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SUMMARY STATEMENT OF FINDINGS RELATED TO THE DISTRIBUTION, CHARACTERISTICS, AND BIOLOGICAL AVAILABILITY OF FALLOUT DEBRIS ORIGINATING FROM TESTING PROGRAMS AT THE NEVADA TEST SITE

by

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LEGAL NOTICE

TABLE OF CONTENTS

ABSTRACT

Included in this report are summary statements of significant findings related to the distribution, characteristics, and biological availability of fallout debris originating from testing programs at the Nevada Test Site during the past decade.

The delineation of fallout patterns has been accomplished by the use of aerial and ground monitoring surveys. Only about 25 per cent of the total amount of fission products produced by tower supported detonations was deposited within distances corresponding to fallout time of H + 12 hrs; very much less was deposited by balloon-supported detonations. Fallout particles less than 44 microns in diameter are presumed to be of greatest biological significance. About 30 per cent of the fallout radioactivity from tower-supported detonations was contained in the 0 to 44 micron particles as compared to almost 70 per cent for balloon-supported detonations. Fallout debris from balloon-supported detonations was also much more water and acid soluble than was the debris from tower-supported detonations. The < 44 micron fallout particles contained a higher percentage of Sr89, 90 and Ru103, 106 than did larger sized particles, and there was a higher percentage of these radioelements in the particles from balloon-supported detonations. Within distances corresponding to H + 12 hours fallout time, balloon-supported detonations deposited a maximum of 0.13 per cent of the theoretical total Sr89 produced; tower-supported detonations deposited a maximum of 2 per cent. Tower-supported detonations also deposited a maximum of 7.2 per cent of the theoretical total amount of Sr90 produced. Beta decay curves approximated the $T^{-1.2}$ decay expression from H + 12 to H + 6000 hours; gamma decay curves deviated to the extent that irradiation doses calculated by the observed decay values were 1.5 to 2 times greater than those calculated by the $T^{-1.2}$ relationship.

Fallout radioactivity is apparently confined to the first 2 inches of the soil surface unless the surface had been mechanically disturbed. Most of the fallout debris that was redistributed by various environmental factors after original deposition consisted of particles less than 44 microns in diameter; the particles in this size range also represented the predominant contamination on plant foliage. Sr90 levels in surface soil ranged from 31.9 to 142 mc/sq. mile in virgin areas near known fallout pattern midlines and from 7.5 to 22.7 mc/sq. mile in agricultural areas which did not necessarily coincide with fallout pattern midlines. The accumulation of radioiodine by native animals was observed to be a function of distance from Ground Zero. Radiobarium-140, Y-91, Sr89 and Sr90 were major bone contaminants. Post-series sampling of native animals indicated that the accumulation of Sr89 was also a function of distance from the point of detonation; however, the Sr90 accumulation by animals correlated poorly with the strontium unit levels in soils. The strontium unit levels increased in milk immediately following contamination of the farm with fallout debris, and then decreased with time as well as the amount of Sr associated with the cattle's diet.

Observations during the past decade indicate that less than 10 per cent of the total Sr produced from nuclear detonations at Nevada Test Site has been deposited within 200 miles from the point of detonation.

SUMMARY STATEMENT OF FINDINGS RELATED TO THE DISTRIBUTION, CHARACTERISTICS, AND BIOLOGICAL AVAILABILITY OF FALLOUT DEBRIS ORIGINATING FROM TESTING PROGRAMS AT THE NEVADA TEST SITE (*)

INTRODUCTION

During the past decade the Environmental Radiation Division has been involved in progressively intensified programs designed to answer one principal question, viz., "How much man-made radioactivity distributed in the environment can be tolerated safely by man and his economy?"

The more specific objectives of our effort within this broad context include:

(a) Delineation of fallout patterns and their characteristics with respect to particle size in order to define the mechanics of fallout more accurately. This, in turn, leads to a comparison of the effects of the yield of the detonated device, the type of device support, and the geometric relation between the detonation and ground surface on the resultant fallout debris deposited within the fallout pattern.

(b) A detailed study of the chemical, physical and radiological characteristics of fallout debris relative to its particle size and occurrence within the fallout pattern.

(c) Determination of the biological availability, rate of accumulation, and retention of the fallout debris for various native and domestic plants and animals, as well as the persistence and redistribution of residual contamination in the total environment.

FALLOUT PHENOMENOLOGY AND ITS CHARACTERISTICS

Fallout from test devices detonated at Nevada Test Site is governed by many complex variables such as: (a) energy yield, (b) wind structure, (c) support used for the detonation of devices, (d) nature of ground surface, (e) degree of fireball intersect with ground surface, (f) mass of inert material surrounding the device. Data presenting the resultant deposition and characteristics of fallout from various detonations studied by this laboratory are summarized in the following statements.

(*) Presented as testimony during the Hearings on "Biological and Environmental Effects of Nuclear War" before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, Congress of the United States; June 22-26, 1959.

1. <u>Characteristics of Fallout Patterns</u>: The coordination of aerial survey measurements of fallout patterns with ground survey meter measurements has greatly increased the detail and accuracy of fallout pattern delineation as well as the distances to which fallout patterns can be extended from the point of detonation.

By use of aerial survey equipment and techniques as developed by the U. S. Geological Survey, fallout radiation intensities within an area of approximately 10,000 square miles were measured in about 12 hours by one aircraft. Aerial measurements agreed within ± 10 per cent of measurements taken 3 feet above the ground by conventional survey meters. During the Plumbbob Test Series, (1957) fallout patterns were routinely measured to distances of 200 to 300 miles from Ground Zero; however, one fallout pattern from a tower-supported detonation was documented as far as 700 miles from the Nevada Test Site with the radiation levels readily detectable at that distance (Figs. 1, 2, and 3) (1).

The detailed documentation of fallout patterns during the Plumbbob Series (1957) afforded the opportunity to confirm the existence of "hot spots" in most fallout patterns. "Hot spots" were first identified in 1948 when the fallout pattern of the Trinity detonation New Mexico had been outlined in detail (2).

It is the opinion of the authors that terrain features such as mountain ridges create a significant turbulence in the radioactive dust cloud as it moves over the ridge causing an increased amount of fallout to occur on the leeward side. Examples of this are illustrated in the patterns of Shot Diablo (Fig. 1) and Shot Smoky (Fig. 2) of the Plumbbob Series. Rainouts have also been reported to be responsible for "hot spots" within 300 miles of Nevada Test Site; however, the documented "hot spots" referred to by this Laboratory occurred in areas in which no precipitation occurred during fallout.

While the occurrence of "hot spots" has been associated with prominent terrain features in many cases, data are insufficient to fully explain their mechanism of formation and to permit their prediction. Nevertheless, the radiation intensity contours of fallout patterns in general have been quite accurately predicted as illustrated by the

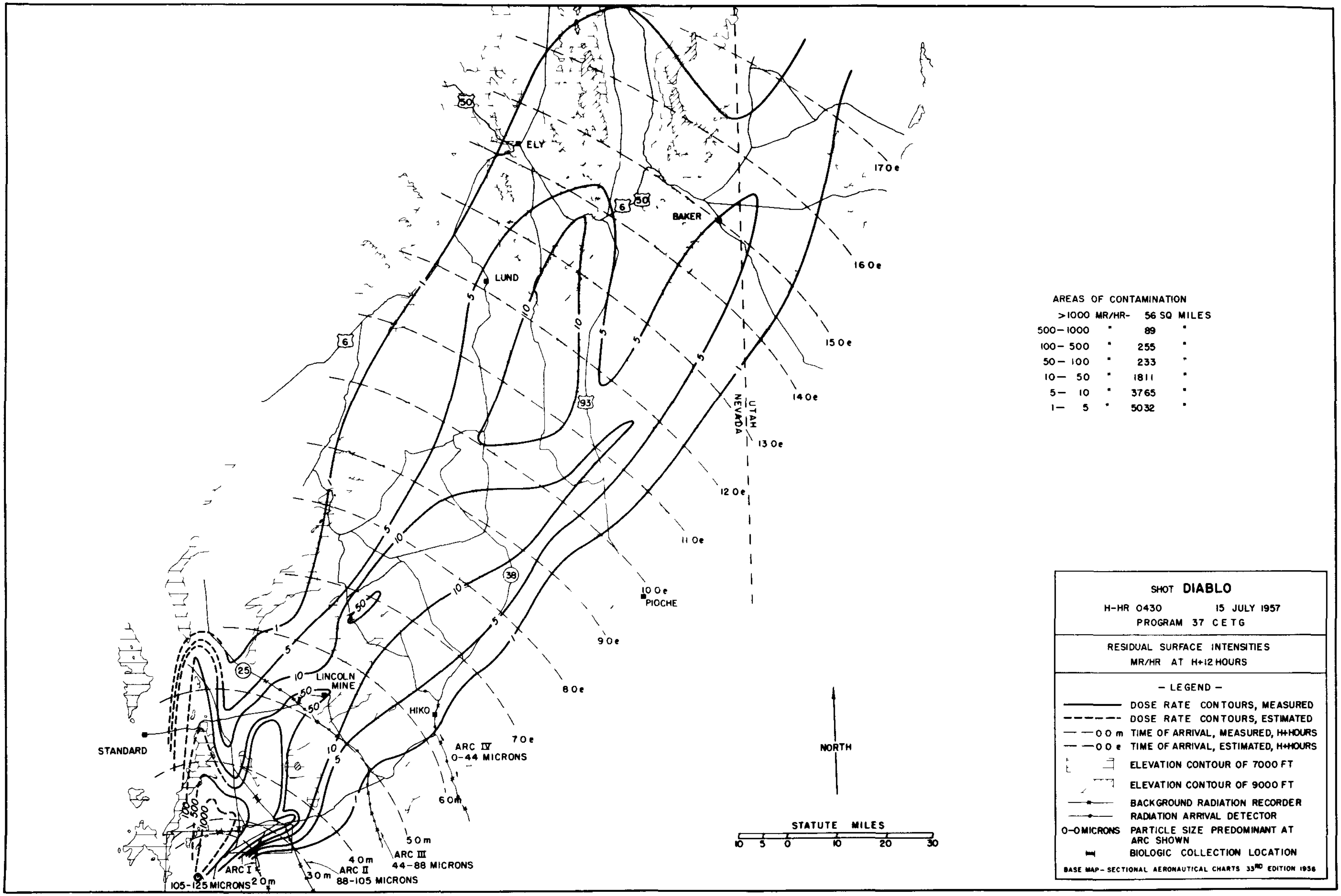
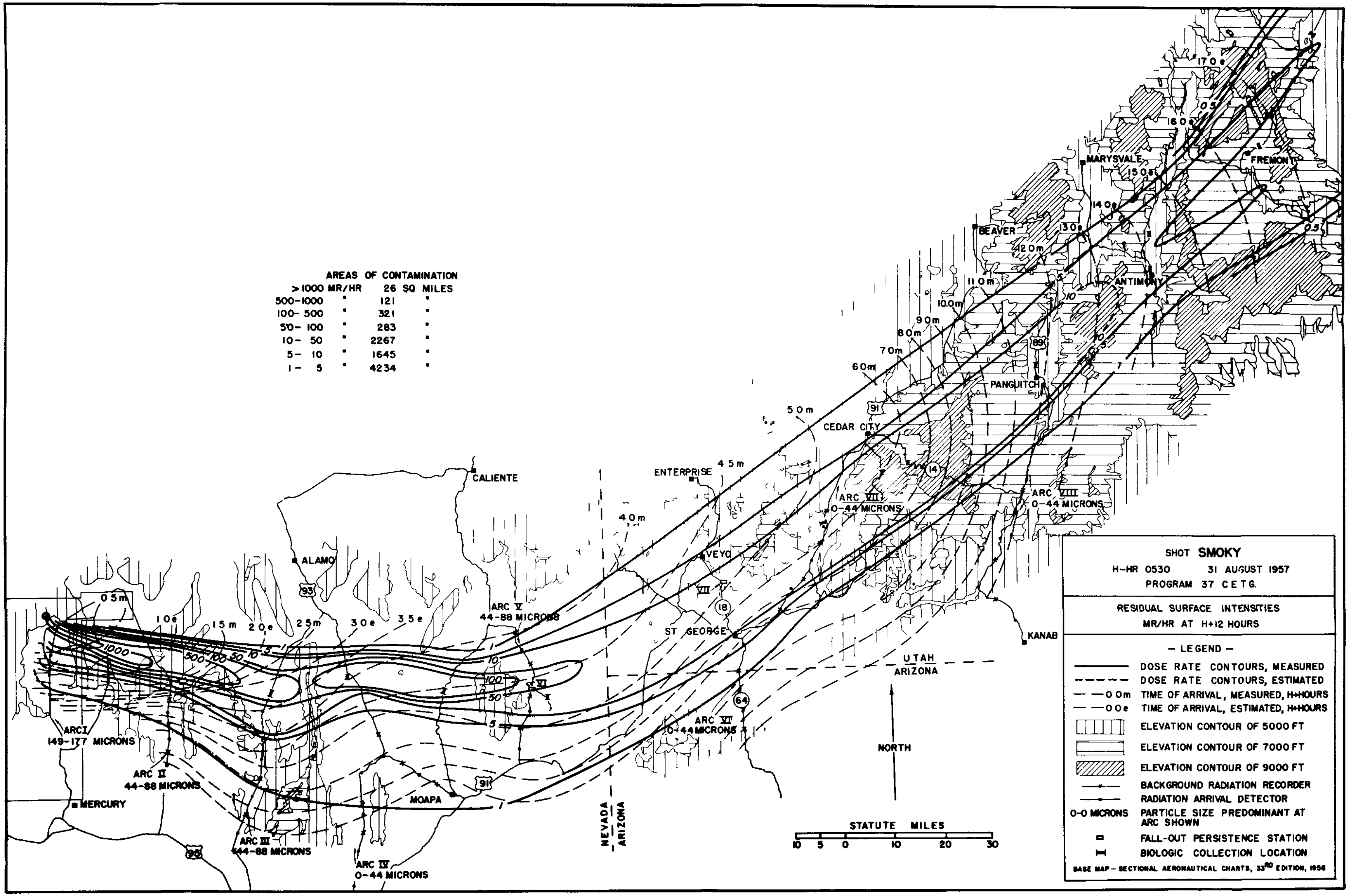


