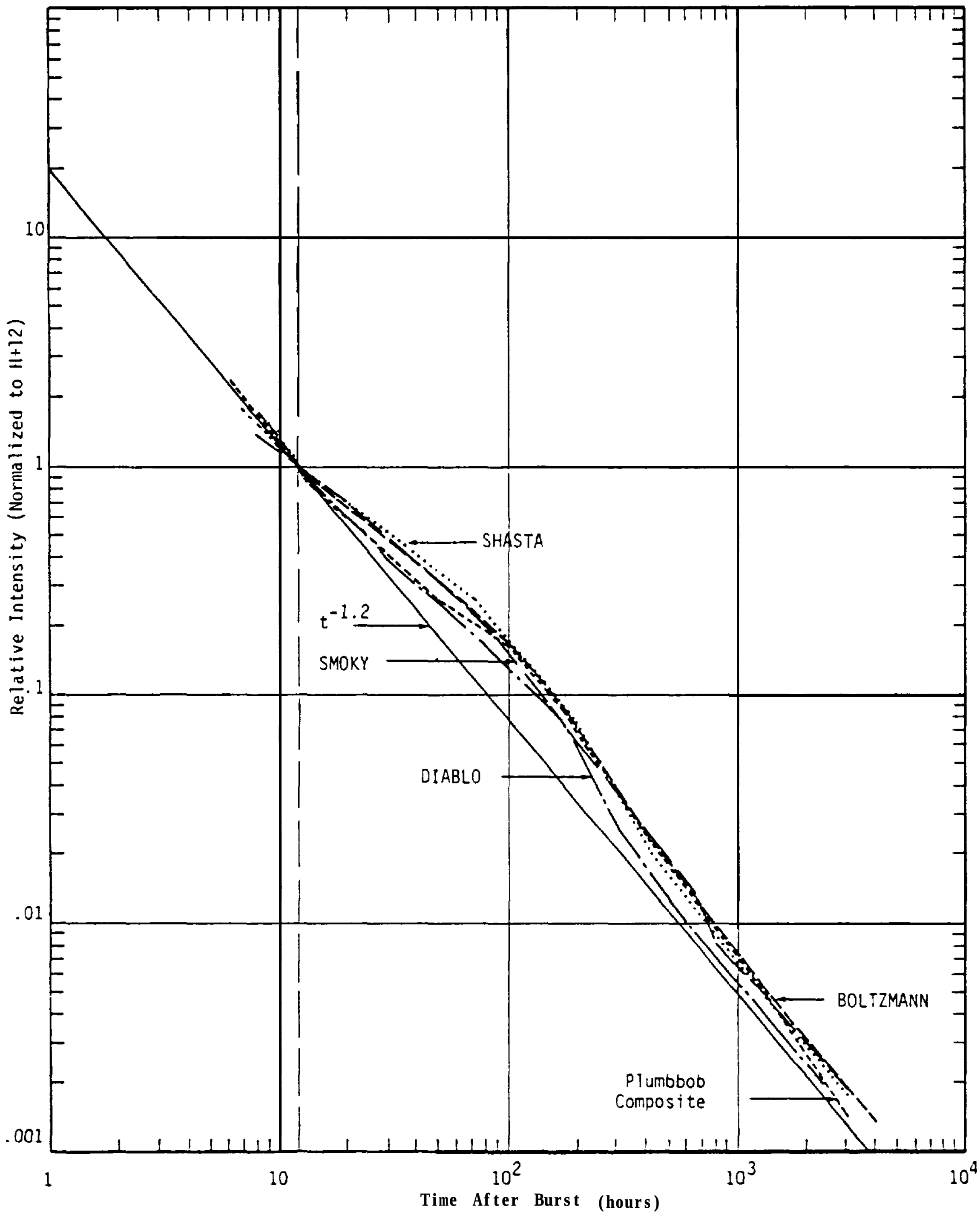

Figure II-1. Fallout Decay Comparison

TABLE II-6

FACTORS TO COHVERT H+12 INTENSITIES TO INTENSITIES ON SPECIFIC DATES

Date →	JULY									AUGUST															SEPTEMBER	
Shot ↓	15	17	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3
BOLTZMANN	.006	.006	.005	.005	.005	.005	.005	.004	.004	.004	.004	.004	.004	.004	.004	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003
FRANKLIN	.007	.006	.006	.006	.005	.005	.005	.005	.004	.004	,004	.004	.004	.004	.003	.003	,003	.003	.003	.003	.003	.003	.003	.002	.002	.002
WILSON	.012	.011	.010	.009	.009	.008	.008	.007	,007	.006	.006	.006	.005	.005	.005	.005	.004	.004	.004	.004	.004	.004	.003	.003	.003	.003
DIABLO	1	.22	.12	.084	.058	.039	.028	.022	.018	.015	.013	.012	.011	.010	.009	.008	.008	.007	.007	.006	.006	.005	.005	.005	.005	.004
KEPLER						.41	.20	.12	.084	.058	.043	.033	.027	.022	019	.017	.015	.014	.012	.011	.010	.009	.009	.008	.008	.007
PASCAL "A"							.41	.20	.12	.084	.058	.043	.033	.027	.022	.019	.017	.015	.014	.012	.011	.010	.009	.009	.008	.008
SHASTA																		1	.29	.15	.10	.068	.048	.036	.028	.022
FRANKLIN PRIME																								1	.27	.15
SMOKY																									.42	.19
GALILEO																										.41

NOTE: Dates shown are based on 24-hour increments after H+12. For more precise conversions. use the method described in the text.

APPENDIX III

GAMMA INTENSITY CALCULATIONS FOR THE SMOKY FALLOUT FIELD

Because the HumRRO exercise was conducted near the hotline of the SMOKY fallout field, the log-quadratic model introduced in Appendix I, $\log I = ax^2 + bx + c$, was used for dose reconstructions. As this model introduces some complications in the analysis, it is discussed here separately.

All gamma survey data for the SMOKY fallout field could have been fit to the log-quadratic (Gaussian) model; however, a few trials showed that this model implied iso-intensity contours very nearly the same as for the log-linear model. Simultaneous fitting of data on both sides of the hotline was not generally possible. Consequently, the SMOKY contours (Figure I-9), derived through the log-linear model, have been used as a basis for interpolating with the log-quadratic model.

