Bechtel Nevada

DOE/NV/11718-005
UC-702
JUNE 1996

RECEIVED
JUN 12 1996
OSTI

THE
REMOTE
SENSING
LABORATORY
OPERATED BY BECHTEL NEVADA
FOR THE U.S. DEPARTMENT OF ENERGY

IN SITU RADIATION MEASUREMENTS AT THE FORMER SOVIET NUCLEAR TEST SITE

SEMIPALATINSK, KAZAKHSTAN

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DATE OF SURVEY: JULY 21-30, 1994

DISCLAIMER

**Portions of this document may be illegible
electronic image products. Images are
produced from the best available original
document.**

IN SITU RADIATION MEASUREMENTS AT THE FORMER SOVIET NUCLEAR TEST SITE

SEMIPALATINSK, KAZAKHSTAN

DATE OF SURVEY: JULY 21-30, 1994

W. J. Tipton
Project Scientist

This Document is UNCLASSIFIED

T. M. Hayes

Authorized Derivative Classifier

PREFACE

An earlier version of this report appeared as Appendix II of *Final U.S. Government Report to the Republic of Kazakhstan Reporting the Survey Results at the Former Semipalatinsk Test Site*, EG&G Report No. RSL-9405.

The major difference between this report and that appendix is the addition of the comparison of the Russian and Kazakhstani data with the United States *in situ* measurements using the measured depth distribution from the Russian and Kazakhstani soil sample analysis rather than using the assumed depth distribution.

ABSTRACT

A team from the Remote Sensing Laboratory conducted a series of *in situ* radiological measurements at the former Soviet Nuclear Test Site near Semipalatinsk, Kazakhstan, during the period of July 21-30, 1994. The survey team measured the terrestrial gamma radiation at selected areas on the site to determine the levels of natural and man-made radiation. The survey was part of a cooperative effort between the United States team and teams of radiation scientists from the National Nuclear Center of the Republic of Kazakhstan and the V.G. Khlopin Radium Institute in St. Petersburg, Russia.

In addition to *in situ* radiation measurements made by the United States and Russian teams, soil samples were collected and analyzed by the Russian and Kazakhstani teams. All teams conducted their measurements at ten locations within the test site. The United States team also made a number of additional measurements to locate and verify the positions of three potential fallout plumes containing plutonium contamination from nonnuclear tests. In addition, the United States team made several measurements in Kurchatov City, the housing area used by personnel and their families who work(ed) at the test site.

Comparisons between the United States and Russian *in situ* measurements and the soil sample results are presented, as well as comparisons with a Soviet aerial survey conducted in 1990-1991. The agreement between the different types of measurements made by all three countries was quite good.

CONTENTS

Preface	ii
Abstract	iii

Sections

1.0 Introduction	1
2.0 Systems and Procedures	1
3.0 Conversion Factors	7
4.0 Results	11
5.0 Comparison with the Russian and Kazakhstani Results	28
6.0 Summary	34

Figures

1 <i>In Situ</i> Measurement System	2
2 Detector Efficiency Curve	3
3 Detector Angular Response Curve	4
4 <i>In Situ</i> Survey Areas Superimposed on the 1990 Soviet Aerial Survey Results	5
5 Sampling Pattern Used in Areas 1-10	6
6 Survey Areas Within the Atmospheric Test Field	8
7 Spectral Data Obtained in Area 1	17
8 Spectral Data Obtained in Area 2	18
9 Spectral Data Obtained in Area 3	19
10 Spectral Data Obtained in Area 4	20
11 Spectral Data Obtained in Area 5	21
12 Spectral Data Obtained in Area 6	22
13 Spectral Data Obtained in Area 7	23
14 Spectral Data Obtained in Area 8	24

15	Spectral Data Obtained in Area 9	25
16	Spectral Data Obtained in Area 10	26
17	Spectral Data Obtained in Kurchatov City	31
18	Spectral Data Obtained at the Institute	32

Tables

1	Survey Parameters for Areas 1-10	7
2	Survey Parameters for Areas 11-18	9
3	Survey Results from Areas 1-10	12
4	Survey Results from Areas 11-18 for Americium-241	27
5	Survey Results from Measurements in Kurchatov City	29
6	Natural Background and Cesium-137 Results from Areas 1-10	30
7	Depth Distribution Correction Factors	33
8	Corrected <i>In Situ</i> Survey Results for 5-cm Depth	34
9	<i>In Situ</i> Survey Results for 20-cm Depth	35
10	Comparison of United States <i>In Situ</i> and Russian Soil Sample Data	36
11	Cs-137 Comparison Data	37
12	<i>In Situ</i> Comparison Data	38

1.0 INTRODUCTION

A ground-based *in situ* radiation survey was conducted over selected areas within the former Soviet nuclear test site near Semipalatinsk, Kazakhstan, from July 21 to July 30, 1994. The survey was performed by a joint team from the U.S. Department of Energy (DOE) and the U.S. Defense Nuclear Agency (DNA). Actual *in situ* measurements were conducted by personnel from the DOE's Remote Sensing Laboratory, operated by EG&G Energy Measurements, Inc. In addition to the United States team, scientists from both the Kazakhstan National Nuclear Center and the Russian V.G. Khlopin Radium Institute of St. Petersburg conducted field measurements and collected soil samples for comparison data. Results from these measurements were published separately by the respective groups. Summary comparison data are presented in this report.

The *in situ* radiation survey was conducted as part of a Joint Statement of Intent between the United States government and the government of Kazakhstan, signed September 24, 1993, to assess the level and extent of contamination caused by Soviet nuclear testing. A visit to Kazakhstan was made by a United States team in November 1993 to evaluate existing data presented by the Russians and Kazakhstani. An aerial radiation survey, conducted by the Soviets over the entire test site in 1990 and 1991, provided a broad overview of the residual contamination. The United States team felt these data were adequate for a sitewide overview, but the data did not provide any information on potential plutonium contamination on the site. It was recommended that additional ground-based radiation measurements be conducted to address the potential plutonium problem and to help correlate the aerial survey results. The combined United States, Kazakhstani, and Russian effort of July 1994 was the result of these recommendations.

In situ measurements have proven to be a fast, sensitive, and reproducible method for quantifying the radionuclide activity in near-surface soils. The primary advantage of this type of measurement over the more traditional method using soil samples is the large area which is covered with each measurement. For a typical, uncollimated germanium detector, at a height of 1 m, this area is a circle approximately 10 m (33 ft) in diameter. Thus, a single measurement actually covers approximately ten thousand times as much area as a typical soil sample of 10 cm (4 in) in diameter. This large sample

size allows low-level activity to be detected within short measurement times. The large measurement area also helps to smooth out the local variations often found in contamination resulting from fallout from nuclear tests. These local variations often lead to erratic and nonreproducible results when soil samples are used to map a contaminated area. This is the case especially for plutonium contamination resulting from nonnuclear dispersal.

2.0 SYSTEMS AND PROCEDURES

The survey utilized two n-type, high-purity germanium detectors and battery-powered, 4,096-channel, portable analyzers. The detectors were mounted on a tripod with the face of the detector 1 m above ground. Figure 1 shows a typical setup for the field measurements.

The two detectors were 70 mm (2.8 in) in diameter, with lengths of 70 mm (2.8 in) and 79 mm (3 in). N-type germanium detectors were used because of their increased sensitivity at low energies compared to the standard, p-type germanium detector. This was important for maximizing sensitivity for the 60-keV gamma ray from americium-241 (^{241}Am), which is used to determine plutonium contamination from *in situ* measurements.

The detectors were calibrated for efficiency and angular response at the DOE's Remote Sensing Laboratory in Las Vegas, Nevada, prior to leaving for the survey. Figures 2 and 3 (see pages 3 and 4) show the results for one of the detectors. The other detector had similar efficiency and angular response curves. Individual conversion factors were developed for each detector using these calibration data, as described in the next section.

Ten primary survey areas were selected for the measurements. The areas are identified on Figure 4, which is a photocopy of the 1990 Soviet aerial survey data. Areas 1-4 were located within the atmospheric test field. Area 5 was located in the south plume identified from the aerial survey, and Areas 6 and 7 were in the southeast plume. Areas 8 and 9 were located near the cratering experiment site (Lake Chagan) in the Balapan test area. Area 10 was located in a typical natural background area near Kurchatov City. Twenty measurement locations were marked at each survey area. Figure 5 shows the layout, orientation, and numbering scheme used for the 20 measurement locations. For Areas 1-4 and 10, all 20 locations were measured. Because of the uniformity of the contamination found in these areas, only 10 locations were

FIGURE 1. IN SITU MEASUREMENT SYSTEM

FIGURE 2. DETECTOR EFFICIENCY CURVE

measured in the remaining five areas. The pattern used when only 10 locations were measured is also shown in Figure 5. Acquisition times varied from 5 minutes to 15 minutes. In most areas, a longer acquisition time was also used at the last location for

each system. This provided a check on potential low-level activity that might not have been detectable with the normal measurement times. Table 1 (see page 7) gives the actual coordinates for each survey area plus other pertinent data.