FIG I SHOT DIABLO FALLOUT PATTERN

FIG. 2 SHOT SMOKY DETAILED FALLOUT PATTERN



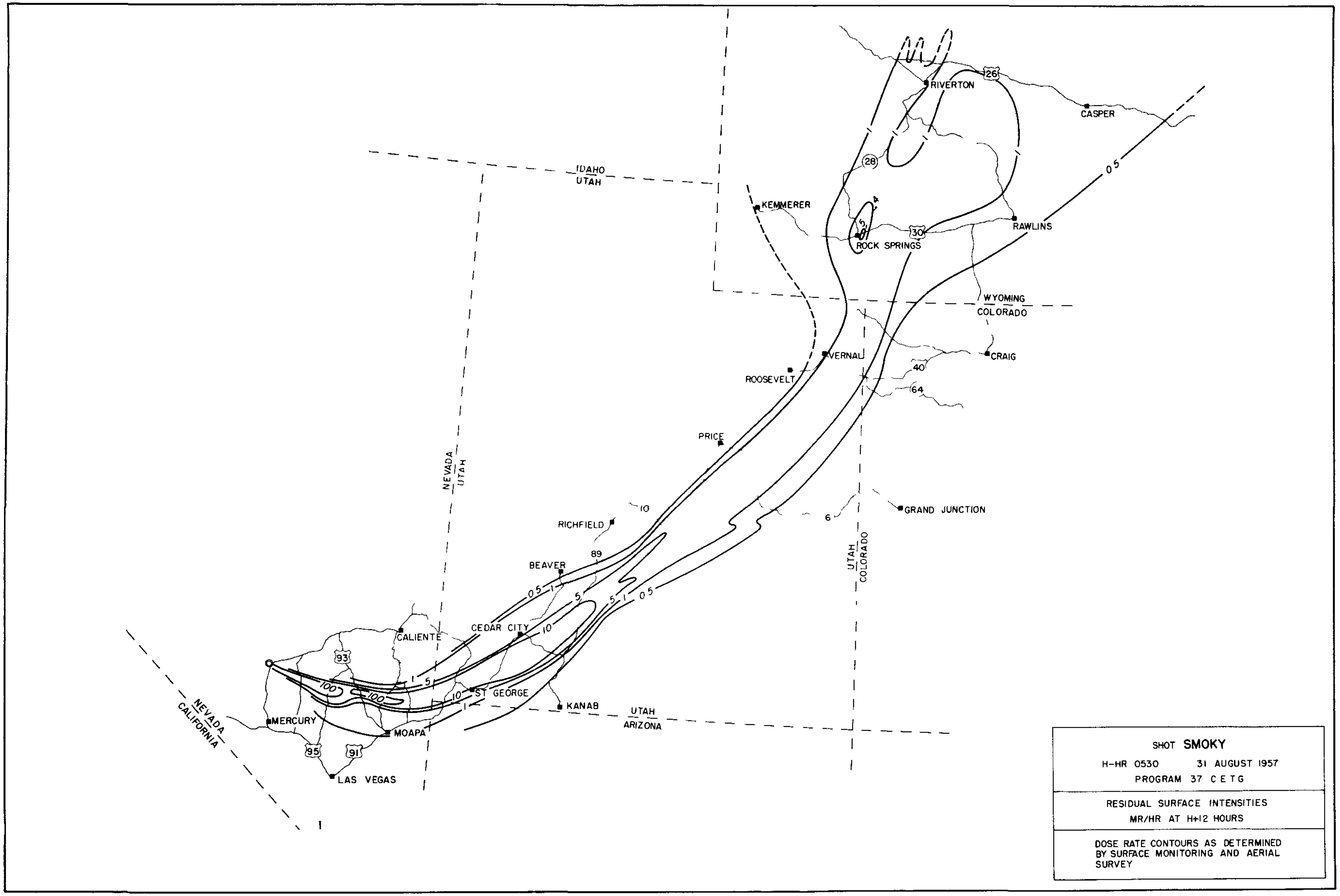


FIG. 3 SHOT SMOKY EXTENDED FALLOUT PATTERN

Weather Bureau prediction and the measured pattern of Shot Smoky (Fig. 4). It should be noted that quite radical deviations from "idealized" fallout patterns may result from local meteorological conditions; the pattern of Plumbbob Series Shot Wilson (Fig. 5) illustrates the effect of widely divergent wind directions of different air strata at the time of detonation.

2. 'Local' Fallout Rainout Intensity Levels: Fallout from aerial bursts has not been detectable by conventional ground survey methods within 200 miles of Ground Zero (3). Two test devices detonated from balloons at 1500 feet without the fireball intersecting the ground surface deposited less than 0.2 per cent of the theoretical fallout radioactivity[1]. The area measured is defined in this case by the 0.1 mr/hr radiation intensity contour (at H + 12 hrs) between the distance of 1 mile from Ground Zero and the distance corresponding to a fallout time of H + 12 hrs. To illustrate the effect of the intersection of fireball, a balloon-supported shot which did intersect the ground surface deposited 2.12 per cent of the theoretical fallout within the 1 mr/hr contour to H + 12 hr fallout time. However, fallout originating from test devices mounted on steel towers whose fireballs in some cases intersected the ground surface, and in other cases did not, deposited 6.7 to 24.5 per cent of the theoretical fallout radioactivity within the same area limits (1).

3. Particle Size Distribution in Fallout Patterns: The size of fallout particles decreased with greater distance from Ground Zero. Also, the size of fallout particles decreased with greater lateral distance from the line of maximum radiation intensity along a fallout pattern or "midline" of fallout (1, 3, 4). The relative amount of radioactivity associated with particle sizes less than 44 microns in diameter was increased by decreasing the mass of device support and cab materials; therefore, the amount of fallout occurring at greater distances from Ground Zero in this particle size range increased (1).

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[1] The theoretical fallout is calculated on the basis of 300 gamma megacuries at H + 1 hr per kt yield.