The log-quadratic model was applied by fitting a normal to the hotline through the location to be exposure-analyzed and utilizing its intersections with the 100 and 1000 mr/hr contours on either side of the hotline. These four intersections were used to determine a least squares fit (with one degree'of freedom) to the model. From fits so obtained, H+12 intensities at the infiltration course and parking area were determined as 6100 mr/hr and 2200 mr/hr, respectively. Log-linear interpolation was used to determine the intensity along the path from the tracks to the infiltration course. This was justified because the march was more parallel to than normal to the hotline, and was done in lieu of calculating a dense set of log-quadratic fits to provide intensities all along the marching path. The average intensity between the parking area and the infiltration course was determined from

$$\bar{I} = \frac{I_2 - I_1}{\ln(I_2/I_1)}$$

yielding 3800 mr/hr. With the assumption of a constant-velocity march, this value was used directly in dose computations.

Error analysis of these intensities concerned the choice of model and the interpolation associated with a quadratic fit. While a quantitative error estimate cannot be obtained concerning the choice of model, it was instructive to compare with the results of a more sophisticated model. A curve of Gaussian form was a simple expedient for crossing a hotline, but it had one disturbing feature for use on the SMOKY fallout field: the contour lines on the north of the hotline were more closely spaced than those on the south, to such a degree that uncertainty in contour position was too small to account for the difference in spacing. The Gaussian fit forced equal spacing on either side of the hotline. A function was sought which would accomodate the skew in the contour lines. Many such functions exist, but most have the undesirable property of having a zero at a finite position. One that does not is of the form:

$$I(x) = \frac{ce^{a(x-b)^2}}{1 + e^{d(x-b)}}$$

With four parameters, this expression exactly fits the four intersections of the 100 and 1000 mr/hr lines. Although the implied hotline intensities for the two models are quite different, (7600 mr/hr for the Gaussian, 13900 mr/hr for the skewed Gaussian), agreement of the two forms is good for the intensities at the parking area and at the infiltration course. On this basis the Gaussian model appears adequate for the required intensity estimates at and between the areas of concern.