FIGURE 3. DETECTOR ANGULAR RESPONSE CURVE

The detector systems were set to a full-scale energy of 1.5 MeV. An energy calibration check was made each morning during initial equipment checkout in the laboratory, as well as prior to starting the measurements in the field. As a quality control check, a 5-minute background measurement was made in the laboratory before leaving for the field and again

after returning. These measurements showed no change in the efficiency of either detector during the course of the survey.

One detector did show a degradation in resolution by approximately a factor of two from the original value measured in Las Vegas. This detector

КАРТА ПЛОТНОСТИ ЗАГРЯЗНЕНИЯ ЦЕЗИЙ-137 И СТРОНЦИЙ-90

FIGURE 4. IN SITU SURVEY AREAS SUPERIMPOSED ON THE 1990 SOVIET AERIAL SURVEY RESULTS

FIGURE 5. SAMPLING PATTERN USED IN AREAS 1-10

continued to be used since the two backup detectors were experiencing vacuum problems and were not operational for most of the survey. The wider photopeak windows were compensated for in the data processing. The only impact on the survey results was in calculating the minimum detectable activity (MDA) value, which is a function of the background counts in a given photopeak window. The wider photopeak windows led to a higher value for the MDA for this detector compared to that of the other detector.

The original, planned survey was completed two days ahead of schedule. This allowed time for some

additional measurements to be made. The additional measurements concentrated on trying to better define the potential plutonium contamination within the atmospheric test field, primarily from tests which had little or no nuclear yield. Three potential plutonium plumes from Soviet tests conducted at test area P-7 (also referred to as test area P-2G) had been identified by the Russians. The plumes were thought to extend in directions of 33 degrees, 115 degrees, and 356 degrees from the P-7 site. Eight additional survey areas (Areas 11-18) were selected to try to verify the existence of these plumes. Figure 6 (see page 8) shows the locations of the survey areas, as well as the locations of the

Table 1. Survey Parameters for Areas 1-10

Area	Latitude	Longitude	Survey Date	Locations Measured	Acquisition Time (min)	Average Count Rate (cps)	Extended Measurement Time (min)
1	50°23'18"	77°53'30"	July 24	20	10	550	30
2	50°24'19"	77°51'18"	July 24	20	15	600	60
3	50°27'10"	77°49'16"	July 23	20	10	950	—
4	50°27'21"	77°48'32"	July 23	20	10	950	20
5	50°17'18"	77°40'54"	July 25	10	10	700	30
6	50°17'54"	77°54'42"	July 25	10	10	750	30
7	50°08'32"	78°04'18"	July 26	10	10	1,300	45
8	49°56'53"	79°00'11"	July 27	10	5	15,000	10
9	49°57'12"	79°03'40"	July 27	10	10	350	—
10	50°43'16"	78°26'22"	July 22	20	15	350	—

primary testing areas used by the Soviets in the atmospheric test field. Also shown are the locations of the original four survey areas measured in this part of the test site.

Test area P-1 was the site used for the first three atmospheric nuclear tests conducted in this area. The tests included the first Soviet nuclear test conducted in August 1949 and the first thermonuclear test conducted in August 1953. The southeast fall-out plume, shown in Figure 4, resulted from the 1953 test. The southern plume shown in Figure 4 apparently resulted from fallout from the second atmospheric test conducted at this location in September 1951. Test areas P-2, P-3, P-5, and P-7 were also used for atmospheric tests from 1954 to 1962.

For Areas 11-18, measurements were not made on a regular grid pattern. Four to eight locations were measured at each survey area in a random pattern, spaced approximately 10-30 m (33-98 ft) apart. Table 2 (see page 9) provides the coordinates for these areas, number of measurements, and measurement times. Coordinates were determined using a portable Global Positioning System (GPS) instrument located near the center of the random measurement locations.

In addition to these areas located on the site, five survey areas were measured in Kurchatov City. One measurement was made in each of the three school yards, one in front of the bakery, and two at an equipment storage location inside the Institute of Radiation Safety and Ecology.

3.0 CONVERSION FACTORS

Conversion factors have been calculated which relate the measured photopeak count-rate data to radionuclide activity in the soil. The values are determined by combining a laboratory measurement of the detector efficiency to a given energy gamma ray with a theoretical calculation of the gamma-ray flux arriving at the detector as a function of source distribution in the ground.

The unscattered gamma-ray flux, ϕ , from a point source with activity, S_0 , at a distance, r , from the source is given by

$$\phi = \frac{S_0}{4\pi r^2} e^{-r/\lambda_a} \quad (1)$$

FIGURE 6. SURVEY AREAS WITHIN THE ATMOSPHERIC TEST FIELD. Also shown are locations of Soviet Nuclear Test Areas.

Table 2. Survey Parameters for Areas 11-18

Area	Latitude	Longitude	Survey Date	Locations Measured	Acquisition Time (min)
11	50°24'08"	77°52'15"	July 28	8	10
12	50°24'00"	77°52'30"	July 28	6	10
13	50°23'53"	77°52'14"	July 28	4	10
14	50°24'13"	77°52'10"	July 28	4	10
15	50°24'27"	77°51'48"	July 28	4	10
16	50°26'24"	77°50'51"	July 29	6	10
17	50°27'12"	77°50'53"	July 29	4	10
18	50°22'11"	77°52'20"	July 29	4	10

where λ_a is the gamma-ray mean free path in air. This can also be written as

$$\phi = \frac{S_0}{4\pi r^2} e^{-(\mu/\rho)_a \rho_a r} \quad (2)$$

where

$(\mu/\rho)_a$ = air mass attenuation coefficient

ρ_a = air density

This expression can be expanded to the more general case of a source distributed within the ground. In this case, the unscattered flux of gamma rays of energy, E , at a height, h , above a smooth, air-ground interface due to an emitter distributed in the soil is given by

$$\phi = \int_0^\infty \int_0^\infty \frac{S_v}{4\pi r^2} e^{-(\mu/\rho)_a \rho_a r_a} e^{-(\mu/\rho)_s \rho_s r_s} 2\pi x dx dz \quad (3)$$

where

S_v = activity per unit volume
[(γ /sec)/cm³]

$r = r_a + r_s$ (cm)

$(\mu/\rho)_a, (\mu/\rho)_s$ = air and soil mass attenuation coefficients (cm²/g)

ρ_a, ρ_s = air and soil density (g/cm³)

A visible representation of these parameters is given by

This expression assumes a source distribution, which varies only with depth. A uniform distribution in the horizontal plane is assumed, which leads to results expressed in terms of an average value over the field-of-view of the detector.

The detector response to a given flux, ϕ , of gamma rays of energy, E , incident at an angle, θ , can be given in terms of an effective detector area, A , defined by

$$A = \frac{N_p}{\phi} \quad (4)$$

where N_p is the net photopeak count rate, normally given in units of counts per second (cps). The effective area, in general, varies as a function of the

gamma-ray angle of incidence and is usually written as

$$A = A_0 R(\theta) \quad (5)$$

where

A_0 = detector photopeak count rate for a unit flux incident perpendicular to the detector face [cps/(γ /sec $\cdot$ cm²)]

$R(\theta)$ = ratio of the detector response at an angle θ to that at $\theta = 0^\circ$

Combining Equations 4 and 5 with Equation 3 leads to an expression which relates the measured photopeak count rate to source activity in the ground. This is given by

$$N_p = \int_0^\infty \int_0^\infty \frac{S_v A_0 R(\theta)}{4\pi r^2} e^{[-(\mu/\rho)_a \rho_a r_a]} e^{[-(\mu/\rho)_s \rho_s r_s]} 2\pi x dx dz \quad (6)$$

In order to evaluate Equation 6, it is necessary to make an assumption on the source distribution with depth. Three primary types of source distributions are normally encountered in environmental measurements. Relatively fresh fallout activity is represented by a uniform surface distribution. A uniform volume distribution is assumed for naturally occurring background radiation. Fallout activity which has aged into the soil over a period of time is most often represented by an exponential distribution of the form

$$S_v = S_v^0 e^{-\alpha z} \quad (7)$$

where

S_v^0 = activity per unit volume at the surface (γ /sec)/cm³

α = reciprocal of the relaxation length (cm⁻¹)

For this often-utilized depth distribution, Equation 6 becomes

$$N_p = \frac{S_v^0 A_0}{2} \int_0^{\pi/2} \frac{R(\theta) \tan \theta e^{[-(\mu/\rho)_a \rho_a h \sec \theta]}}{\alpha + (\mu/\rho)_s \rho_s \sec \theta} d\theta \quad (8)$$

This expression relates the measured photopeak count rate, N_p , to the activity per unit volume at the surface, S_v^0 . The detector parameters, A_0 and $R(\theta)$, are obtained empirically for a given system using standard calibration sources. Mass attenuation coefficients for air and typical soils can be found in standard reference tables. Air density varies slowly with outside air temperature and atmospheric pressure and can also be found in standard reference tables. An average soil density of 1.5 g/cm³ is assumed unless actual measured values are available. The detector height, h , can be measured. The last parameter required to evaluate Equation 8 is α , which is usually measured in the field since it can vary with location and isotope. Artificial soil disturbance will also affect the value of this parameter.