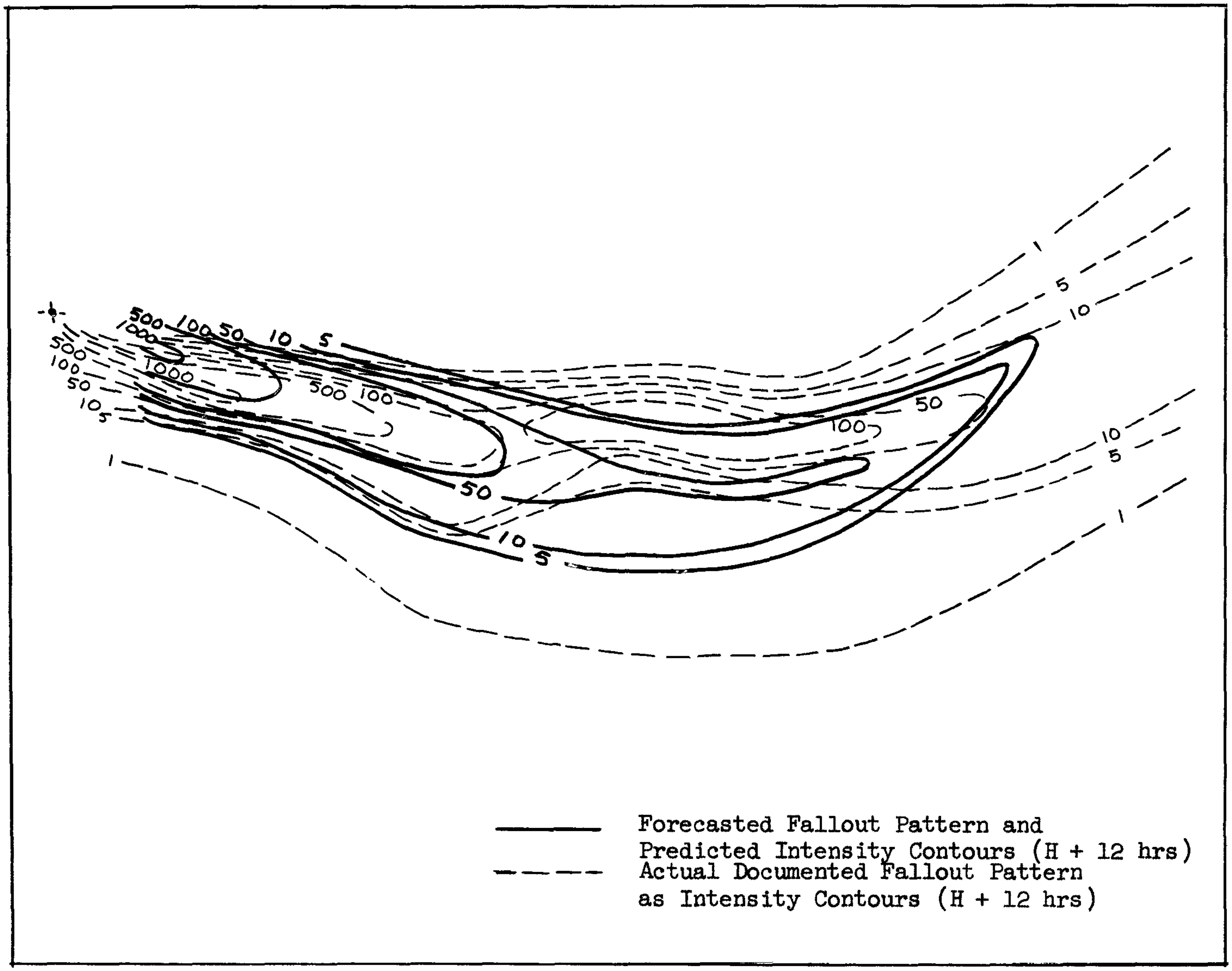


Fig. 4 COMPARISON OF FORECAST TO ACTUAL SHOT SMOKY FALLOUT PATTERNS

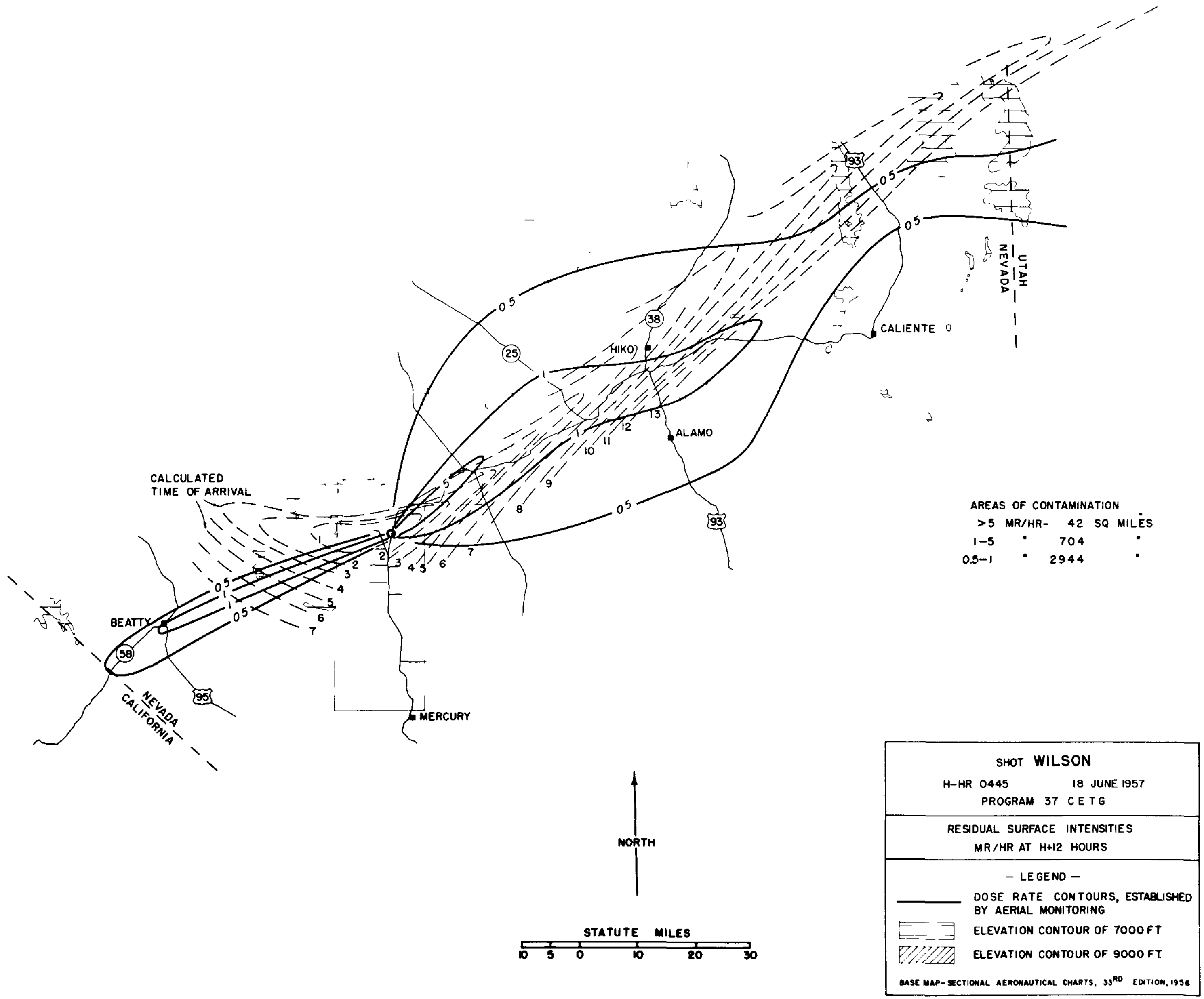


FIG 5 SHOT WILSON FALLOUT PATTERN

It was found that vegetation in the environs of Nevada Test Site during the Teapot Series (1955) retained predominately less than 44 micron fallout particles (5). Therefore, this size range has been emphasized in our recent studies.

Within the limits of 1 mile from Ground Zero out to a distance corresponding to H + 12 hr fallout time, test devices detonated on 500- and 700-foot towers produced approximately 30 per cent of the fallout radioactivity in the particle size range less than 44 microns in diameter. However, a test device of nearly comparable kt yield mounted on a 700-foot balloon produced 70 per cent of the fallout radioactivity in the less than 44 micron particle size range.

Within the less than 44 micron diameter particle size range samples, it was found that from 38 to 50 per cent of the radioactivity was associated with particles less than 5 microns in diameter in fallout samples from tower-supported detonations; from 51 to 83 per cent of the radioactivity was associated with the less than 5 micron diameter particles from balloon-supported detonations. Significant percentage contributions of radioactivity by particles less than 5 microns in diameter were observed at virtually all sampling locations for both tower and balloon-supported detonations (1).

4. Radiochemical Properties of Fallout Debris (1): Fallout particles less than 44 microns in diameter had greater percentages of Sr89, 90 and Ru103, 106 at 30 days after detonation than did the larger sized particles. The percentage of Sr89, 90 and Ru103, 106 in balloon-supported detonation fallout debris was from 2 to 4 times higher than it was in corresponding particle sizes from tower-supported detonations. The reverse was observed for Zr-95. Ba140, Ce-141, 144 and Y-91 varied to a lesser degree between fallout from tower and balloon-supported detonations. Strontium90 averaged 2.7 per cent of the total radiostrontium at D + 30 days in fallout originating from detonations supported by towers.

The percentage concentration (D + 30 days) of radioisotopes of Ba-140, Ce-141, 144, Ru-103, 106, Sr-89, 90, Y-91 and Zr-95 in different fallout particle size fractions from tower- and balloon-supported detonations is illustrated in Fig. 6. The average values expressed as per cent of the total activity from the primary contributing isotope (s) at D + 30 days are summarized in Table 1.

TABLE 1

Average Contributions of Radioisotopes to Total Beta Activity in Fallout Debris Originating from Tower-and Balloon-Supported Detonations

	Average Per Cent of Total Beta Activity at D + 30 Days		
Isotope	Tower Support	Balloon Support	Theoretical U235 Fission Products*
Ba^{140}	13.7	17.9	10.49
$Ce^{141, 144}$	17.6	14.3	13.10
$Ru^{103, 106}$	2.6	9.2	5.99
Sr^{89}	1.83	4.3	6.00
Sr^{90}	0.05	---	0.08
Y^{91}	10.4	14.0	7.74
Zr^{95}	7.8	3.93	8.13

*Bolles and Ballou USNRDL-456

5. Solubility of Fallout Debris: Solubility of fallout debris is one of the most important properties to consider with respect to the "internal emitter" problem in biological systems. The solubility of radioactive fallout debris in water and in 0.1 N hydrochloric acid (HCl) has been used arbitrarily as indices of biological availability.

The radioactivity in fallout debris from tower-supported detonations has been observed to be from 1 to 2 per cent soluble in water (16). Fallout debris from balloon-supported detonations was more soluble in both water and 0.1 N HCl than that produced by other types of detonations (1). The solubility of fallout debris from tower-supported detonations increased with decreasing particle size; however, in the case of balloon-supported detonations, the smaller sized particles were somewhat less

