Radionuclide Inventory and Distribution Program:

The Galileo Area

DOE/NV/10162--14

by

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Prepared for the U.S. Department of Energy, Nevada
Operations Office, under Contract DE-AC08-81NV10162

28 December 1983

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Abstract

The Galileo area is the first region of the Nevada Test Site to be surveyed by the Radionuclide Inventory and Distribution Program (RIDP). This report describes in detail the use of soil sampling and in situ spectrometry to estimate radionuclide activities at selected sampling locations; the descriptions of these methods will be used as a reference for future RIDP reports. The data collected at Galileo were analyzed by kriging and the polygons of influence method to estimate the total inventory and the distribution of six man-made radionuclides. The results of the different statistical methods agree fairly well, although the data did not give very good estimates of the variogram for kriging, and further study showed the results of kriging to be highly dependent on the variogram parameters. The results also showed that in situ spectrometry gives better estimates of radionuclide activity than soil sampling, which tends to miss highly radioactive particles associated with vegetation.

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Radionuclide Inventory and Distribution Program: The Galileo Area

I. Introduction

1. The Project

The testing of nuclear explosives at the Nevada Test Site (NTS) has caused widespread contamination of the surface soil. Atmospheric and surface tests in the 1950's produced most of the contamination, although the Plowshare experiments of the 1960's and several containment failures of underground tests have also contributed. While many of the original contaminants have decayed away, several long-lived radionuclides remain at levels high enough to be a source of concern. The areas which present an immediate safety hazard are generally well-known and well-controlled. Other areas, however, may be sufficiently contaminated to represent long-term health hazards. In addition, the entire Test Site is a source of resuspendible radioactivity.

The Radionuclide Inventory and Distribution Program (RIDP) was developed to provide information necessary to evaluate such problems. Its objective is to determine both the distribution and the total inventory of the radionuclides in the NTS surface soil. The project incorporates data from three sources:

1. Field measurements of external exposure rate and radionuclide activities by in situ spectrometry. These measurements provide the primary data base for the inventory calculations and distribution maps.
2. Aerial surveys of external exposure rate. The results of these surveys are used as the basis for sampling plans for the field measurements. In some areas, it may be possible to use the field data to calibrate the aerial survey data and

then use the aerial data directly. In most of Yucca Flat, however, the occurrence of several shots in the same area makes such calibration impossible.

3. Soil samples. Calibration of the in situ measurement system requires parameters such as soil density, soil attenuation, and the depth distribution of the various radionuclides in the soil. In addition, radiochemical analysis of soil samples provides information about radionuclides which do not emit gamma rays and therefore cannot be measured by in situ spectrometry. Soil sampling is thus a necessary aspect of the program, although we consider it the most difficult and least precise of the methods used.

Additional details of the RIDP may be found in Kordas and Anspaugh (1982).

2. Preliminaries

The names of several organizations involved in the RIDP are abbreviated throughout this report:

DRI	Desert Research Institute, University of Nevada System
EG&G	EG&G, Inc., Las Vegas, Nevada
LLNL	Lawrence Livermore National Laboratory, Livermore, California
REEC	Reynolds Electrical and Engineering Company, Inc., Las Vegas, Nevada

For ease of typing, all mass numbers are written with a hyphen rather than a left superscript; for example, Eu-152 is used instead of ¹⁵²Eu. Symbols which appear without a mass number refer to specific radionuclides:

Co	cobalt-60
Cs	cesium-137
Pu	sum of plutonium-239 and plutonium-240
Am	americium-241
Sr	strontium-90

Locations on the Nevada Test Site are described by their Nevada Grid Coordinates, which give the distance of a point north and east of an arbitrary reference point. The distances are in feet, and all distances and areas derived from Nevada Grid Coordinates are also expressed in feet. The metric equivalents can be found with the conversion factors:

$$1 \text{ foot} = .3048 \text{ meter}$$

$$1 \text{ square foot} = .0929 \text{ square meters.}$$

Throughout this report, the word "concentration" refers to pCi/cm³ of a radionuclide in the soil. The integral of the concentration over the soil depth gives an "areal concentration" or "activity", expressed in nCi/m². The integral of the activity over a given area is the total amount (in Curies) or "inventory" of a radionuclide.

II. Methods

1. The Galileo Area

The region chosen for the initial RIDP investigation is on the western edge of Yucca Flat, near the intersection of Pahute Mesa Road and the Tippipah Highway in Area 1. For convenience it is called the Galileo area, although it was the scene of four tower shots in the mid-1950's:

Easy	May 7, 1952
Simon	April 25, 1953
Apple II	May 5, 1955
Galileo	September 2, 1957

The ground zero (GZ) for all four shots was E664588, N838780.