In general, it is more useful to relate the photopeak count-rate data to an average concentration within a given depth rather than a surface concentration as given in Equation 8. The average concentration in the top z cm, S_v^z , for a source distributed exponentially with depth is given by

$$S_v^z = \frac{1}{z} \int_0^z S_v^0 e^{-\alpha z} dz = \frac{S_v^0}{\alpha z} (1 - e^{-\alpha z}) \quad (9)$$

Another result often required is the total activity per unit area. This is given by

$$S_A = \int_0^\infty S_v^0 e^{-\alpha z} dz = \frac{S_v^0}{\alpha} \quad (10)$$

The conversion factors derived for all three source distributions relate a measured photopeak count rate, expressed in units of cps, to source activity expressed in units of gammas per second per unit area or unit volume. For a specific isotope, the source activity is changed to units of curies or becquerels. The average activity per unit volume can also be converted to average activity per unit mass by dividing with the soil density.

Measurement results provided in the next section are given in units of becquerels per kilogram of soil (Bq/kg), averaged over the top 5 cm of soil. This averaging depth was chosen to correspond to the sample depth used for soil samples taken by the Russians and the Kazakhstanis. A relaxation length, $1/\alpha$, of 3 cm was used for ^{241}Am . A value of 10 cm was used for the other man-made isotopes. For the natural background radionuclides (uranium, thorium, and potassium), a uniform volume distribution was assumed. These were representative values based on soil profile data taken at the various United States nuclear test sites. A value of 1.5 g/cm³ was assumed for the soil density.

As part of the soil sampling program, both the Kazakhstani and Russian teams took a profile sample at the center of each survey area. Results from these measurements provided additional information on the typical depth distribution at the Semipalatinsk nuclear test site. The soil results, and their impact on the original United States data, are described after the discussion of the *in situ* results.

4.0 RESULTS

Initial processing of the measurement results was performed in Kurchatov City. Final processing was performed after the team returned to Las Vegas.

In order to maximize sensitivity, each spectrum was individually examined for potential photopeaks from man-made radionuclides. A photopeak window was set up for each potential photopeak that might be encountered. Background windows on either side were used to perform a straight-line background subtraction. The net result was then compared to the three-sigma value due to counting statistics in the photopeak and background windows to determine if a peak was actually present. Although this type of processing is slower than using an automated peak search routine, the method provides more reliability in identifying and properly extracting the net photopeak count rate for weak sources.

Results for Areas 1-10 are given in Table 3 (see pages 12-16) for the five man-made radionuclides, ^{241}Am , cesium-137 (^{137}Cs), cobalt-60 (^{60}Co), europium-152 (^{152}Eu), and europium-154 (^{154}Eu). Results include the activity, in units of Bq/kg averaged over the top 3 cm for ^{241}Am and 5 cm for the others, and the one-sigma error due to counting statistics. Results can be converted to units of picocuries per gram (pCi/g) by dividing with 37. When the

net counts were less than the three-sigma value, a notation of less than minimum detectable activity ($\leq \text{MDA}$) is given in the error column, with the calculated MDA value given in the results column. Results are given for each measurement location using the numbering system shown in Figure 5. Due to the uniform nature of the activity identified in each of the survey areas, results are only given for the ten location measurement patterns.

Figures 7-16 (see pages 17-26) show typical spectra obtained from each of the ten primary survey areas. Two spectra are shown for each area. The first shows the full 1.5-MeV spectrum on a logarithmic vertical scale. The second shows the first 400 keV on a linear vertical scale to better identify the presence or absence of the low-energy gamma rays. Gamma rays are identified for each of the five man-made radionuclides that were present, as well as those due to the naturally occurring radionuclides. Naturally occurring uranium-238 (^{238}U) is identified by the photopeaks from radium-226 (^{226}Ra) and its daughters, lead-214 (^{214}Pb) and bismuth-214 (^{214}Bi). Naturally occurring thorium-232 (^{232}Th) is identified from the photopeaks of lead-212 (^{212}Pb), actinium-228 (^{228}Ac), and thallium-208 (^{208}Tl). Natural potassium is identified by the 1,461-keV gamma ray from potassium-40 (^{40}K).

Areas 11-18 were measured specifically to detect the potential presence of ^{241}Am as an indicator of plutonium contamination arising from Soviet tests conducted at test area P-7. Three potential plumes had been identified by the Russians extending in directions of 33 degrees, 115 degrees, and 356 degrees from P-7. Figure 6 shows the locations of test area P-7 and survey Areas 11-18 relative to these potential plume paths. Results of the measurements for ^{241}Am are given in Table 4 (see page 27). These results can be converted to plutonium values by multiplying by ten, according to verbal information provided by the Russians during the *in situ* survey. Measurement locations for Areas 11-18 were not preselected but selected with the aid of a spare HPGe detector operated from a van. The van was driven to various locations and a short (1-minute) measurement was made out of the side of the vehicle, with the detector pointed towards the ground. A visual inspection of the portable analyzer display was made to determine if ^{241}Am was present. This system was used to help determine the locations for making the actual measurements using the tripod-mounted systems.

Table 3. Survey Results from Areas 1-10

Area Date	Stake ID No.	Am-241		Cs-137		Co-60		Eu-152		Eu-154	
		Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error
1 24-Jul-94	1	89.5	4.9	117.4	1.8	1.5	0.4	11.7	3.7	4.4	≤ MDA
	4	64.6	10.8	114.6	2.5	2.5	≤ MDA	19.9	≤ MDA	10.0	≤ MDA
	6	78.3	11.3	117.0	2.4	2.6	≤ MDA	19.9	≤ MDA	9.5	≤ MDA
	7	71.9	4.8	117.4	1.8	1.9	0.4	13.0	3.6	5.0	≤ MDA
	9	71.3	4.8	114.7	1.8	1.4	≤ MDA	15.3	3.7	5.2	≤ MDA
	12	61.0	11.2	106.4	2.4	2.5	≤ MDA	19.3	≤ MDA	9.3	≤ MDA
	14	64.1	11.2	109.9	2.5	2.7	≤ MDA	18.3	≤ MDA	9.5	≤ MDA
	15	31.5	4.7	90.5	1.8	1.4	≤ MDA	11.0	≤ MDA	5.2	≤ MDA
	17*	61.8	2.8	94.6	1.0	0.8	≤ MDA	10.3	1.9	2.8	≤ MDA
	18*	67.0	6.4	109.4	1.5	1.5	≤ MDA	12.5	≤ MDA	6.6	≤ MDA
	20	75.8	11.1	112.0	2.4	2.6	≤ MDA	18.6	≤ MDA	10.9	≤ MDA
Average Activity		67.0 Bq/kg		109.4 Bq/kg		1.9 Bq/kg		15.4 Bq/kg		7.1 Bq/kg	
Standard Deviation		14.5		9.1		0.7		3.8		2.8	
Minimum Activity		31.5		90.5		0.8		10.3		2.8	
Maximum Activity		89.5		117.4		2.7		19.9		10.9	
2 24-Jul-94	1	131.6	4.6	179.5	1.9	1.6	0.3	20.3	3.4	4.1	≤ MDA
	4	148.9	10.4	209.7	2.5	3.3	0.6	15.2	≤ MDA	8.5	≤ MDA
	6	143.1	10.0	179.6	2.4	1.5	≤ MDA	12.6	≤ MDA	8.8	≤ MDA
	7	115.9	4.6	176.1	1.9	1.7	0.4	15.6	3.4	4.1	≤ MDA
	9	103.6	4.4	177.5	1.9	1.6	0.4	17.4	3.4	3.8	≤ MDA
	12	138.7	10.1	195.5	2.4	2.4	0.6	13.1	≤ MDA	8.2	≤ MDA
	14	153.0	10.2	203.9	2.5	3.2	0.7	13.1	≤ MDA	8.3	≤ MDA
	15	84.9	4.5	188.7	2.0	2.2	0.3	19.5	3.5	3.0	≤ MDA
	17*	90.7	2.2	194.7	1.0	1.9	0.2	22.9	1.7	2.1	≤ MDA
	18*	110.7	5.0	193.9	1.2	2.3	0.4	6.6	≤ MDA	4.2	≤ MDA
	20	152.0	10.2	210.4	2.5	3.9	0.6	13.5	≤ MDA	8.8	≤ MDA
Average Activity		124.8 Bq/kg		191.8 Bq/kg		2.3 Bq/kg		15.4 Bq/kg		5.8 Bq/kg	
Standard Deviation		24.9		12.6		0.8		4.5		2.7	
Minimum Activity		84.9		176.1		1.5		6.6		2.1	
Maximum Activity		153.0		210.4		3.9		22.9		8.8	

* Measurement acquired using longer live-time counting interval

Error: ± one sigma counting error

≤ MDA: Minimum Detectable Activity [$3 \cdot \text{SQRT}(\text{Net Counts} + 2 \cdot \text{Background Counts}) \cdot \text{Conversion Factor}$]

Table 3. Survey Results from Areas 1-10 (continued)