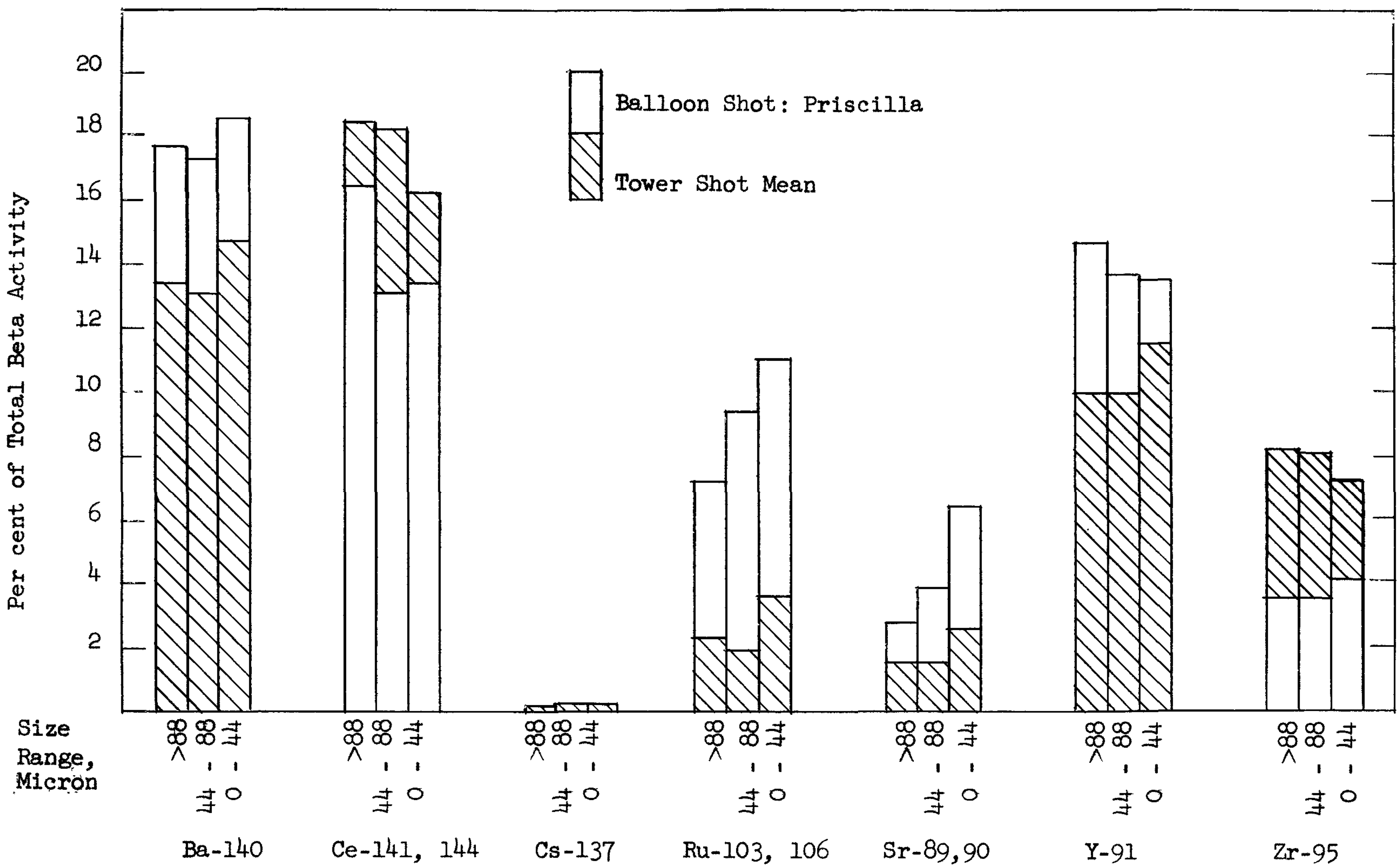


Fig. 6 Comparison of Radioelement Percentages of Different Particle Size Fractions of Tower and Balloon Shot Fallout

soluble than larger particles (Table 2).

TABLE 2

Solubility in Water and 0.1 N HCl of Fallout Debris from Tower and Balloon-Supported Detonations

Support	Particle Size Range (Micron)	Solubility (Per cent of β Activity) Water	0.1 N HCl
Tower	>44	<1	5
	<44	<2	14 to 36
Balloon	>44	31	> 90
	<44	14	> 60

The solubility of the 0 to 44 micron particle size fallout debris from the underground detonation, Jangle Series (1951), was intermediate to that observed from tower and balloon-supported detonations (5.4 per cent soluble in water, 25 per cent soluble in 0.1 N HCl) (7).

6. Comparison of Properties of Fallout Debris from Balloon and Tower-Supported Detonations (1): A comparison of fallout debris from a balloon (Priscilla) and a tower-supported detonation (Smoky) having nearly similar kt yield and the same detonation height of 700 feet indicated that the amounts of water soluble Ba^{140} and $Sr^{89, 90}$ deposited in the less than 44 micron particle size fraction within the 1 to 15-hour fallout time period were similar despite relatively large differences in the total amounts of radioactivity deposited in this particle size fraction.

The widespread distribution of the less than 44 micron particle size fraction from all types of devices detonated at the Nevada Test Site indicates that this particle size fraction is probably the most significant with respect to total area contaminated. Assuming that the soluble fractions of the fallout debris samples studied contain the same ratio of radioelements as is present in the original fallout debris, the application of this ratio to the per cent of the soluble activity yields the per cent of the various radioelements present in the 0.1 N HCl and water-soluble extracts. Based on such calculations, the relative amounts of the several radioelements in the soluble fractions of equal quantities of less than 44 micron fallout debris from tower and balloon-supported detonations of similar yield and height of detonation are presented in Fig. 7. It should be noted, however, that the deposition of less than 44 micron fallout debris from the tower-supported detonation considerably exceeded that from the balloon-supported detonation at different fallout times from 1 to 15 hours (Fig. 8).

The application of soluble radioelement percentages to the measured and the integrated radioactivities of the less than 44 micron particle size fractions from the two detonations gives an estimate of the relative amounts of the various radioelements deposited at different fallout times. As examples, the relative amounts of total acid-soluble and water-soluble Ba140 and Sr89, 90 derived from the less than 44 micron particle size fraction deposited by the two detonations at various fallout times are illustrated in Figures 9 and 10. While the amounts of total and acid-soluble Ba140 and Sr89, 90 deposited by less than 44 micron fallout debris from the tower-mounted detonation were higher over the 1- to 15-hr fallout period, the amounts of water-soluble Ba140 and Sr89, 90 were similar.

7. <u>Radioactive Decay of Fallout Debris</u> (1): Fallout debris from a specific detonation during the Plumbbob Series had similar beta decay curves regardless of particle size and time of fallout. Beta decay curves of most detonations approximated the $T^{-1.2}$ decay relationship over a period of H + 12 to H + 6,000 hrs. However, slopes of the order of $T^{-1.4}$ occurred from H + 6,000 to H + 10,000 hrs.

Decay curves of the gamma emmission rate were different from those of beta decay for fallout debris from a specific detonation. Gamma decay curves of fallout debris from different detonations were generally similar, but more variable than corresponding beta decay curves.

Plumbbob beta and gamma decay curves, derived from measurements of fallout samples from seven detonations, are illustrated in Fig. 11 in relation to the $T^{-1.2}$ decay curve and a theoretical mixed fission product

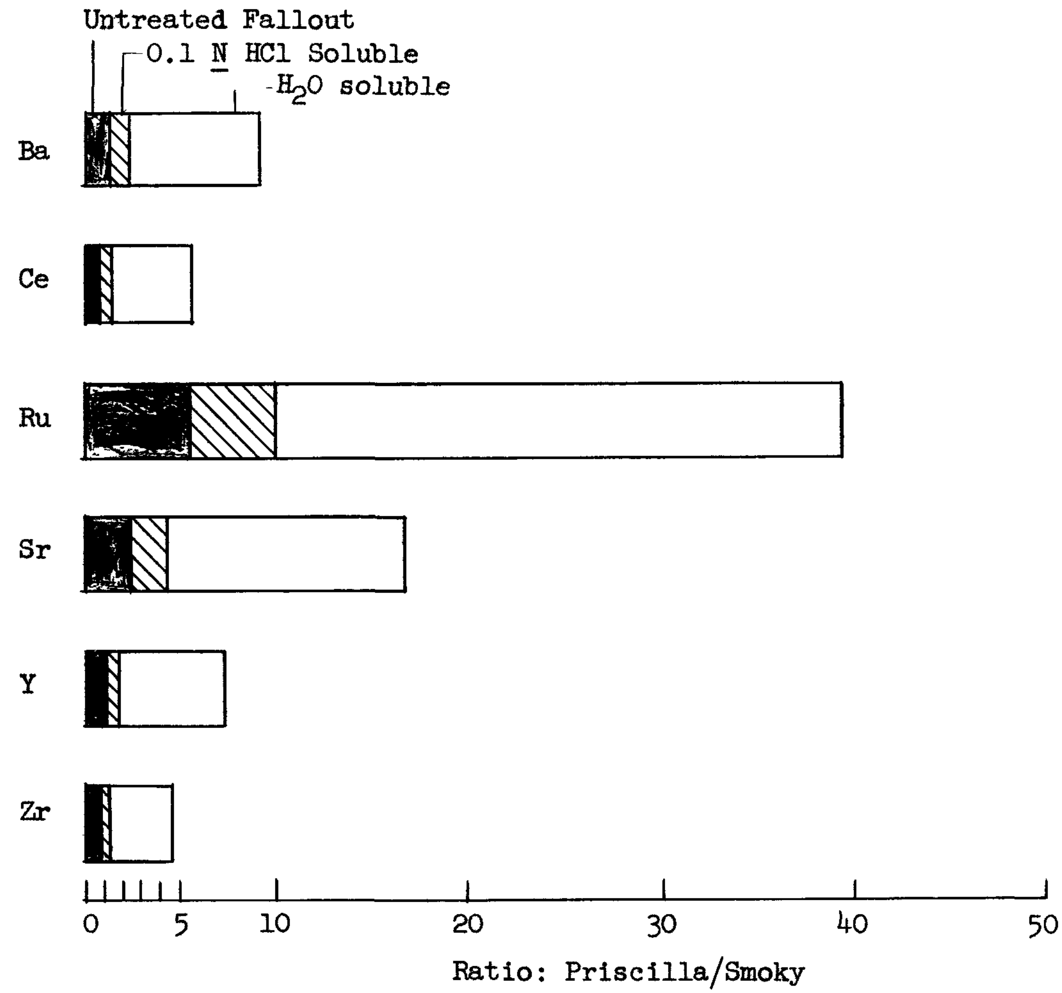


Fig. 7 Calculated Priscilla/Smoky D + 30 Day Radioelement Ratios in Untreated, Acid-Soluble, and Water-Soluble Fractions of 0 - 44 micron Fallout Particles