Error estimation of the interpolation with a Gaussian was expedited by using the fallout plot uncertainties as a base. The error factor of 1.46 obtained for fallout plots in Appendix I is strictly applicable only to the lines along which data was analyzed and at the mid-data location along a line. The points used for the Gaussian fit satisfied both criteria fairly well. For the quadratic fit, the standard error of the model cannot be well characterized by a single value that is good over a wide range of data. Owing to the lack of data near the hotline, intensities in its vicinity were predicted with less precision than those near the 100 and 1000 mr/hr points (of coordinates denoted below as x_1 through x4). Even at these points, the standard error was not identical. The standard error at any coordinate, x, of the quadratic fit was found through the following expression:.

$$\text{s.e.}(\log I(x)) = \sigma[B^T(AA^T)^{-1}B]^{1/2}$$

where matrix $A = \begin{pmatrix} 1 & 1 & 1 & 1 \\ x_1 & x_2 & x_3 & x_4 \\ x_1^2 & x_2^2 & x_3^2 & x_4^2 \end{pmatrix}$ and matrix $B = \begin{pmatrix} 1 \\ x \\ x^2 \end{pmatrix}$

The standard error of log I at the infiltration course was 1.64 times the root-mean-square average of the standard errors at x_1 through x_4. The standard error of the fallout plot alone, multiplied by this factor, gave the standard error inclusive of interpolation to the infiltration course*. Expanding to 90 percent confidence limits and examining I rather than log I, the combined error factor at the infiltration course was:

error factor (plot + interpolation) = anti log (1.64 . log 1.46) = 1.86.

The rule for relating error factors (Reference 5) was used to determine that the error factor for interpolation alone was (coincidentally) 1.64. With similar analysis, the interpolative error factor at the parking area was found to be 1.35.

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* The average standard error for points x_1 through x4 was not the same as implied by the error factor for fallout plots mainly because few points were explicitly used in determining the Gaussian, as compared to the many determining the contours; in essence, a pre-determined standard deviation existed for the Gaussian. Hence, the combined standard error was normalized to that of the fallout plot alone.

APPENDIX IV

GROUND CONCENTRATION OF RADIOACTIVITY IN THE HUMRRO AREA

Plumbbob shots BOLTZMANN, DIABLO, SHASTA, and SMOKY deposited fallout in the HumRRO site prior to one or more of the exercises held there. Ground contamination was measured at neither the time nor the position of HumRRO activities. The beta/gamma surface activity may be related, however, to the gamma intensities determined for locations of interest in Section 4.1. This relationship varies with the time-dependent energy spectrum of fission-product emissions.

The ORIGEN isotope generation and depletion code (Reference 27), as supplemented by Reference 29, is applied to all fissionable materials in each weapon to determine the radioisotopes produced by the burst. By following the decay modes of all radioisotopes present, the code calculates the inventory of fission products and actinides following the burst. The spectra for all isotopes, weighted to account for emission modes, are combined to form a single gamma emission spectrum for each time of interest. The ANISN radiation transport code (Reference 12) is used to calculate the attenuation and scattering of photons from a uniform, plane fallout field. The photon incidence on a receptor at the standard one-meter survey height is then translated into a gamma intensity in mr/hr.