Area (Date)	Stake ID No.	Am-241		Cs-137		Co-60		Eu-152		Eu-154	
		Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error
3 23-Jul-94	1	94.3	7.5	694.9	4.5	7.0	0.7	80.5	6.9	6.8	1.6
	4	193.1	18.0	1,009.1	6.2	13.3	1.1	99.7	12.9	11.8	≤ MDA
	6	144.2	16.8	737.8	5.2	10.4	0.9	76.9	11.1	15.5	3.1
	7	91.6	7.6	753.8	4.7	9.0	0.7	97.4	8.2	5.0	≤ MDA
	9	98.6	7.3	620.1	4.2	6.5	0.6	104.3	7.4	7.2	1.5
	12	136.4	16.4	652.1	5.2	7.7	0.9	58.0	10.6	10.2	≤ MDA
	14	144.5	16.3	683.4	5.0	8.8	0.9	96.5	10.6	10.2	≤ MDA
	15	78.5	7.2	631.6	4.2	6.4	0.6	90.0	7.5	4.8	≤ MDA
	17	144.7	7.9	1,028.7	5.4	10.2	0.8	171.7	9.1	7.6	1.8
	20	133.6	16.2	697.0	5.3	9.0	1.0	54.2	10.8	11.4	≤ MDA
Average Activity		126.0 Bq/kg		750.9 Bq/kg		8.8 Bq/kg		92.9 Bq/kg		9.1 Bq/kg	
Standard Deviation		34.8		147.5		2.1		32.6		3.4	
Minimum Activity		78.5		620.1		6.4		54.2		4.8	
Maximum Activity		193.1		1,028.7		13.3		171.7		15.5	
4 23-Jul-94	1	198.8	7.8	730.0	4.7	10.2	0.7	134.6	7.9	5.0	≤ MDA
	4	195.8	17.4	703.6	5.3	10.8	0.9	49.0	11.1	11.2	≤ MDA
	6	216.6	17.7	783.7	5.5	10.6	1.0	44.3	11.5	9.6	≤ MDA
	7	219.2	8.1	857.0	5.1	11.2	0.7	152.8	8.4	9.8	1.6
	9	188.2	8.0	804.9	4.9	9.6	0.8	149.6	8.2	6.8	1.7
	12	215.3	17.3	774.1	5.5	10.3	1.0	66.5	11.3	10.7	≤ MDA
	14	172.0	16.8	624.7	5.0	9.1	0.9	52.6	11.7	10.0	≤ MDA
	15	226.6	8.0	905.7	5.2	10.1	0.8	164.1	8.6	6.5	1.7
	17	198.5	7.9	786.4	4.8	9.5	0.7	144.6	8.1	7.2	1.6
	19*	168.2	5.4	637.1	3.0	7.3	0.5	104.4	4.5	4.3	≤ MDA
	20*	202.6	12.5	911.7	4.2	11.5	0.8	76.3	8.6	8.0	≤ MDA
Average Activity		200.2 Bq/kg		774.4 Bq/kg		10.0 Bq/kg		103.5 Bq/kg		8.1 Bq/kg	
Standard Deviation		18.8		96.1		1.2		47.0		2.3	
Minimum Activity		168.2		624.7		7.3		44.3		4.3	
Maximum Activity		226.6		911.7		11.5		164.1		11.2	

* Measurement acquired using longer live-time counting interval

Error: ± one sigma counting error

≤ MDA: Minimum Detectable Activity [$3 \cdot \text{SQRT}(\text{Net Counts} + 2 \cdot \text{Background Counts}) \cdot \text{Conversion Factor}$]

Table 3. Survey Results from Areas 1-10 (continued)

Area (Date)	Stake ID No.	Am-241		Cs-137		Co-60		Eu-152		Eu-154	
		Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error
5 25-Jul-94	1	15.8	≤ MDA	356.1	3.5	2.2	0.4	13.5	≤ MDA	5.2	≤ MDA
	4*	29.6	7.1	352.4	2.2	1.9	0.5	12.4	≤ MDA	5.5	≤ MDA
	6	39.8	≤ MDA	449.6	4.1	2.5	≤ MDA	21.5	≤ MDA	10.0	≤ MDA
	7*	20.4	2.9	380.9	1.8	0.8	≤ MDA	7.5	≤ MDA	2.5	≤ MDA
	9	31.1	5.4	484.0	3.6	1.4	≤ MDA	14.0	≤ MDA	5.0	≤ MDA
	12	38.0	≤ MDA	379.0	3.8	2.4	≤ MDA	20.9	≤ MDA	7.9	≤ MDA
	14	41.8	13.0	412.5	3.9	2.6	≤ MDA	20.6	≤ MDA	9.3	≤ MDA
	15	15.5	≤ MDA	393.8	3.6	1.5	≤ MDA	13.2	≤ MDA	5.2	≤ MDA
	17	17.8	5.4	472.0	3.8	1.4	≤ MDA	12.6	≤ MDA	5.0	≤ MDA
	20	40.2	12.7	422.7	4.0	2.9	≤ MDA	21.5	≤ MDA	10.4	≤ MDA
Average Activity		29.0 Bq/kg		410.3 Bq/kg		1.9 Bq/kg		15.8 Bq/kg		6.6 Bq/kg	
Standard Deviation		10.8		46.4		0.7		4.9		2.6	
Minimum Activity		15.5		352.4		0.8		7.5		2.5	
Maximum Activity		41.8		484.0		2.9		21.5		10.4	
6 25-Jul-94	1	137.4	6.7	214.3	2.6	2.2	0.5	27.6	5.0	5.8	≤ MDA
	4*	218.7	8.3	216.4	1.9	2.6	0.6	15.6	4.8	6.5	≤ MDA
	6	276.5	14.9	254.4	3.3	3.1	≤ MDA	43.7	7.2	11.8	≤ MDA
	7*	80.6	3.3	129.4	1.2	1.3	0.3	29.3	2.5	3.2	≤ MDA
	9	119.4	6.4	229.4	2.7	1.9	0.5	34.9	4.8	5.6	≤ MDA
	12	160.2	14.2	208.2	3.2	3.4	1.0	21.2	6.6	11.1	≤ MDA
	14	146.9	14.4	208.2	3.1	3.0	≤ MDA	29.1	7.0	10.4	≤ MDA
	15	141.3	6.3	214.0	2.5	2.4	0.5	32.1	4.8	5.8	≤ MDA
	17	115.1	6.5	239.6	2.7	1.8	≤ MDA	30.4	4.9	5.8	≤ MDA
	20	148.8	14.4	211.0	3.2	2.9	≤ MDA	27.5	5.5	11.1	≤ MDA
Average Activity		154.5 Bq/kg		212.5 Bq/kg		2.5 Bq/kg		29.1 Bq/kg		7.7 Bq/kg	
Standard Deviation		55.6		32.9		0.7		7.5		3.1	
Minimum Activity		80.6		129.4		1.3		15.6		3.2	
Maximum Activity		276.5		254.4		3.4		43.7		11.8	

* Measurement acquired using longer live-time counting interval

Error: ± one sigma counting error

≤ MDA: Minimum Detectable Activity [$3 * \text{SQRT} (\text{Net Counts} + 2 * \text{Background Counts}) * \text{Conversion Factor}$]

Table 3. Survey Results from Areas 1-10 (continued)

Area (Date)	Stake ID No.	Am-241		Cs-137		Co-60		Eu-152		Eu-154	
		Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error
7 26-Jul-94	1	19.4	≤ MDA	856.9	4.8	8.5	0.7	134.4	7.5	5.6	≤ MDA
	4*	29.8	8.4	741.2	2.6	6.2	0.5	43.7	5.3	5.8	≤ MDA
	6*	19.5	3.3	717.2	2.1	6.5	0.3	94.3	3.1	2.9	≤ MDA
	7	17.9	≤ MDA	775.6	5.4	7.1	1.0	76.2	10.2	11.2	≤ MDA
	9	19.8	≤ MDA	877.3	4.8	8.2	0.7	122.8	7.5	5.8	≤ MDA
	12	18.0	≤ MDA	830.2	5.5	6.9	1.0	59.4	10.5	11.2	≤ MDA
	14	19.6	≤ MDA	810.0	4.6	7.3	0.6	121.6	7.4	5.8	≤ MDA
	15	59.5	18.2	852.0	5.5	8.2	1.0	85.9	10.3	11.4	≤ MDA
	17	19.8	≤ MDA	856.5	4.8	8.0	0.7	115.1	7.5	5.8	≤ MDA
	20	54.5	18.1	853.5	5.6	8.3	1.0	63.9	10.4	12.1	≤ MDA
Average Activity		27.8 Bq/kg		817.0 Bq/kg		7.5 Bq/kg		91.7 Bq/kg		7.7 Bq/kg	
Standard Deviation		15.8		54.8		0.8		31.0		3.3	
Minimum Activity		17.9		717.2		6.2		43.7		2.9	
Maximum Activity		59.5		877.3		8.5		134.4		12.1	
8 27-Jul-95	1*	110.5	23.0	6,800.8	15.1	1,816.5	8.2	2,419.7	30.2	1,021.3	11.2
	4*	171.3	55.5	8,581.3	23.7	2,279.8	11.5	3,282.0	75.2	1,125.0	19.8
	6	98.7	≤ MDA	5,476.7	19.1	1,618.3	10.7	2,223.9	40.5	913.6	15.0
	7	262.7	73.7	6,779.2	28.5	1,905.2	13.9	3,363.9	117.0	923.8	23.4
	9	161.9	34.8	7,369.7	22.6	2,126.5	12.4	2,864.0	46.4	1,203.6	17.8
	12	269.5	77.8	6,713.8	28.5	1,735.5	13.8	2,900.3	109.5	856.4	22.7
	14	115.7	≤ MDA	10,165.2	26.7	2,882.8	14.6	4,025.5	54.5	1,603.9	21.4
	15	248.2	≤ MDA	8,316.9	32.6	2,390.7	16.6	4,077.4	124.2	1,166.9	28.2
	17	150.2	36.4	7,233.9	22.3	2,419.9	12.8	3,221.8	47.6	1,322.3	18.9
	20	313.9	80.3	6,986.2	29.5	2,037.1	14.9	3,318.1	116.8	1,076.0	25.2
Average Activity		190.3 Bq/kg		7,442.4 Bq/kg		2,121.2 Bq/kg		3,169.7 Bq/kg		1,121.3 Bq/kg	
Standard Deviation		76.9		1,290.1		382.3		601.3		222.7	
Minimum Activity		98.7		5,476.7		1,618.3		2,223.9		856.4	
Maximum Activity		313.9		10,165.2		2,882.8		4,077.4		1,603.9	