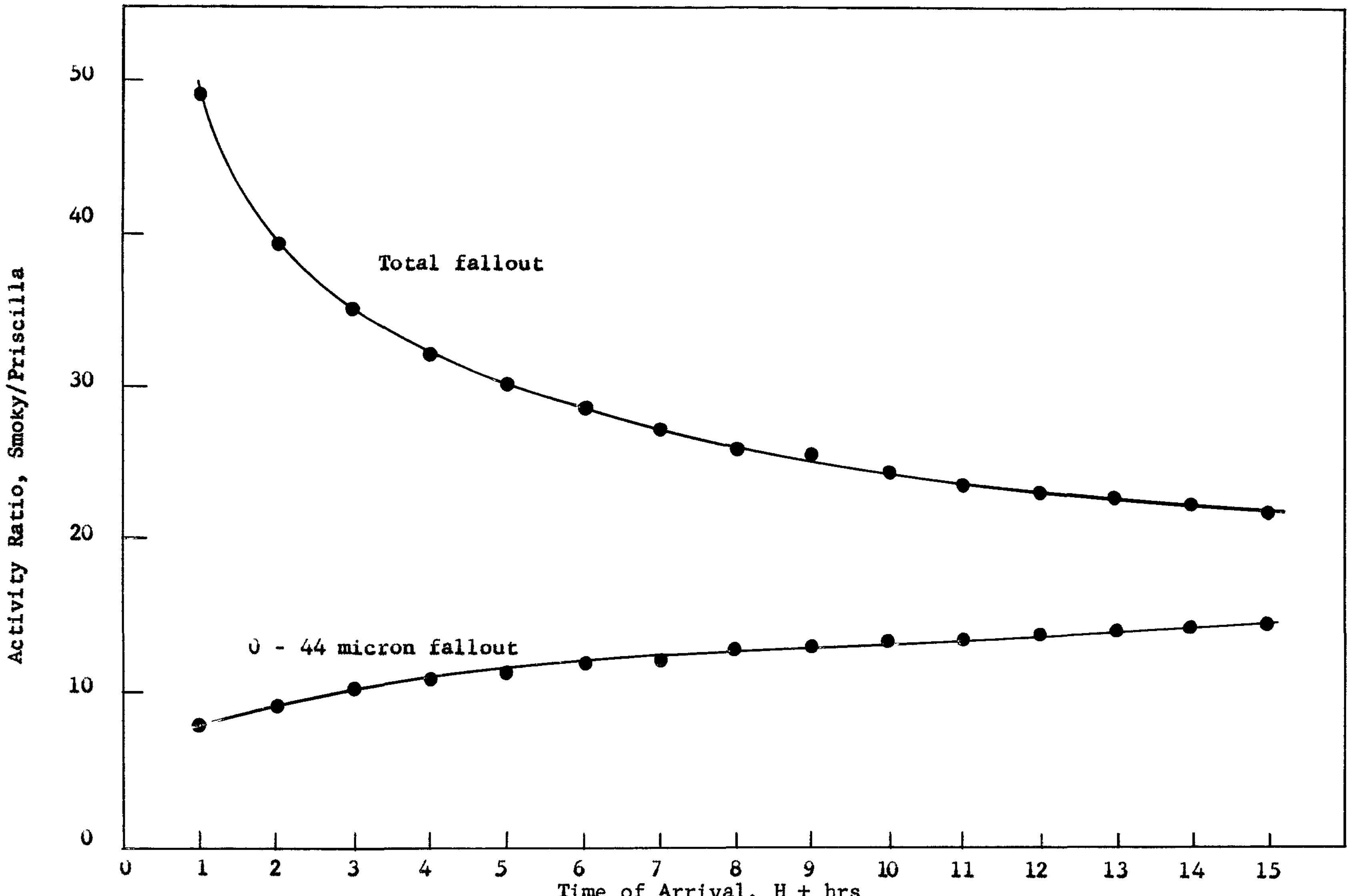


Fig. 8 Smoky/Priscilla Total and 0 - 44 micron Activity Ratios at Different Times of Fallout Arrival

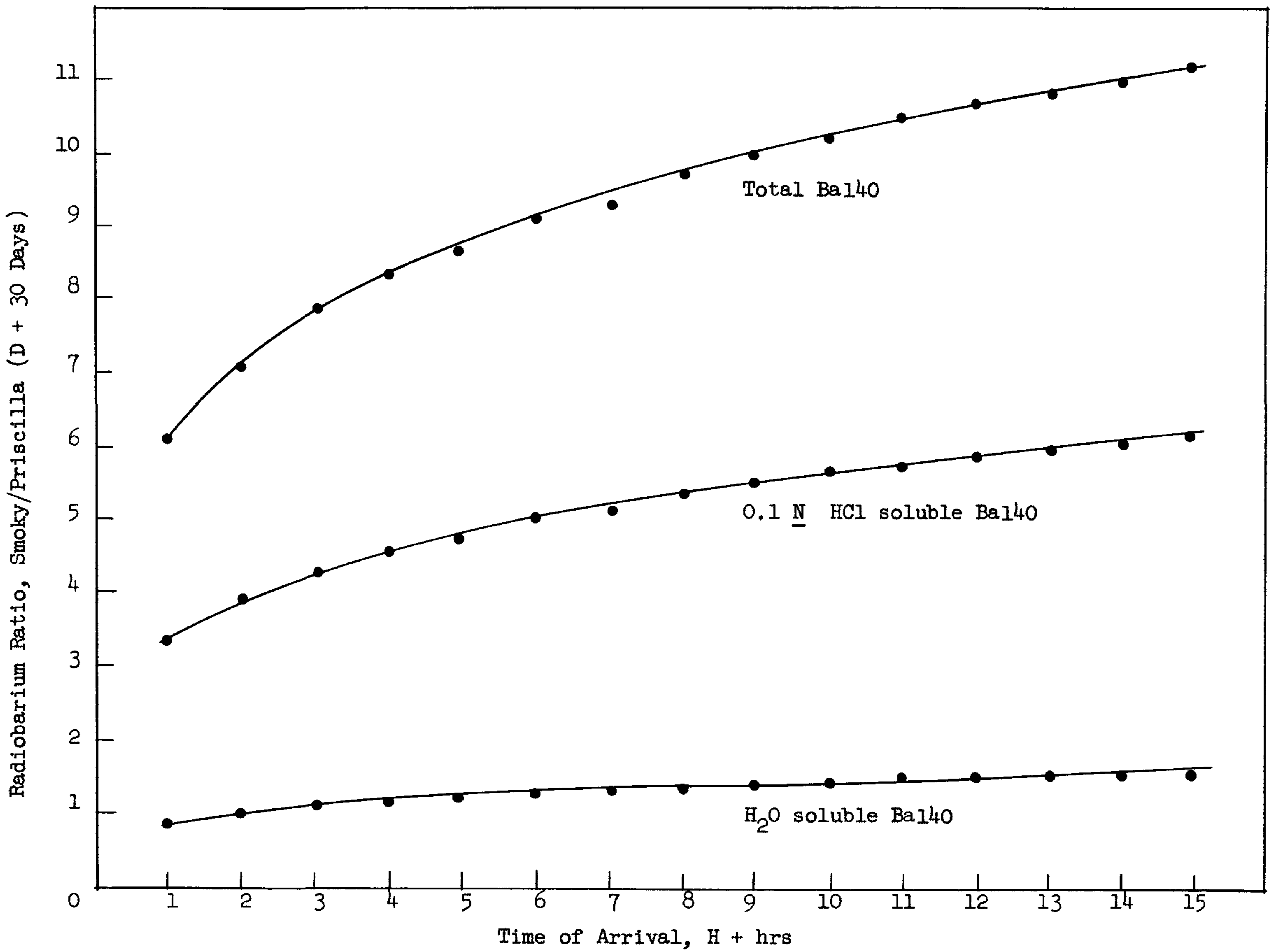


Fig. 9 Calculated Smoky/Priscilla Total, Acid-soluble, and Water-soluble 0 - 44 micron Fallout Debris Radiobarium Ratios at Different Times of Fallout Arrival

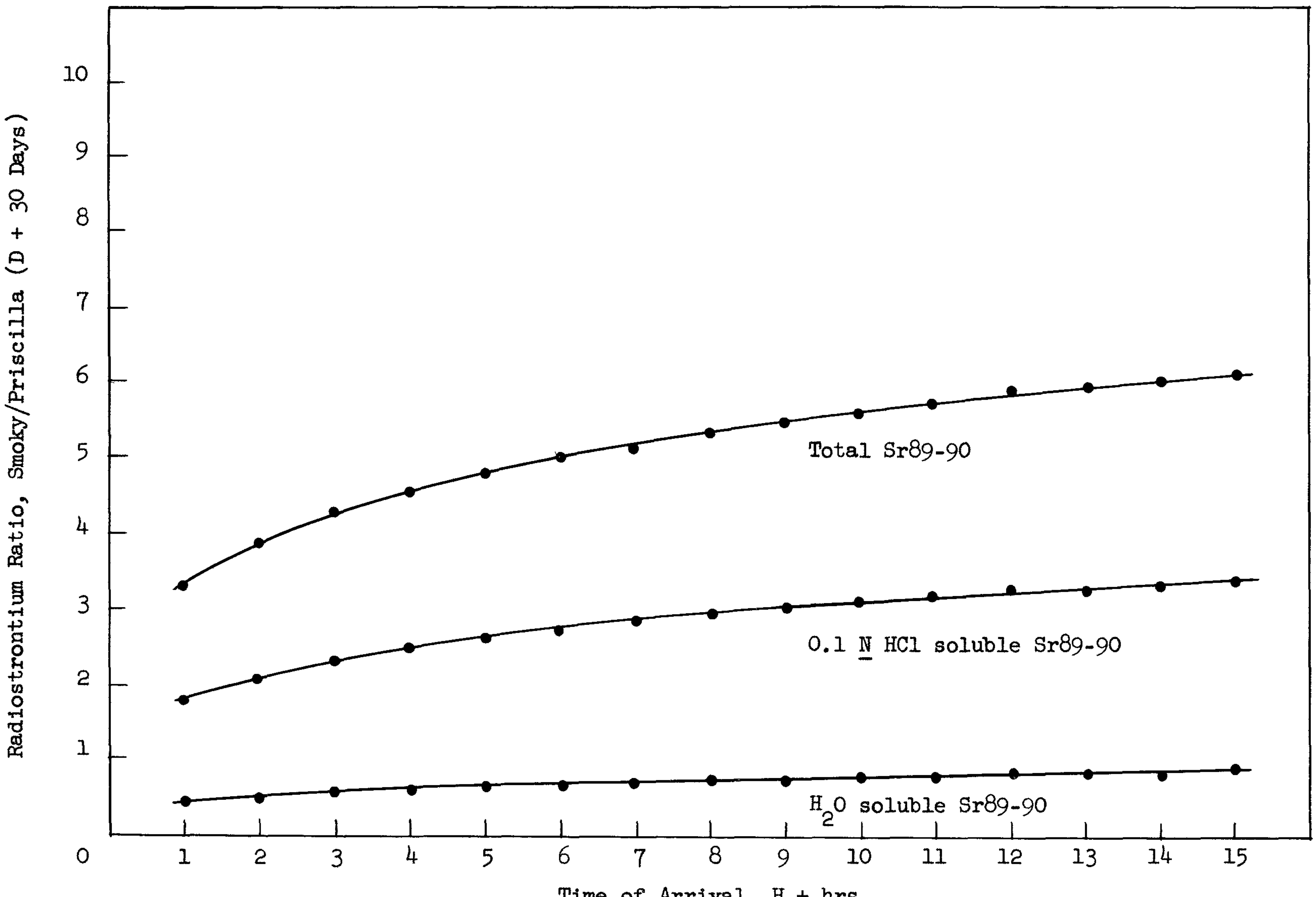


Fig. 10 Calculated Smoky/Priscilla Total, Acid-soluble, and Water-soluble 0 - 44 micron Fallout Radiostrontium Ratios at Different Times of Fallout Arrival

(U^{235}) decay curve.

Estimates of dosage in fallout areas have generally been based, in part, on a decline of dose-rate (mr/hr) with time according to the $T^{-1.2}$ relationship. A dose-rate decline with time according to the Plumbbob gamma decay (PGD) curve yields calculated doses which are 1.5 to 2 times greater than those calculated by the $T^{-1.2}$ relationship for different fallout times out to approximately 400 days after detonation (Table 3).