The exposure rate isopleths from the aerial survey, shown in Figure 1, clearly delineate both the GZ area and a waste dump northwest of the GZ. The isopleths are from a complete aerial survey of Yucca Flat carried out by EG&G in 1978 (Fritzsche, 1982). The survey used 20 NaI(Tl) scintillation detectors mounted on a helicopter which crossed the area in lines 60 m apart at an altitude of 30 m. This system measures average radiation levels over a circle with a diameter of five to ten times the altitude, depending on the gamma-ray energies involved and the source distribution with depth. As a result, localized regions of high activity appear to be spread over a larger area with a lower activity than actually exists on the ground. For activity fairly uniformly distributed over large areas, the agreement between ground measurements and the aerial survey measurements is generally quite good.

Figure 1 also shows the locations at which field measurements were taken. The sampling pattern was developed on the basis of two assumptions:

1. The variance of the estimates would be minimized by sampling on a regular grid.

Figure 1. Exposure rate isopleths and sampling locations.

o = Ground zero (E664588, N838780)

+ = In situ measurement location with sample point number.
Underlined numbers indicate points at which soil profile
samples were taken.

The isopleth levels, proceeding outward from the ground zero,
are 300, 100, 30, 10, 3, and 1 $\mu\text{R/hr}$.

Scale 0 2000 feet

2. The distribution patterns would best be determined by sampling where the activity was changing most rapidly. The measurement points were therefore chosen on an 800-foot grid originating at the Galileo GZ. Not all the grid points were measured in regions of fairly constant activity, and measurements were made at 200-foot and 400-foot intervals in regions of rapidly changing activity, as indicated by the exposure rate isopleths. The selection of points was subjective; no randomization was involved.

2. Soil Sampling

2.1 Density and Moisture Content

The conversion factors described in Section 3.2 were computed assuming a soil wet density of 1.5 g/cm^3 and 10% moisture. To confirm that these values were close to the true values, the density and moisture content at 11 locations in the Galileo area were measured to a depth of 20 cm by Holmes and Narver Materials Testing Laboratory - ID No. 601107. The instrumentation and procedures were those specified by the American Society for Testing and Materials in ASTM D2922-71 and ASTM D3017-72. Briefly, the wet density was obtained from the attenuation of the Cs-137 661.6 keV gamma ray, and the moisture content from the moderation of fast neutrons by the soil.

The results shown in Table 1 were calculated from these measurements using the relations

$$\text{dry density} = \text{wet density} - \text{moisture content}$$

$$\text{percent moisture} = 100 \times \text{moisture content} / \text{dry density}.$$

The average wet density was $1.6 \pm 0.1 \text{ g/cm}^3$. The average dry density was the same as that measured at LLNL during attenuation studies (Section 2.2).

Table 1. Soil density and percent moisture

Location ¹		Dry Density (g/cm ³)	Moisture (%)
N000	W400	1.48	8.3
S800	W1600	1.58	6.5
S400	W1600	1.50	6.0
S400	E400	1.47	7.4
S240	E240	1.37	7.7
S800	E800	1.57	9.4
N000	E800	1.56	12.4
N240	E800	1.40	6.8
N400	E1600	1.61	4.2
N2000	E2000	1.72	10.0
N3400	W3400	1.43	6.1
Mean $\pm$ s.d.		1.5 $\pm$ 0.1	8 $\pm$ 2

¹Distance in feet from the Galileo ground zero.

2.2 Gamma-ray Attenuation

The attenuation of gamma rays by the soil was measured at three energies to check the validity of using the coefficients of Beck et al. (1972) for detector calibration. Dry soil from a surface sample taken in the Galileo area was packed into plastic vials with styrofoam spacers to hold it in place. The uncollided flux I of gamma rays through vials with nine thicknesses of soil (from 0 to 4 cm in 0.5 cm increments) was measured, and the linear attenuation coefficients of the soil were obtained from a least squares fit of the equation

$$I = I_0 \exp(-\mu_f z_f) \exp(-\mu_s z_s),$$

where I_0 = the uncollided flux through an empty vial,

μ_f = the linear attenuation coefficient of the
 spacer material,
 z_f = the spacer thickness,
 μ_s = the linear attenuation coefficient of soil,
 and z_s = the soil thickness.

The linear attenuation coefficients were divided by the
 average dry density of the soil (1.51 g/cm^3) to give the
 measured mass attenuation coefficients shown in Table 2.
 These measured coefficients agree closely with those of Beck
et al. for dry soil.