* Measurement acquired using longer live-time counting interval

Error: ± one sigma counting error

≤ MDA: Minimum Detectable Activity [$3 * \text{SQRT}(\text{Net Counts} + 2 * \text{Background Counts}) * \text{Conversion Factor}$]

Table 3. Survey Results from Areas 1-10 (concluded)

Area (Date)	Stake ID No.	Am-241		Cs-137		Co-60		Eu-152		Eu-154	
		Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error
9 27-Jul-94	1	13.7	≤ MDA	43.5	1.2	1.4	≤ MDA	9.6	≤ MDA	5.6	≤ MDA
	4	31.5	≤ MDA	50.6	1.9	2.6	≤ MDA	17.1	≤ MDA	10.2	≤ MDA
	6	13.9	≤ MDA	42.7	1.3	1.6	≤ MDA	10.4	≤ MDA	5.2	≤ MDA
	7	26.3	≤ MDA	48.8	1.9	2.5	≤ MDA	13.0	≤ MDA	7.9	≤ MDA
	9	13.9	≤ MDA	43.6	1.3	1.6	≤ MDA	10.4	≤ MDA	5.2	≤ MDA
	12	26.1	≤ MDA	46.3	1.9	2.5	≤ MDA	13.0	≤ MDA	7.9	≤ MDA
	14	13.9	≤ MDA	42.7	1.3	1.5	≤ MDA	10.4	≤ MDA	5.2	≤ MDA
	15	26.4	≤ MDA	51.7	1.9	2.2	≤ MDA	13.0	≤ MDA	8.6	≤ MDA
	17	13.6	≤ MDA	40.6	1.3	1.4	≤ MDA	10.1	≤ MDA	5.4	≤ MDA
	20	26.2	≤ MDA	42.3	1.9	2.2	≤ MDA	11.1	≤ MDA	8.8	≤ MDA
Average Activity		20.6 Bq/kg		45.3 Bq/kg		1.9 Bq/kg		11.8 Bq/kg		7.0 Bq/kg	
Standard Deviation		7.3		3.9		0.5		2.2		1.9	
Minimum Activity		13.6		40.6		1.4		9.6		5.2	
Maximum Activity		31.5		51.7		2.6		17.1		10.2	
10 22-Jul-94	1	10.6	≤ MDA	13.2	0.7	1.1	≤ MDA	7.3	≤ MDA	4.0	≤ MDA
	4	24.6	≤ MDA	30.0	1.5	1.9	≤ MDA	12.8	≤ MDA	7.1	≤ MDA
	6	24.7	≤ MDA	15.6	1.3	2.0	≤ MDA	12.8	≤ MDA	7.3	≤ MDA
	7	10.3	≤ MDA	12.8	0.7	1.0	≤ MDA	7.5	≤ MDA	4.0	≤ MDA
	9	10.6	≤ MDA	11.6	0.7	1.0	≤ MDA	7.5	≤ MDA	4.4	≤ MDA
	12	24.6	≤ MDA	12.8	1.3	2.0	≤ MDA	13.3	≤ MDA	8.2	≤ MDA
	14	24.7	≤ MDA	16.0	1.3	2.1	≤ MDA	13.1	≤ MDA	8.0	≤ MDA
	15	10.4	≤ MDA	14.4	0.7	1.2	≤ MDA	7.3	≤ MDA	4.1	≤ MDA
	17	10.4	≤ MDA	14.8	0.7	1.0	≤ MDA	7.7	≤ MDA	3.7	≤ MDA
	20	24.6	≤ MDA	10.6	1.4	1.9	≤ MDA	13.3	≤ MDA	8.2	≤ MDA
Average Activity		17.6 Bq/kg		15.2 Bq/kg		1.5 Bq/kg		10.3 Bq/kg		5.9 Bq/kg	
Standard Deviation		7.5		5.5		0.5		3.0		2.0	
Minimum Activity		10.3		10.6		1.0		7.3		3.7	
Maximum Activity		24.7		30.0		2.1		13.3		8.2	

Error: ± one sigma counting error

≤ MDA: Minimum Detectable Activity [$3 * \text{SQRT}(\text{Net Counts} + 2 * \text{Background Counts}) * \text{Conversion Factor}$]

Areas 11-15 were measured to attempt to confirm and then define the potential plume extending in a direction of 33 degrees from P-7. The first measurement made at Area 11 showed easily detectable ²⁴¹Am. While measurements were being made in

this area, the van system drove closer to the projected 33-degree line. The ²⁴¹Am activity dropped significantly as the van moved from Area 11 closer to the 33-degree line. Areas 12 and 13 were selected along a road near the edge of where the

STS Survey: Location #1: Stake #17
 24-Jul-94 at 1819; LT= 1800 secs
 Detector: 34-TN30888; MCA: 5856

Location #1; Stake #17
 Expanded Energy Region: 10 to 400 keV

FIGURE 7. SPECTRAL DATA OBTAINED IN AREA 1

STS Survey: Location #2: Stake #17
 24-Jul-94 at 1221; LT= 3600 seconds
 Detector: 34-TN30888: MCA: 5856

Location #2: Stake #17
 Expanded Energy Region: 10 to 400 keV

FIGURE 8. SPECTRAL DATA OBTAINED IN AREA 2

STS Survey: Location #3; Stake #1
 23-Jul-94 at 1106; LT= 600 seconds
 Detector: 34-TN30888; MCA: 5856

Location #3; Stake #1
 Expanded Energy Region: 10 to 400 keV

FIGURE 9. SPECTRAL DATA OBTAINED IN AREA 3

FIGURE 10. SPECTRAL DATA OBTAINED IN AREA 4

STS Survey: Location #5; Stake #7
 25-Jul-94 at 1606; LT= 1800 seconds
 Detector: 34-TN30888; MCA: 5856

Location: #5; Stake #7
 Expanded Energy Region: 10 to 400 keV

FIGURE 11. SPECTRAL DATA OBTAINED IN AREA 5

STS Survey: Location #6; Stake #7
 25-Jul-94 at 1147; LT=1800 seconds
 Detector: 34-TN30888; MCA: 5856

Location #6; Stake #7
 Expanded Energy Region: 10 to 400 keV

FIGURE 12. SPECTRAL DATA OBTAINED IN AREA 6

Marker: 4072 = 1560.75keV 0Cnts
L7_6XD.CHN

STS Survey: Location #7; Stake #6
26-Jul-94 at 1237; LT= 2700 seconds
Detector: 34-TN30888; MCA: 5856

Display
☐ MCB ☒ Buffer
MCB#1 SEG#1
☒ Full ☐ Expand
Vert: LOG
Horz: 4096
ROI: Unmark

Time
Start 12:37:00
26-Jul-94
Real 2759.00
Live 2700.00
Dead %

Marker: 1036 = 398.14keV 694Cnts

Location #7; Stake #6
Expanded Energy Region: 10 to 400 keV

Display
☐ MCB ☒ Buffer
MCB#1 SEG#1
☐ Full ☒ Expand
Vert: 16K
Horz: 1024
ROI: Unmark

Time
Start 12:37:00
26-Jul-94
Real 2759.00
Live 2700.00
Dead %

FIGURE 13. SPECTRAL DATA OBTAINED IN AREA 7

Marker: 4072 = 1561.56keV 0Cnts

STS Survey: Location #8; Stake #1
27-Jul-94 at 1526; LT= 600 seconds
Detector: 34-TN30888; MCA: 5856

Display
☐ MCB ☒ Buffer
MCB#1 SEG#1
☒ Full ☐ Expand
Vert: LOG
Horz: 4096
ROI: Unmark

Time
Start 15:26:00
27-Jul-94
Real 754.00
Live 600.00
Dead %

Marker: 144 = 56.64keV 11655Cnts

Location #8; Stake #1
Expanded Energy Region: 10 to 400 keV

Display
☐ MCB ☒ Buffer
MCB#1 SEG#1
☐ Full ☒ Expand
Vert: 32K
Horz: 1024
ROI: Off

Time
Start 15:26:00
27-Jul-94
Real 754.00
Live 600.00
Dead %

FIGURE 14. SPECTRAL DATA OBTAINED IN AREA 8

STS Survey: Location # 9; Stake # 1
 27-Jul-94 at 1213; LT= 600 seconds
 Detector: 34-TN30688; MCA: 5856