TABLE 3

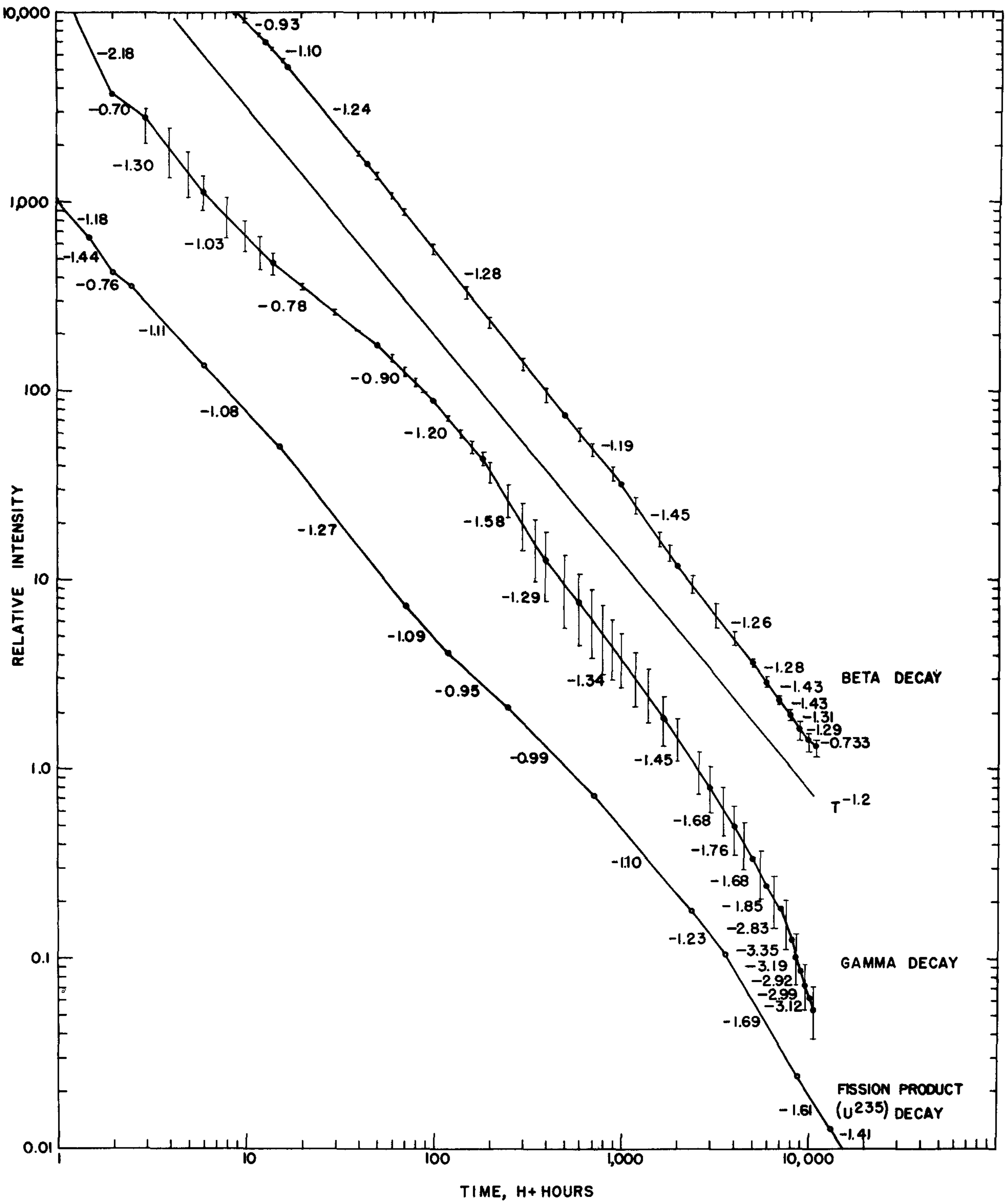
Comparison of Radioactivity Dose to 10,000 Hrs Calculated on the Basis of Plumbbob Gamma Decay Curve and $T^{-1.2}$ Relationship (Using 100 mr/hr Intensity at Time of Arrival for Illustration)

Time of Arrival (hr)	Dose to 10,000 hrs Using PGD Curve (mr)	Dose to 10,000 hrs Using $T^{-1.2}$ (mr)	Ratio of PGD Dose to $T^{-1.2}$ Dose
H + 2	1,638	818	2.00
H + 4	2,635	1,582	1.67
H + 6	3,993	2,319	1.72
H + 8	4,979	3,041	1.64
H + 10	5,917	3,744	1.58
H + 12	6,679	4,437	1.51

8. Deposition of Radiostrontium in Areas Adjacent to Nevada Test Site (1): Approximately 0.13 per cent of the total amount of Sr^{89} produced by a balloon-supported detonation whose fireball intersected the ground surface was deposited within the fallout time of arrival of H + 12 hrs. On the other hand, only 0.004 and 0.008 per cent of the total Sr^{89} produced was deposited within H + 12 hrs fallout time by two balloon-supported detonations whose fireballs did not intersect the ground. Tower-supported detonations deposited from 0.5 to 2 per cent of the Sr^{89} produced and from 1.6 to 7.2 per cent of the total Sr^{90} produced [2] within H + 12 hrs fallout time. Calculations were based on the results of analyses of fallout debris

[2] The theoretical potential Sr^{89} and Sr^{90} fallout is based on the production of 1 gram or 27,700 curies of Sr^{89} and 1.14 gram or 146 curies of Sr^{90} per kt yield.

FIG. 11 COMPARISON OF MEASURED PLUMBBOB BETA AND GAMMA, $T^{-1.2}$, AND THEORETICAL DECAY CURVES.



samples for Sr89 and Sr90 and integrated fallout radiation intensities converted to curies by ratios of $\mu c/ft^2$ and mr/hr. The analysis of balloon detonation fallout debris for Sr90 was not performed.

The tower shot percentage deposition of Sr89 was less than that of Sr90 out to distances corresponding to H + 12 hr fallout arrival time. This is attributed to relatively low percentages of Sr89 in larger fallout particle size fractions which generally represent the majority of the fallout radioactivity in areas close to Ground Zero. This fractionation of Sr89 and Sr90 with respect to particle size may be predicted on the basis of the different half-lives of their noble gas precursors, Kr89 and Kr90, respectively, and the rate of particle formation.

BIOLOGICAL AVAILABILITY AS RELATED TO THE FATE AND PERSISTENCE OF FALLOUT DEBRIS IN FALLOUT PATTERNS OUT TO 400 MILES FROM NEVADA TEST SITE

1. Distribution and Redistribution of Fallout Debris in Soils: In undisturbed areas the radioactive debris from fallout was confined to the surface 2 inches of the soil profile even after 9 years following fallout contamination (Trinity Areas, New Mexico) (8). In agricultural areas under cultivation, the distribution of fallout radioactivity was found down to depths of 4 to 8 inches due to plowing, harrowing, etc. Soil leaching experiments preformed in the Laboratory using the equivalent of 84 inches of water translocated the surface deposited radioactivity only about 0.5 inch into the soil.

Surface-deposited fallout debris tends to become mechanically trapped in the soil. Natural disturbance by wind action causes minor amounts of the total fallout debris deposited in various areas studied to be redistributed within the fallout pattern from the point of original deposition. Fallout particles 44 to 88 microns in diameter contributed an average of 9.7 per cent of the total redistributed fallout debris following the Priscilla (balloon) detonation as compared to 21.0 per cent following the Smoky (tower) detonation of the Plumbbob Test Series. Particles less than 44 microns in diameter contributed an average of 85.8 per cent of the radioactivity deposited from the Priscilla detonation as compared to 68.3 per cent from the Smoky detonation (1).

2. Sr90 Contamination Levels in Nevada and Utah Soils (10): Strontium 90 levels of the surface 0 to 1 inch depth soil samples collected in Nevada and Utah in August, 1958, ranged from 31.9 to 142 mc/sq mile in virgin areas near known fallout intensity midlines and from 7.5 to 22.7 mc/sq in agricultural areas which did not necessarily coincide with fallout midlines.

The Sr90 contamination level in cultivated 0 to 1 inch surface soil samples was lower than that of virgin area samples (Table 4) probably as a result of both reduced contamination by fallout debris from Nevada Test Site activities and subsequent cultivation of the soil. The observed Sr90 levels in agricultural area samples were similar to those reported for other areas of the country; however, the comparative levels of Sr90 in the subsoil are not known.

The assumption that Nevada Test Site activities represent the major source of Sr90 contamination in the virgin area locations is supported by Sr90 percentages of mixed fission product beta activity. The theoretical percentages for various Testing Series tended to be approached by the observed percentages (Table 5).

Four soil sampling sites were subjected to a comparative study of Sr90 contamination measured by total solubilization following alkali fusion and by leaching with 6 N HCl. The results clearly indicate that in the Nevada - Utah area, total solubilization of soil samples is necessary in order to more accurately evaluate area contamination. The amounts of Sr90 leached by 6 N HCl varied within the range from 13 to 78 per cent of the total Sr90 present (Table 6).

TABLE 6

Comparison of Sr90 Levels in Nevada and Utah Soil Samples Determined by Alkali Fusion or 6 N HCl Leaching

Location	Sr90 Level (mc/sq mile)		Per cent Sr90 Soluble in 6 N HCl
	Na_2CO_3 Fusion	6 N HCl Leaching	
Columbia, Utah	67.2	52.8	78.6
Enterprise, Utah	41.2	7.6	18.5
Moapa, Nevada	142	18.6	13.1
Panguitch, Utah	31.9	16.2	50.7

TABLE 4

Sr90 Levels Measured by Fusion Analysis in Soil Samples Collected from Eleven Selected Areas in Nevada and Utah in August, 1958

Area	Location	Sr90 Activity (0 to 1" Depth) mc/sq Mile	Sr90 Activity (0 to 1" Depth) μμc/g Ca
Cultivated Agricultural Areas			
Alamo, Nevada	1 mi S	21.3	6.8
Moapa, Nevada	7.7 mi NW	16.3	2.5
Riverside, Nevada	0.4 mi S	22.7	9.6
St. George, Utah	1 mi SE	14.4*	4.5
Hurricane, Utah	1 mi SW	12.4	3.5
Enterprise, Utah	0.7 mi N	7.46	8.6
Cedar City, Utah	2 mi SW of Enoch	16.7	4.6
Vernal, Utah	4 mi S	13.8	8.7
Virgin Undisturbed Area, Fallout Midline Locations			
Moapa, Nevada	8 mi N	142	38.3
Elgin, Nevada	3.8 mi SW	114	140
St. George, Utah	5 mi N	45.6	406
Enterprise, Utah	9 mi N	41.2	51.2
Panguitch, Utah	City Limit, NW corner	31.9	14.9
Sunnyside, Utah	3.1 mi S of Columbia, Utah	67.2	202

* The Sr90 activity determined by fusion analysis in the 0-6" depth at this sampling location is 100 mc/sq. mile.