The procedure for determining the beta surface activity (Ci/m^2) from the one-meter gamma intensity for any position at time t is summarized as follows:

1. Use ORIGEN to:
   a. compute the abundance of all radioisotopes at time t.
   b. identify the decay rate and the gamma energy and probability for all emission modes, for each radioisotope.

c. determine the overall gamma energy spectrum from a and b.

d. determine the disintegrations per unit time of each radioisotope, and sum to find the total Curies.

2. Assume the total activity is uniformly distributed on a large planar surface; this gives a surface activity in Ci/m^2.

3. Use ANISN to:

   a. calculate the spectrum at one meter above the surface from the spectrum of surface emissions.

   b. determine the gamma intensity (mr/hr) from the spectrum at one meter.

4. The ratio thus found of Ci/m^2 to mr/hr is applicable to gamma survey readings of any intensity taken at time t.

Surface activities, presented in Table IV-1, are calculated from 49 beta/gamma-emitting fission products for which dose factors (discussed in Section 4.3) were reported in Reference 22. From ORIGEN it is determined that these 49 radionuclides represented 98.4 percent of the beta/gamma activity from SMOKY fallout at H+51 hours and a greater percentage from older fallout. This suggests that all radionuclides contributing significantly to a 50-year dose are incorporated in the analysis.

In radiochemical analyses of fallout it is often found that the mix of isotopes varies with location. A different fraction of a given isotope may be found in close-in fallout as compared to that deposited farther away. In the ORIGEN calculations, radioisotopes of the inert gases are eliminated from consideration, but other evidence of fractionation is found when the calculations are compared with measured data. Ruthenium and strontium abundances are overpredicted by several hundred percent in comparison with the data of Larson (Reference 11). Agreement of other calculated and measured radioisotope abundances is generally within 25 percent. Consequently, calculated abundances are used for all radioisotopes with the exception of ruthenium and strontium, which are normalized to the measurements for shot SMOKY. A comparison of Larson's data and calculated values is displayed in Table IV-2.

TABLE IV-1

SURFACE CONCENTRATIONS OF BETA/GAMMA EMITTERS FOR THE HUMRRO REHEARSALS AND TEST

Shot	(μCi/m^2)/(mr/hr)	mr/hr	μCi/m^2
		23 August	
BOLTZMANN	184	0.9	166
DIABLO	178	0.12	21
SHASTA	122	2.6	317
		26 August	
BOLTZMANN	184	0.9	166
DIABLO	179	0.1	18
SHASTA	117	1.36	159
		2 September	
BOLTZMANN	185	0.9	167
DIABLO	179	0.1	18
SHASTA	127	0.5	64
SMOKY	140	660*	92400
		1830**	256000
		1140***	160000
		103****	14000

* At parking area
** At infiltration course
*** Average during march
**** Average during truck transit in contaminated area

TABLE IV-2

MEASURED AND CALCULATED PERCENT OF BETA ACTIVITY FOR SELECTED NUCLIDES AT H + 720 HOURS

Shot	Ba-140	Ce-141+Ce/Pr-144	Cs-136.137	Ru-103.106*	Sr-89.90*	Y-91	Zr-95
SMOKY	(4.6 mi from GZ, 4.7 mi S. of midline)						
measured	10.4	20.7	NS**	1.39	1.3	9.7	7.78
calculated	12.0	17.0	0.1	1.39	1.3	8.7	9.1
SHASTA	(15 mi from GZ, 1.3 mi W. of midline)						
measured			NS	1.48	1.36	9.7	8.10
calculated	12.[illegible]	1[illegible].[illegible]	0.2	1.44	1.32	7.2	8.6
DIABLO	(16 mi from GZ, 6.7 mi E. of midline)						
measured	13.3	15.8	0.15	1.8	1.58	10.3	9.3
calculated	12.0	14.8	0.20	1.48	1.36	7.3	8.6
BOLTZMANN	(36 mi from GZ, 0.0 mi from midline)						
measured	14.6	18.5	0.20	5.5	1.75	9.6	9.3
calculated	12.0	14.9	0.21	1.48	1.36	7.1	8.5