Location # 9; Stake # 1
 Expanded Energy Region: 10 to 400 keV

FIGURE 15. SPECTRAL DATA OBTAINED IN AREA 9

STS Survey: Location #10; Stake #11
 22-Jul-94 at 1247; LT= 900 seconds
 Detector: 34-TN30888; MCA: 5856

Location #10; Stake #11
 Expanded Energy Region: 10 to 400 keV

FIGURE 16. SPECTRAL DATA OBTAINED IN AREA 10

Table 4. Survey Results from Areas 11-18 for Americium-241							
Area (Date)	Sample ID No.	Am-241		Statistical Summary			
		Bq/kg	± Error	Average	Std Dev	Minimum	Maximum
11 28-Jul-94	11.1C	232.3	13.1	249.5	60.1	197.8	365.4
	11.2C	219.2	13.0				
	11.3C	199.6	13.0				
	11.4C	224.0	13.0				
	11.1D	197.8	6.3				
	11.2D	365.4	7.2				
	11.3D	239.5	6.5				
	11.4D	318.3	6.9				
12 28-Jul-94	12.1C	88.7	11.2	63.2	22.6	31.9	88.7
	12.2C	80.6	11.4				
	12.3C	58.8	11.2				
	12.1D	76.8	5.5				
	12.2D	31.9	5.1				
	12.3D	42.7	5.1				
13 28-Jul-94	13.1C	91.0	12.0	73.3	11.9	64.8	91.0
	13.2C	64.8	12.2				
	13.1D	69.0	5.4				
	13.2D	68.5	5.4				
14 28-Jul-94	14.1C	428.8	14.6	464.2	43.4	428.8	524.4
	14.2C	436.6	15.0				
	14.1D	524.4	7.9				
	14.2D	466.9	7.7				
15 28-Jul-94	15.1C	214.8	12.4	151.7	45.0	113.1	214.8
	15.2C	152.1	13.1				
	15.1D	126.9	5.7				
	15.2D	113.1	5.7				
16 29-Jul-94	16.1C	54.5	8.9	39.0	9.3	30.8	54.5
	16.2C	42.2	9.0				
	16.3C	42.5	9.0				
	16.1D	31.3	6.0				
	16.2D	32.8	6.0				
	16.3D	30.8	6.0				
17 29-Jul-94	17.1C	24.7	≤ MDA	27.7	7.1	22.1	38.0
	17.2C	22.1	4.7				
	17.1D	38.0	5.4				
	17.2D	26.1	2.1				
18 29-Jul-94	18.1C	925.1	16.8	1,006.9	172.8	843.8	1,244.0
	18.2C	1,244.0	17.5				
	18.1D	843.8	9.7				
	18.2D	1,014.8	9.5				

Error: ± one sigma counting error

MDA: Minimum Detectable Activity [$3 \cdot \text{SQRT}(\text{Net Counts} + 2 \cdot \text{Background Counts}) \cdot \text{Conversion Factor}$]

van system could detect ^{241}Am . While these measurements were being made, the van moved in the opposite direction from Area 11 and found increasing activity. Area 14 was selected in an area typical of the ^{241}Am activity found by the van during spot measurements made approximately 100 m (33 ft) apart along the road between Areas 11 and 15. The van system showed a dropoff in activity past Area 14, with ^{241}Am barely detectable just past the site of the Area 15 measurements. These data suggest, supplemented by the van results, that a plume of plutonium extends in this general direction. However, it seems to lie in a direction closer to 20 degrees from P-7 rather than the 33 degrees originally assumed. At a distance of 3 km (1.9 mi) from P-7, the plume appears to be approximately 1 km wide. Activity levels at Area 14 are typical of those across the center of the plume.

Measurements were made at Areas 16 and 17 to attempt to detect the 356-degree plume. Even though the van was driven back and forth across the projected location of this plume, the system was not able to detect any elevated activity. Measurements were made at Areas 16 and 17 to document the levels along this line. The results showed values that were barely above the MDA in this region of the site.

In order to detect the potential plume at 115 degrees, the van system was driven cross-country along a north-to-south line selected to cross the suspected plume. Spot measurements were made approximately every 300 m (984 ft). The location which showed the highest activity during this transect was chosen as Area 18. The area is approximately 1.5 km (0.9 mi) from test area P-7 at an angle of approximately 130 degrees. Americium-241 was detected by the van system to a distance of 1,500 m (4,920 ft) north of Area 18. The 1-minute measurement made at 1,800 m (5,904 ft) north did not show any obvious ^{241}Am activity. Only two van measurements were made south of Area 18, at distances of approximately 350 m (1,148 ft) and 700 m (2,296 ft). Both showed easily detectable ^{241}Am but at levels less than one-half that found at Area 18. The activity level for ^{241}Am was more than twice as high at Area 18 as at Area 14, which was the next highest value measured. Thus, it appeared that a plume containing elevated americium (and therefore plutonium) extended outward in this general direction. The north-to-south transect made by the van showed detectable ^{241}Am from 1,500 m (4,920 ft) north to more than 700 m (2,296 ft) south of the Area 18 location. This suggests a rather wide plume, at least

along this transect located approximately 1.5 km (0.9 mi) from test area P-7.

Six additional measurements, in five survey areas, were made within Kurchatov City. Results from these measurements are given in Table 5. Comparison data from Areas 1-10 are given in Table 6. Only natural background and ^{137}Cs , typical of worldwide fallout, were found at these locations, with the exception of the measurements made at the Institute. The spectral data from the Institute showed a weak but still detectable peak at 60 keV from ^{241}Am . The calculated activity level was approximately 30 Bq/kg. Figure 17 (see page 31) shows a typical spectrum obtained in Kurchatov City. Figure 18 (see page 32) shows the spectrum obtained at the Institute.

5.0 COMPARISON WITH THE RUSSIAN AND KAZAKHSTANI RESULTS

In order to provide comparison data for the United States *in situ* measurements, both the Russian and Kazakhstani teams collected soil samples at each of the ten primary measurement areas. In addition, the Russian team also conducted measurements with their germanium-based *in situ* system. Detailed results of these measurements were given in separate reports by each country. The following provides a summary of these results and a comparison to those obtained by the United States team.

Three types of soil sample data were taken. At the center of each measurement area, a profile measurement was made. Samples were collected at depths of 0-2, 2-4, 4-6, 6-8, 8-10, 10-15, and 15-20 cm (0-8 in) by the Russian team and at depths of 0-5, 5-10, 10-15, and 15-20 cm by the Kazakhstani team. A single composite sample was made for each area by combining a 20-cm soil sample taken at each corner and at the center. This composite sample was mixed and then divided between the Russian and Kazakhstani teams for independent laboratory analysis. In addition, the Russian team collected a 5-cm-deep sample at each corner and the center of each area. These five samples were analyzed separately to provide information on the variability of the activity within each measurement area. Each country analyzed its soil sample data in the laboratory with germanium detectors.

Profile data are required to provide information on the depth distribution for each isotope. Generally, fallout activity which has weathered into the soil with

Table 5. Survey Results from Measurements in Kurchatov City*								
Survey Areas	Cs-137		K-40		Bi-214		Ti-208	
	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error
Bread Factory	5.1	1.7	664.9	13.7	75.6	2.9	8.7	1.0
School near Hotel	16.9	1.7	640.0	13.5	50.6	2.6	8.7	1.0
School near Market (Soccer Field, dirt & grass)	5.2	0.8	685.0	12.5	46.2	1.8	8.0	0.8
School next to the School near Hotel (Soccer Field, cinder & coal)	7.7	0.8	686.9	12.5	46.6	1.8	9.5	0.8
Institute – Bldg #25A front: dirt & grass	22.6	1.8	705.9	15.0	89.3	3.1	8.8	1.2
side: near road	20.6	1.2	642.8	12.3	93.1	2.5	9.0	0.9

* Comparison data for Areas 1-10 are given in Table 6.

Error: ± one sigma counting error

time takes the form of an exponential distribution, as previously given in Equation 7. Prior to obtaining the measurement results, it was necessary to assume a depth distribution to process the *in situ* data. Results given in Tables 3-6 are based on the assumed depth distribution. These results can be corrected to provide better quantitative data using results of the measured depth distribution. Table 7 shows the values which were assumed for each isotope, the actual measured values, and the corresponding correction factor for the *in situ* data.

Depth profile data for ^{137}Cs could be obtained at all the measurement areas. Results for the depth distribution parameter, α , for Areas 1-9 varied from 0.23 to 0.53 with an average value of 0.38, which is quite different from the assumed value of 0.10. In Area 10, a value of 0.01 was obtained. This represents a uniform distribution with depth over the top 20-30 cm (8-12 in). This particular area had been ploughed a number of times for farming, which accounts for the different depth distribution. Because this area was so different, correction factors and comparison data are given only for Areas 1-9. Depth profile data could be obtained in only two areas for ^{241}Am and in one area for the remaining isotopes. The activity levels for these isotopes in the other areas was too low to be detectable within the profile samples collected.

All results in Tables 3-6 should be multiplied by the correction factor given in Table 7 to provide the best data. It can be seen that the correction factor is quite small for all the isotopes. This is primarily due to the fact that the *in situ* results were given in terms of an average value over the top 5 cm of soil. At this shallow averaging depth, variations in actual depth distribution do not greatly affect the calculated results. This is not the case for deeper distributions. For comparison with the 20-cm soil samples, it is critical to use the correct depth distribution.