TABLE 5

Observed and Theoretical Sr90 Percentages of Mixed Fission Product Beta Activity in 0 to 1" Surface Soil Samples from Locations on Midlines of Fallout Patterns

Area	Location	Origin of Contamination: Testing Series	Origin of Contamination: Name of Detonation	Area Contamination (mc/sq mi)	Sr90 Activity as of Aug. 1958 (Per Cent of Total Activity): Observed*	Sr90 Activity as of Aug. 1958 (Per Cent of Total Activity): Theoretical (for Series)**
Moapa, Nevada	8 miles N	Upshot-Knothole	Simon	142	12.2 ± 3.18	18 - 19
St. George, Utah	5 miles N	Upshot-Knothole	Annie	45.6	3.06 ± 0.10	18 - 19
Elgin, Nevada	3.8 miles SW	Teapot	Met	114	6.77 ± 1.15	11 - 12
Enterprise, Utah	9 miles N	Teapot	Met	41.2	7.01 ± 3.79	11 - 12
Panguitch, Utah	City Limit	Plumbbob	Smoky	31.9	2.38 ± 0.30	2 - 3.5
Columbia, Utah	3.1 miles S	Plumbbob	Smoky	67.2	2.57 ± 0.38	2 - 3.5

* Standard deviation values refer to variation of Sr90 percentages of 5 surface soil samples at each location.

** Determined from values published by Bolles and Ballou. USNRDL-456

3. Fallout Debris Contamination of Forage Plants:

Forage plants are recontaminated due to redistribution of small sized fallout particles. This provides a continuous source of internal emitters to grazing animals and a persistent low radiation field which is dependent on the changing proportions of medium- to long-lived fission products. During the Teapot (5) and Plumbbob (1) Test Series, it was found that the principal source of radioactive contamination on forage plants was from fallout particles in the less than 44 micron size fraction, i.e., vegetation within fallout patterns out to 300 miles from Nevada Test Site was a 'selective' particulate collector. The number of fallout particles retained by the foliage is dependent upon its surface characteristics such as hairs, glands, and other mechanical traps. As much as 21.6 per cent of the radioactive contamination on plant foliage was soluble in 0.1 N HCl, which suggests that a similar percentage of the radioactivity in any fallout debris ingested might be available to animals (5).

The fallout debris contamination of native plant material persisted through the 18-day period following both Priscilla and Smoky detonations; the only change was that due to radioactive decay (1).

A very small fraction of the total contamination of the soil by fallout debris from tower-supported detonations was accumulated through the root systems of forage crops (within 300 miles of the Nevada Test Site) (5). Also, it was demonstrated that some fission products, primarily Sr89, were taken up by radish and Ladino clover plants grown in soil contaminated with fallout debris from the Jangle Series underground detonation (10).

4. Fission Product Accumulation by Native Animals:

During the 1955 Teapot Test Series, the concentration of radioiodine I131 in the thyroids of rabbits and other native rodents was found to be a function of distance. The maximum concentrations measured at approximately 60 miles from Ground Zero were from 2 to 7 times higher than those measured at 20 miles or at 160 miles (5). During the Plumbbob Series, between 82 and 87 per cent of the total radioactivity found in the thyroid tissue of the native rodents at H + 72 hrs was radioiodine. Of this amount, 17 to 20 per cent was Iodine131 and 65 to 67 per cent was Iodine133. The maximum accumulation occurred at approximately D + 14 days; samples taken at D + 20 days contained only Iodine131. Of the several fission products (Sr89-90, Y91, Ce144, Cs137, and Ba140) accumulated in bone, 12.5 to 40.0 per cent was accounted for as radiobarium and radiostrontium at D + 20 days.

Maximum tissue accumulation of fission products occurred in samples of native animals collected at locations corresponding to fallout times of H + 2 to H + 3 hrs. Fission product concentrations then decreased as the fallout time of arrival increased. For the single balloon-supported detonations studied, this decrease was constant between locations corresponding to H + 2 to H + 12 hrs. For tower-supported detonations, however, the accumulated fission product concentration tended to be uniform over distances corresponding to fallout times of H + 5 to H + 14 hrs.

For any given sampling location, the relative tissue contents of the accumulated fission products from Priscilla and Smoky fallout debris were comparable; the maximum levels of accumulation occurred by D + 7 days.

Biological "hot spots" were identified geographically in the Boltzmann (78 miles from Ground Zero), Diablo (60 miles from Ground Zero), Smoky (70 miles from Ground Zero), and Shasta (172 miles from Ground Zero) fallout patterns. The rate of decay of radioactivity in skin, G. I. tract, and muscle tissue samples collected from the field at the beginning of any particular study and the decline of radioactivity in these tissues serially sampled from the field population, was similar to the rate of radioactive decay of fallout debris. Liver and kidney tissue radioactivity levels showed similar decay characteristics but deviated markedly from the rate of radioactive decay of fallout debris. These relationships were not apparent for bone, which reflected the build-up and retention of specific isotopes.

The radioelement content of jack rabbit bone tissue was studied during the Plumbbob Test Series as a function of time of collection after fallout had occurred (Fig. 12). Ba140, Sr89 and Y91 concentration increased with time after fallout. These radioisotopes also were predominant contributors of the beta activity present in the bone. The presence of relatively high levels of Y91 was of particular interest; the predominant isotope presumably was the Y91 daughter product of the short-lived Sr91 precursor.

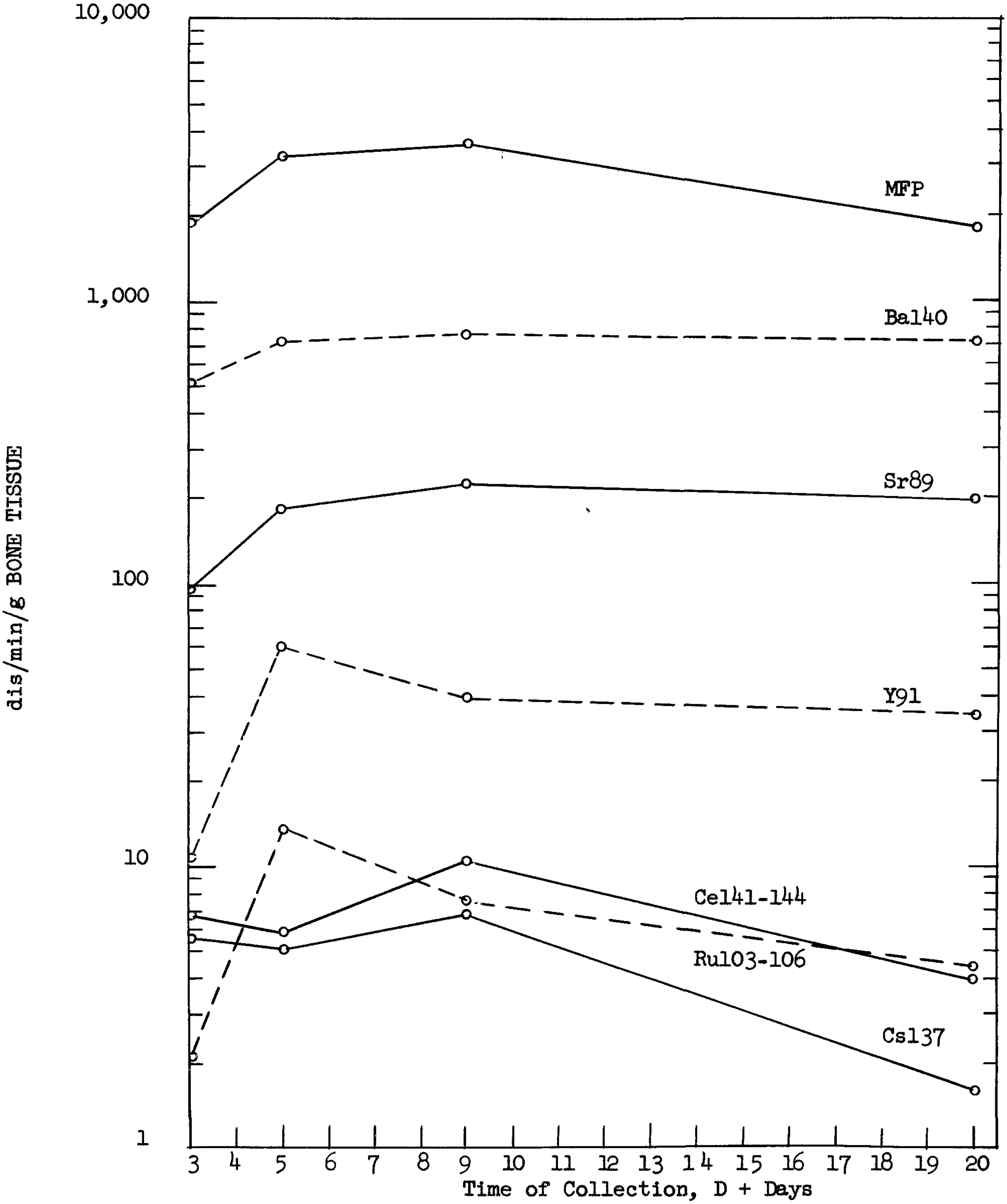


Fig. 12

Radioelement and mixed fission product activities of jack rabbit bone tissue as a function of time of collection at Smoky Station VII

Effects of chronic exposure of native animals in fallout contaminated areas upon the radiostrontium content in bone tissue have been investigated. Twelve months after the Upshot-Knothole Series (11), and six months after the Teapot Series (5), the accumulated radiostrontium was found to be a function of distance from the point of detonation. The maximum radiostrontium concentrations in rabbit bones occurred at 130 miles from Ground Zero in previously delineated fallout patterns.

Strontium 90 bone concentrations in rabbits collected along Plumbbob fallout patterns approximately twelve months post-series correlated poorly with soil Sr90 levels (9). In areas where surface soil Sr90 levels ranged from 13.8 to 142 mc Sr90/sq. mi. and from 2.5 to 406 Sr90/g Ca, bone contents ranged from 10 to 22 μμc Sr90/g Ca with some of the lowest bone contents coinciding with high levels of soil contamination.

The Sr90 level in the bones of male Big Horn sheep from the Desert Game Range, Clark County, Nevada, collected during the 1956 and 1957 hunting seasons, or pre- and post-Plumbbob Operation, was determined (12). Approximately 20 specimens were analyzed from each season. The mean Sr90 content for 1956 was 2.8 μμc Sr90/g Ca. The corresponding value for 1957 was 6.6 μμc Sr90/g Ca, or slightly more than double the 1956 level.

A survey of deer bones collected primarily in the NE quadrant of Nevada gave similar results; some levels as high as 25 μμc Sr90/g Ca were observed. Where samples were obtained during 1956 and 1957 from the same locality, an increase in the Sr90 level during 1957 was quite apparent.