* Calculation normalized to SMOKY measurements

** Not Significant

A second source of uncertainty involves the distribution of surface activity with depth. The presence of activity in the top layer of ground rather than precisely on the surface reduces the measured mr/hr for a given Ci/m^2. ANISN is used with both a true surface source and a uniform distribution to a depth of 1 cm. The latter results in a $(Ci/m^2)/(mr/hr)$ ratio almost 50 percent greater than the former. Because this depth distribution (a simulation of the effect of surface irregularities as well as the settling of fallout into the ground) results in better agreement between theoretical and measured fallout gamma intensities, it is used in the derivation of Table IV-1.

Proper comparison with Larson's experimental ratios is difficult because they were determined at unreported times and improperly normalized to a common time base. They are in general agreement with computed values, however. Larson's data for shot SMOKY were in the range of 94 to 152 (@i/m*)/(mr/hr). These are consistent with other ratios for tower shots cited in weapons test reports.

Alpha Activity Surface Concentration

The predominant source of alpha activity from the four shots of interest in assessing HumRRO ground contamination was the unreacted weapon material. Secondary contributions came from reaction products in the devices. The amounts and types of alpha emitters considered for each shot are determined based on the yield fractions from each weapon component. The ORIGEN code is used to determine the quantity of each radioisotope produced, the amount of weapon material consumed, and the quantity of unreacted material.

ORIGEN provides a ratio of alpha to beta/gamma activity which is invariant if it is assumed that the alpha emitters are uniformly distributed with the fission products. The alpha activity concentration on the ground is determined from this ratio and the surface beta/gamma activity. The results of this computation, performed for all shots and all post-shot times of interest, are not presented because they contain classified information concerning the make-up of each device.

Ground Contamination From Tower Activation Products

To complete the assessment of potential internal exposure, isotopes produced by neutron activation of cab and tower materials must be considered. Because only limited measurements were made of the isotopic composition of SMOKY fallout, the activation contribution from experiments conducted in conjunction with other tower shots is used. For some tower shots in Operation Upshot-Knothole, measurements were made of the ratios of atoms per fission of various activation products. Because the samples were obtained at long distances from the test site, it is necessary to assume these ratios are independent of particle size (i.e., no fractionation).

To correlate the atoms-per-fission data and infer similar ratios for SMOKY, the amount of structural material involved must be compared. The tower weight and height, as well as the cab weight, are available for SMOKY and some Upshot-Knothole shots. The length of tower vaporized or melted is deduced through cube root yield scaling of data from shot FIZEAU (Plumbbob). It is thus determined that the weights of vaporized material for shots NANCY and SIMON were similar to that for SMOKY. Atoms-per-fission ratios, similar for these two shots, are used for SMOKY.

The number of atoms (N_0) produced of any radioisotope (with decay constant A) is the total number of fissions multiplied by the atoms per fission for that isotope. Activity (A) at any time (t) is found through the expression:

$$A\ (Ci) = \frac{1\ Ci}{3.7 \times 10^{10}\ \frac{dis}{sec}}\ N_0\ \lambda(sec^{-1})\ e^{-\lambda t}$$

The proportionality between this activity and the total beta activity is applied to ground concentrations as well. Of the radioisotopes measured in the Upshot-Knothole analyses, those that would contribute the most to the 50-year bone dose of BIG BANG participants are Fe^{55}, Fe^{59}, Co^{58}, and Co^{60}. The surface beta activity at the infiltration course at the time of the HumRRO exercise for these isotopes is shown below:

Isotope	Fe^{55}	Fe^{59}	Co^{58}	Co^{60}
Activity ($\mu Ci/m^2$)	1.3	4.5	1.9	0.3

These values are so much less than the fission product surface activity from SMOKY at the infiltration course (see Table IV-l) that a 50-year dose from tower activation products, even if extremes of biologic retention are considered, is not significant compared to that from fission products.