Tables 8 and 9 (see pages 34 and 35) summarize the corrected data for the United States *in situ* measurements. Values are given for the average activity in the top 5 cm in Table 8 and in the top 20 cm in Table 9. If an entry is marked "MDA" in either of these tables, fewer than five measurements at the site were recorded above the minimum detectable activity of the instrument. Results are given in units of Bq/kg for comparison to the Russian and Kazakhstani data. Also given in each table is a value for the "stored activity" within each averaging depth. This is a value routinely used by both the Russians and Kazakhstanis. It represents the total activity per unit area within the appropriate depth of soil, given in units of $\mu\text{Ci}/\text{m}^2$.

Table 6. Natural Background and Cesium-137 Results from Areas 1-10

Area (Date)	Stake ID No.	Cs-137		K-40		Bi-214		TI-208	
		Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error	Bq/kg	± Error
1	17*	94.6	1.0	556.7	6.4	27.9	0.8	8.9	0.5
24-Jul-94	18*	109.4	1.5	572.5	7.9	34.0	1.9	8.6	0.9
2	17*	194.7	1.0	598.4	4.7	18.7	0.6	8.8	0.4
24-Jul-94	18*	193.9	1.2	549.3	5.8	22.4	1.2	7.2	0.5
3	1	694.9	4.5	615.4	12.1	21.1	1.9	7.7	1.2
23-Jul-94	4	1,009.1	6.2	622.2	13.5	23.1	4.3	5.5	1.7
4	19*	637.1	3.0	643.0	8.8	23.4	1.2	9.8	0.8
23-Jul-94	20*	911.7	4.2	624.5	9.7	18.4	3.0	6.3	1.2
5	4*	352.4	2.2	425.2	7.0	32.4	1.7	3.9	0.6
25-Jul-94	7*	380.9	1.8	447.7	5.7	31.6	0.9	8.4	0.5
6	4*	216.4	1.9	770.3	8.6	25.8	1.8	8.0	0.7
25-Jul-94	7*	129.4	1.2	811.8	7.7	24.1	0.9	12.0	0.5
7	4*	741.2	2.6	745.0	7.5	27.5	1.9	6.5	0.7
26-Jul-94	6*	717.2	2.1	805.1	6.3	35.6	0.9	13.2	0.6
8	1*	6,800.8	15.1	549.8	16.9	20.9	≤ MDA	13.7	≤ MDA
27-Jul-94	4*	8,581.3	23.7	487.1	31.3	52.5	≤ MDA	19.0	≤ MDA
9	1	43.5	1.2	589.5	11.5	35.0	1.5	7.2	0.7
27-Jul-94	4	50.6	1.9	616.8	13.0	31.1	2.6	6.1	1.0
10	1	13.2	0.7	649.6	9.8	16.1	1.1	8.3	0.6
22-Jul-94	4	30.0	1.5	647.7	11.3	18.5	2.0	5.5	0.8

* Measurement acquired using longer live-time counting interval

Error: ± one sigma counting error

MDA: Minimum Detectable Activity [$3 \cdot \text{SQRT} (\text{Net Counts} + 2 \cdot \text{Background Counts}) \cdot \text{Conversion Factor}$]

Table 10 (see page 36) compares the United States *in situ* data with the average results obtained by the Russians for the 5-cm-deep soil sample data. Results are given for ^{241}Am , ^{137}Cs , and ^{40}K . The agreement for ^{241}Am and ^{137}Cs is quite good in

some areas and off by factors of 2 or 3 in other areas. This is primarily due to the variability of the contamination within each area. Because the *in situ* system averages over a much larger area than a typical soil sample, it is not unusual to see these

STS Survey: Kurchatov City; School near market; Middle of soccer field; dirt and grass terrain
 29-Jul-94 at 1637; LT=600 seconds
 Detector: 34-TN30888; MCA: 5856

Kurchatov City; School near market; Middle of Soccer Field
 Expanded Energy Region: 10 to 400 keV

FIGURE 17. SPECTRAL DATA OBTAINED IN KURCHATOV CITY

Kurchatov City: Institute - in front of building # 25A; terrain is grass, dirt & weeds
 29-Jul-94 at 1741; LT= 600 secs
 Detector: 34-TN30888; MCA: 5856

Kurchatov City: Institute - in front of building # 25A
 Expanded Energy Region: 10 to 400 keV

FIGURE 18. SPECTRAL DATA OBTAINED AT THE INSTITUTE

Table 7. Depth Distribution Correction Factors			
Assumed Exponential Distribution $Y = A \exp(-Bz)$			
Isotope	B (assumed)	B (measured) ^a	Correction Factor ^b
Am-241	0.33	0.35 (2)	0.98
Cs-137	0.10	0.38 (9)	0.93
Co-60	0.10	0.20 (1)	1.04
Eu-152	0.10	0.32 (1)	1.03
Eu-154	0.10	0.23 (1)	1.03

^a Number of sites with measurable profile data given in parentheses.

^b Multiplication factor to correct original U.S. *in situ* data presented in Tables 3-6. Results in Bq/kg averaged over the top 5 cm.

kinds of variations in comparing soil sample with *in situ* data. The comparison with ⁴⁰K is much better over all the areas. Potassium-40 is a naturally occurring radionuclide and is fairly uniform in distribution within a given area. Therefore, it is normal to see better quantitative agreement for this and the other natural background radionuclides.

Table 11 (see page 37) shows the comparison for ¹³⁷Cs between the United States *in situ* data and the 20-cm composite samples analyzed by both the Russians and the Kazakhstans. Two values are given for the Kazakhstani data since their sample was further divided in two and independently analyzed in two separate laboratories. Also shown for comparison are the results of the Russian *in situ* measurements and their 1991 aerial survey data. The aerial survey results are those reported by the Russians based on a more complete set of data taken in 1991, with much closer line spacings, than that shown in Figure 4, which was obtained in 1990. The *in situ* measurements and the aerial data represent area-averaging techniques which tend to smooth out local variations in contamination. With the very localized sampling inherent in soil sample analysis, these types of variations can cause large variations in results. Even for common samples, such as the original composite used here for all sets of soil sample analysis, mixing is not perfect, and variations in results from different aliquots are often observed. Considering the above, the overall comparison between the various results is quite good.

This is especially true for the *in situ* data taken by both the Russian and the United States teams.

The agreement between the *in situ* data and the aerial data is also quite good for most areas. The major exception is Area 8. The activity in this area has a very sharp gradient going away from the Lake Chagan crater. This condition often leads to disagreement between aerial and *in situ* data, with the aerial data normally showing lower values, as it does here. The aerial data were collected in a helicopter at altitudes between 50 and 80 m (164 and 262 ft). At these altitudes, the field-of-view of the aerial system was approximately 200-400 m (656-1,312 ft) in diameter, compared to approximately 10 m (33 ft) in diameter for the *in situ* systems. The much larger averaging area obviously has included areas with lower activity than the area measured with the *in situ* systems, leading to a lower average value.

A more complete comparison between the United States and Russian *in situ* data is given in Table 12 (see page 38). The Russian data are an average of five measurements made within each survey area, while the United States data are an average over ten measurement areas. Although somewhat different areas were averaged, the overall agreement between the two sets of measurements is extremely good. The fact that two completely different *in situ* systems, independently calibrated in two different countries, gave such good comparison that data provide a strong justification for using this type of measurement technique.

Table 8. Corrected <i>In Situ</i> Survey Results for 5-cm Depth					
Average Concentration in Top 5 cm (Bq/Kg)*					
Site	Am-241	Cs-137	Co-60	Eu-152	Eu-154
1	66 ± 14	102 ± 8	2.1 (MDA)	18 (MDA)	7.3 (MDA)
2	122 ± 24	178 ± 12	2.4 ± 0.8	19 ± 3	6.0 (MDA)
3	123 ± 34	698 ± 137	9.2 ± 2.2	96 ± 34	9.2 (MDA)
4	196 ± 28	720 ± 89	10 ± 1.3	107 ± 48	8.7 (MDA)
5	30 ± 10	382 ± 43	2.0 (MDA)	16 (MDA)	6.8 (MDA)
6	151 ± 54	198 ± 31	2.4 ± 0.7	30 ± 8	7.9 (MDA)
7	19 (MDA)	760 ± 51	7.8 ± 0.8	94 ± 32	7.9 (MDA)
8	202 ± 74	6,921 ± 1,200	2,206 ± 398	3,265 ± 619	1,155 ± 229
9	20 (MDA)	42 ± 4	2.0 (MDA)	12 (MDA)	7.2 (MDA)
Stored Activity in Top 5 cm (μCi/m ²)					
Site	Am-241	Cs-137	Co-60	Eu-152	Eu-154
1	0.13	0.21	MDA	MDA	MDA
2	0.25	0.36	0.005	0.04	MDA
3	0.25	1.41	0.02	0.19	MDA
4	0.40	1.46	0.02	0.22	MDA
5	0.06	0.77	MDA	MDA	MDA
6	0.31	0.40	0.005	0.06	MDA
7	MDA	1.54	0.02	0.19	MDA
8	0.41	14.0	4.5	6.6	2.3
9	MDA	0.09	MDA	MDA	MDA

* Average ± standard deviation for all measurements in each site which gave a positive result.