5. Strontium90 Contamination in Milk Produced in Nevada and Utah:

Milk samples collected before, during and immediately after the Plumbbob Test Series from Nevada (Table 7) and Utah (Table 8) farms generally reflected an increase in Strontium Unit (μμc Sr90/g Ca) following farm contamination by Plumbbob detonations and a reduction in Strontium Unit with increased time after contamination (1). Data suggest that increases in Sr90 levels of milk produced on farms contaminated by Nevada Test Site fallout could be minimized by immediate reduction of pasture grass consumption following contamination. The substitution of protected or imported feeds for a period of several months will conceivably reduce milk Strontium Unit values to as little as one-third the levels otherwise present.

TABLE 7

Strontium90 Content of Milk Serially-Sampled at Specific Farms in Nevada

Location	Date	Event	Estimated Fallout Activity Levels (mr/hr at H + 12 hrs)	Type and Origin of Feed as Indicated by Owner of Herd	Sr90 Content in Milk (μμc Sr90/g Ca)
Alamo, Nevada	5/2/57	Milk sample	---	1956 Idaho hay, St. George	4.7
	6/18/57	Wilson fallout	0.75	---	---
	6/24/57	Priscilla fallout	0.75	---	---
	7/15/57	Diablo fallout	0.8	---	---
	8/ 3/57	Milk sample	---	Home-grown 1957 hay, St.George concentrates	5.3
	10/31/57	Milk sample	---	Alfalfa pasture, St. George concentrate	5.0
	7/ /58	Milk sample	---	No information available	2.8
Lund, Nevada	5/ 2/57	Milk sample	---	Alfalfa hay, harvested 1956	3.5
	7/ 5/57	Hood fallout	0.3	---	---
	7/15/57	Diablo fallout	6	---	---
	7/25/57	Owens fallout	0.4	---	---
	8/18/57	Shasta fallout	1.0	---	---
	8/23/57	Doppler fallout	>1	---	---
	11/ 4/57	Milk sample	---	Home-grown 1957 hay, alfalfa pasture, local grain	3.2
Mesquite, Nevada	4/26/57	Milk sample	---	No information available	2.8
	8/31/57	Smoky fallout	1.3	---	---
	9/ 8/57	La Place fallout	---	---	---
	10/23/57	Milk sample	---	Local hay, St. George feed	6.1
Pahrump, Nevada	5/ 9/57	Milk sample	---	Alfalfa hay, first 1957 harvest on farm	4.2
	11/ 1/57	Milk sample	---	Home-grown hay, ensilage, grain	2.7

TABLE 8

Strontium 90 Content of Milk Serially-Sampled at Specific Farms in Utah

Location	Date	Event	Estimated Fallout Activity Levels (mr/hr at H + 12 hrs)	Type and Origin of Feed as Indicated by Owner of Herd	Sr90 Content in Milk (μμc Sr90/g Ca)
Antimony, Utah	8/31/57	Smoky fallout	7	---	---
	9/20/57	Milk sample	---	Home-grown hay harvested after Smoky Shot	13.6
	10/21/57	Milk sample	---	50% of hay in Smoky fallout	10.0
	7/ /58	Milk sample	---	No information available	3.5
Fremont, Utah	8/31/57	Smoky fallout	4	---	---
	9/ 9/57	Milk sample	---	Home-grown 1956 hay 5%, pasture 80%, commercial feed	12.1
	9/21/57	Milk sample	---	No information available	9.5
	10/19/57	Milk sample	---	Alfalfa pasture, commercial feed	4.9
	7/ /58	Milk sample	---	No information available	4.4
Milford, Utah	4/29/57	Milk sample	---	Home-grown 1956 hay, home-grown grain	3.1
	8/31/57	Smoky fallout	<0.5	---	
	10/26/57	Milk sample	---	50% pasture, 50% 1957 hay, grain	2.7
Panguitch, Utah	8/31/57	Smoky fallout	14	---	---
	9/ 8/57	Milk sample	---	Local pasture	37.3
	9/20/57	Milk sample	---	Local pasture	17.0
	10/21/57	Milk sample	---	"Old" hay	26.2
	7/ /58	Milk sample	---	No information available	9.7
St. George, Utah	4/26/57	Milk sample	---	Home-grown 1957 hay, first harvest	2.8
	6/24/57	Priscilla fallout	0.5	---	---
	8/ 3/57	Milk sample	---	Hay, harvested 8/1/57	2.6
	8/31/57	Smoky fallout	10	---	---
	10/28/57	Milk sample	---	Home-grown 1957 hay and ensilage, grain	4.6

TABLE 8

Strontium 90 Content of Milk Serially-Sampled at Specific Farms in Utah (Cont'd)

Location	Date	Event	Estimated Fallout Activity Levels (mr/hr at H + 12 hrs)	Type and Origin of Feed as Indicated by Owner of Herd	Sr90 Content in Milk (μμc Sr90/g Ca)
St. George, Utah	7/ /58	Milk sample	---	---	3.8
Veyo, Utah	6/24/57	Priscilla fallout	6	---	---
	7/ 9/57	Milk sample	---	1956 hay from Enterprise, local pasture	7.2
	7/15/57	Milk sample	---	1956 hay from Enterprise, local pasture	8.2
	8/ 3/57	Milk sample	---	1956 hay from Enterprise, local pasture	5.1
	8/31/57	Smoky fallout	5	---	---
	9/10/57	Milk sample	---	1956 hay from Enterprise	4.1
	10/27/57	Milk sample	---	Hay from 1957 cutting	4.6
	7/ /58	Milk sample	---	No information available	2.8

The Strontium Unit values of soil samples collected one year after the Plumbbob series at milk-producing farms were generally 1.5 to 2 times higher than those of corresponding milk samples (9). This lack of correlation may be attributable to a number of factors, among which are: (a) variations in biological availability of deposited Sr90; (b) differences in levels of native stable strontium; and (c) variations in the amounts of calcium, stable strontium and Sr90 in the various dairy feeds.

6. Experimentally-Determined Soil-Plant Factors which Affect Sr90 and Cs137 Accumulation in Crops: Several soil and plant factors influence the availability and accumulation of fission products in plants. Radiostrontium was most readily accumulated by crop plants from artificially contaminated soils. Only very small amounts of Y91, Ru106, Cs137, and Ce144 were accumulated (13, 14, 15).

In a short time experiment (21 days), the addition of non-composted organic matter to soils reduced Sr90 uptake by barley seedlings (16, 17). The application of undecomposed organic matter at levels equivalent to 10, 20, 50, and 100 tons per acre reduced the uptake of Sr90, 12, 30, 50, and 75 per cent, respectively. The uptake of Sr90 by tomato plants was also reduced by higher applications of organic matter (17, 19). The influence of the applied organic matter was related to its effect on the soil microbal population and to the change in the chemical composition of the soils as the organic matter decomposed.

The addition of lime ($CaCO_3$) and gypsum ($CaSO_4$) to acidic soils low in native Ca reduced Sr90 uptake by plants (19, 20). Greatest inhibition occurred at treatment levels equivalent to from 2 to 5 tons per acre. At these levels $CaCO_3$ reduced Sr90 uptake about 60 per cent; $CaSO_4$ caused an 80 per cent reduction. These Ca amendments had little or no influence on the uptake of Sr90 from neutral and alkaline soils. The uptake of Sr90 was increased by low-level applications of stable Sr but it was reduced by applications in excess of 5 tons per acre (20, 21).

The uptake of Cs137 occurring as a contaminant increased as the K concentration in the soil was reduced by prolonged cropping (22, 23). The addition of K to contaminated soils low in potassium content reduced the uptake of Cs137 by plants.

SUMMARY AND CONCLUSIONS

The use of aerial surveys has greatly increased the detail and accuracy of fallout pattern delineation. About 25 per cent of the total amount of fission products produced by tower-supported detonations was deposited within distances corresponding to H + 12 hr fallout time; very much less was deposited by balloon-supported detonations.

Particles less than 44 microns in diameter contained about 30 per cent of the fallout radioactivity from tower-supported detonations as compared to about 70 per cent from balloon-supported detonations within distances corresponding to H + 12 hr fallout time. Balloon-supported detonations produced fallout debris of higher water and acid solubility than did tower-supported or underground detonations.

The percentage of Sr89, 90 and Ru103, 106 was higher in fallout particles less than 44 microns in diameter than in larger fallout particles. There was a higher percentage of these radioelements in fallout debris from balloon detonations than from tower detonations. The amounts of water-soluble Ba140 and Sr89, 90 deposited locally by a balloon and a tower-supported detonation of similar yield and detonation height were estimated to be similar despite relatively large differences in the total amounts of these radioisotopes deposited. Within distances corresponding to H + 12 hr fallout time, balloon-supported detonations deposited a maximum of 0.13 per cent of the theoretical total Sr89 produced while tower-supported detonations deposited a maximum of 2 per cent. Tower-supported detonations deposited a maximum of 7.2 per cent of the theoretical total amount of Sr90 produced.

Beta decay curves approximated the $T^{-1.2}$ decay expression from H + 12 to H + 6000 hrs; gamma decay curves deviated to the extent that irradiation doses calculated by the observed decay values were 1.5 to 2 times greater than those calculated by the $T^{-1.2}$ relationship.

In the environment, fallout radioactivity is apparently confined to the first 2 inches of soil unless the soil was mechanically distributed. The majority of the fallout debris which was redistributed by various environmental factors on the soil surface after original deposition consisted of less than 44 micron diameter particles; this size particle also represented the predominant contamination on forage plants. Strontium 90 surface soil contamination levels in Nevada and Utah in August, 1958, ranged from 31.9 to 142 mc/sq mile in virgin areas near known fallout pattern midlines and from 7.5 to 22.7 mc/sq mile in agricultural areas which did not necessarily coincide with fallout pattern midlines.

During the test series operations, the level of uptake of radioiodine by native animals was observed to be a function of distance from Ground Zero. Barium-140, Ru103, 106 and Sr89, 90 were major bone contaminants. Post-series sampling of native animals indicated that the level of uptake of Sr89 was also a function of distance; however, uptake levels of Sr90 correlated poorly with soil contamination or strontium unit levels. Milk samples collected from Nevada and Utah farms before, during and after the Plumbbob Test Series showed that the strontium unit levels increased in milk immediately following contamination of the farm with fallout debris, and then decreased with time.

Radioecological studies clearly indicated that biological effect or hazard cannot be assessed realistically on the basis of measurements of only the gamma radiation field. Fission products from radioactive fallout debris could be assimilated by animals with the maximum degree of accumulation occurring not necessarily near the source of the nuclear detonation. Furthermore, within a distance of 10 to 400 miles from the Nevada Test Site, the plant foliage is a selective collector of small sized fallout particles and is the predominant source of radioactive contaminants to foraging animals. No significant accumulation of radioactive fission products through the root system has been observed in this area during the cropping periods immediately following fallout contamination. Biological availability of fallout debris is strongly influenced by the conditions of fallout contamination and by the physical and chemical nature of the contaminating debris and its interaction with climatic, biotic and edaphic factors.

Observations during the past decade indicate that less than 10 per cent of the total theoretical Sr89 and Sr90 produced from all nuclear detonations at Nevada Test Site since the Ranger Series (1951) has been deposited within 200 miles from the point of detonation.

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