MDA – Minimum Detectable Activity

Note: MDAs are 0.04 (Am-241), 0.004 (Co-60), 0.03 (Eu-152), and 0.015 (Eu-154).

6.0 SUMMARY

The measurements made in the atmospheric test field (Areas 1-4) showed man-made activity from ¹³⁷Cs, ²⁴¹Am, ⁶⁰Co, and ¹⁵²Eu. Areas 3 and 4 showed much higher levels of ¹³⁷Cs, ⁶⁰Co, and ¹⁵²Eu than Areas 1 and 2. Three measurements were made in areas identified as fallout plumes from

the 1990 Soviet aerial survey. Area 5 was located in the southern plume and showed primarily ¹³⁷Cs activity, with very weak levels of ²⁴¹Am and ⁶⁰Co. Two measurements were made in the southeast plume. The one closest to the atmospheric test field, Area 6, showed stronger ²⁴¹Am but weaker ¹³⁷Cs, ⁶⁰Co, and ¹⁵²Eu than Area 7, which was further away. Area 8, approximately 1.5 km (0.9 mi) from

Table 9. <i>In Situ</i> Survey Results for 20-cm Depth				
Average Concentration in Top 20 cm (Bq/Kg)				
Site	Am-241	Cs-137	Co-60	Eu-152
1	20	30	MDA	MDA
2	37	52	0.9	5.9
3	37	205	3.6	30
4	59	211	3.9	33
5	9.1	112	MDA	MDA
6	46	58	0.9	9.4
7	MDA	223	3.0	29
8	61	2,033	857	1,021
9	MDA	12	MDA	MDA
Note: MDAs are 6.0 (Am-241), 0.8 (Co-60), 5.0 (Eu-152).				
Stored Activity in Top 20 cm ($\mu\text{Ci}/\text{m}^2$)				
Site	Am-241	Cs-137	Co-60	Eu-152
1	0.16	0.24	MDA	MDA
2	0.30	0.42	0.007	0.05
3	0.30	1.66	0.029	0.24
4	0.48	1.71	0.032	0.27
5	0.07	0.91	MDA	MDA
6	0.37	0.47	0.007	0.08
7	MDA	1.81	0.024	0.24
8	0.49	16.5	6.95	8.28
9	MDA	0.10	MDA	MDA

Note: MDAs are 0.05 (Am-241), 0.006 (Co-60), 0.04 (Eu-152).

the cratering experiment which formed Lake Chagan, showed the strongest gamma-ray activity of all areas measured. Very strong ^{137}Cs , ^{152}Eu , and ^{60}Co were detected. In addition, ^{154}Eu was also easily detectable in this area. Americium-241 was detected, but at levels near the minimum detectable

activity for this area. The activity level at Area 9, which was located approximately 4.5 km (2.8 mi) from Lake Chagan, was almost as low as the level of local background radiation. Only ^{137}Cs was detected and then only at a level near that of world-wide fallout.

Table 10. Comparison of United States *In Situ* and Russian Soil Sample Data

Average Activity in Top 5 cm (Bq/Kg)						
Site	Am-241		Cs-137		K-40	
	U.S.	Russian	U.S.	Russian	U.S.	Russian
1	66	35	102	119	565	513
2	122	77	178	147	574	531
3	123	41	698	254	618	570
4	196	76	720	430	634	555
5	30	14	382	158	436	446
6	151	201	198	208	791	681
7	19*	19	760	507	775	670
8	202	81	6,921	4,841	519	520
9	20*	10*	42	20	603	535

*MDA values.

Eight survey areas (Areas 11-18) were measured to try to identify three potential plutonium plumes, arising from Soviet tests having little or no nuclear yield, which were conducted at test area P-7 within the atmospheric test field. The measurements identified a plume heading in a direction of approximately 20 degrees from P-7 and another heading approximately 130 degrees from P-7. The measurements were unable to locate the third plume, which was believed to extend in a direction of 356 degrees from P-7.

Measurements made in Kurchatov City and at Area 10, located just outside Kurchatov City, showed primarily naturally occurring radionuclides from uranium, thorium, and potassium. Cesium-137 was

also detected but at levels consistent with world-wide fallout, which typically ranges from 5 to 40 Bq/kg. The ¹³⁷Cs levels in and around Kurchatov City ranged from 5 to 30 Bq/kg based on the *in situ* measurements. One area in Kurchatov City did show a very small amount of ²⁴¹Am. This was an area measured inside the grounds of the Institute of Radiation Safety and Ecology. Both detectors were used at this location and both detected ²⁴¹Am. The average value was approximately 30 Bq/kg. At an assumed plutonium-to-americiium ratio of 10:1, this would imply plutonium activity of 300 Bq/kg or approximately 8 pCi/g. For comparison, the plutonium level used for the Enewetak Atoll cleanup for unlimited occupancy was approximately 1,500 Bq/kg (40 pCi/g) and below.

Table 11. Cs-137 Comparison Data

Site	Soil Sample				In Situ		Aerial Survey
	Russian ^a	Russian ^b	Kazakhstani ^{b,c}	Kazakhstani ^{b,d}	Russian ^e	U. S. ^f	Russian ^g
1	0.10	0.15	0.63	0.16	0.316	0.24	0.3 – 0.4
2	0.046	0.36	0.46	0.26	0.497	0.42	0.3 – 0.4
3	1.73	1.1	1.28	1.46	1.75	1.66	2.0 – 2.5
4	1.83	0.54	0.61	0.62	1.81	1.71	2.5 – 3.0
5	0.202	0.38	0.54	0.58	0.79	0.91	1.5 – 2.0
6	0.324	0.18	0.36	0.08	0.40	0.47	0.2 – 0.3
7	0.607	0.84	0.87	0.76	1.79	1.81	1.5 – 2.0
8	13.78	12.3	17.9	11.3	17.5	16.5	3.0 – 4.0
9	0.054	0.09	0.19	0.03	0.12	0.10	0.4 – 0.5
10	0.282	0.047	0.11	0.02	0.098	0.07	0.10

^a Data from single profile measurement at center of measurement site

^b Data from composite of five samples taken at locations 1, 4, 17, 20 and the center of the site

^c Kazakhstani data for mixed sample (Nuclear Physics Institute)

^d Kazakhstani data for mixed sample (VKGO Laboratory)

^e Data average of readings at locations 6, 7, 14, 15, and center of site

^f Data average of readings at locations 1, 4, 6, 7, 9, 12, 14, 15, 17, and 20

^g Data from 1991 aerial survey

Table 12. *In Situ* Comparison Data

Stored Activity in Top 20 cm ($\mu\text{Ci}/\text{m}^2$)										
Site	Am-241		Cs-137		Co-60		Eu-152		K-40	
	U.S.	Russian	U.S.	Russian	U.S.	Russian	U.S.	Russian	U.S.	Russian
1	0.16	<0.09	0.24	0.32	<0.006	<0.003	<0.04	<0.03	4.58	4.95
2	0.30	0.28	0.42	0.50	0.007	<0.010	0.05	0.05	4.66	5.22
3	0.30	0.23	1.66	1.75	0.029	0.023	0.24	0.20	5.01	5.69
4	0.48	0.36	1.71	1.81	0.032	0.025	0.27	0.21	5.14	5.62
5	0.07	<0.05	0.91	0.79	<0.006	<0.005	<0.04	<0.01	3.54	4.43
6	0.37	<0.22	0.47	0.40	0.007	<0.004	0.08	0.05	6.42	7.18
7	<0.05	<0.11	1.81	1.79	0.024	0.029	0.24	0.16	6.29	6.21
8	0.49	<0.52	16.5	17.5	6.95	6.13	8.28	4.76	4.21	3.69
9	<0.05	<0.05	0.10	0.12	0.006	<0.006	<0.04	<0.02	4.89	5.42

U.S. data average over locations 1, 4, 6, 7, 9, 12, 14, 15, 17, and 20

Russian data average over locations 6, 7, 14, 15, and center of site

DISTRIBUTION

DOE/DP

L. E. Gordon-Hagerty (1)
O. W. Taylor (5)

DOE/NSIC

R. S. Scott (1)

DOE/NV

K. D. Lachman (1)
S. C. Ronshaugen (1)
Public Reading Room (1)
TIO (1)
TIRC (1)

DNA

D. Linger (10)

BN

H.W. Clark LVAO (1)
D. P. Colton LVAO (1)
C. E. Ezra LVAO (1)
R. E. Kelley LVAO (1)
M. F. Mohar WAMO (1)
T. E. Richardson LVAO (1)
S. R. Riedhauser LVAO (1)
L. G. Sasso LVAO (1)
W. J. Tipton LVAO (1)
R. J. Vojtech WAMO (1)

LIBRARIES

RSL (30)
WAMO (1)

OSTI

(2)

IN SITU RADIATION MEASUREMENTS AT THE FORMER
SOVIET NUCLEAR TEST SITE
SEMIPALATINSK, KAZAKHSTAN
DOE/NV/11718-005

DATE OF SURVEY: JULY 21-30, 1994
DATE OF REPORT: JUNE 1996