Table 2. Soil mass attenuation coefficients
 (expressed in cm^2/g)

Energy (keV)	Measured (+1 s.e.)	Beck <u>et al.</u> (1972)
60	.250 $\pm$.034	.254
662	.0712 $\pm$.010	.0762
1332	.0519 $\pm$.0073	.0547

2.3 Depth Distribution

To study radionuclide distribution as a function of
 depth, soil samples were taken at 11 locations on two
 transects through the GZ area (Figure 1). The sampling used
 the "pit/scoop" method as follows: A trench approximately
 0.5 m wide by 1 m long by 30 cm deep was dug with one face at
 the desired sampling location. The front 2.5 to 5.0 cm was
 shaved off the face to expose fresh soil. This soil was
 sampled twice with a 2.5 cm deep scoop, then twice again with
 a 5 cm deep scoop, resulting in a total sampling depth of 15
 cm. The samples were weighed, oven dried, and reweighed,
 then homogenized with a ball mill and sieved through a
 10-mesh screen. The sieved (fine) fraction was analyzed by

gamma-ray spectroscopy at LLNL, with the results shown in Table 3. The sample from point 24 is not listed in Table 3 because it showed no detectable activity for any of the six radionuclides.

The depth distribution of each radionuclide was calculated assuming that the activity is exponentially distributed, that is,

$$I = I_S \exp(-\alpha z)$$

where I = activity per unit volume at depth z ,
 I_S = activity per unit volume at the surface, and
 α = inverse relaxation length in cm^{-1} .

The α 's were obtained from the fractional activity in the top two increments using the equation (Miller et al., 1980)

$$\alpha = -\ln(1-I'/I_0)/z',$$

where I_0 is the total integrated activity per unit area and I' is the activity integrated to depth z' . Two α 's were calculated for each radionuclide at each location: The first used the activity I' integrated to 2.5 cm, while the second used I' integrated to 5.0 cm. The two calculated α 's were then averaged to give the inverse relaxation lengths shown in Table 4.

The standard deviation of each α was estimated from the square root of the sum of the variances of the two calculated α 's. If there was no activity in the third and fourth increments, only one α could be calculated (for the second α , $I'=I_0$). In this case, the error was estimated by propagating the counting errors through the equation as follows:

$$\sigma_{\alpha}^2 = \left(\frac{\partial \alpha}{\partial \Delta I'} \right)^2 \sigma_{\Delta I'}^2 + \left(\frac{\partial \alpha}{\partial \Delta I''} \right)^2 \sigma_{\Delta I''}^2$$

where $\Delta I'$ and $\Delta I''$ are the total activities in pCi/cm^2 in

Table 3. Radionuclide concentrations in soil samples
(Results expressed in pCi/g)

Point	Increment (cm)	Weight (g)		Co-60	Cs-137
		wet	sieved		
14	2.5	488	324	---	0.63 (9.7)
	5	415	321	---	1.21 (5.9)
	10	403	255	---	.055 (100)
	15	647	407	---	---
30	2.5	388	275	13.0 (1.7) ²	9.67 (2.3)
	5	284	196	3.24 (4.2)	4.75 (4.6)
	10	359	256	5.27 (3.2)	0.12 (100)
	15	384	290	4.30 (2.7)	1.51 (8.8)
43	2.5	372	209	58.6 (0.7)	41.4 (2.2)
	5	430	318	33.1 (1.1)	31.1 (1.7)
	10	309	193	20.4 (1.4)	6.61 (4.5)
	15	418	304	16.1 (1.4)	0.20 (100)
48	2.5	298	231	3.95 (2.0)	14.4 (1.5)
	5	386	321	0.78 (5.8)	2.39 (3.4)
	10	532	470	0.24 (14.)	1.38 (4.4)
	15	464	361	---	---
56	2.5	438	316	---	1.66 (4.9)
	5	330	227	---	0.90 (10.)
	10	531	453	---	---
	15	588	499	---	---
85	2.5	259	187	3.31 (2.8)	10.8 (1.9)
	5	260	174	2.47 (4.0)	1.16 (11.)
	10	482	377	1.84 (5.3)	.13 (100)
	15	368	235	0.83 (7.1)	---
94	2.5	509	422	1.60 (3.4)	20.7 (1.1)
	5	274	214	1.80 (4.1)	11.6 (1.5)
	10	526	459	0.21 (36.)	2.04 (4.0)
	15	510	464	0.053 (100)	1.33 (6.1)
101	2.5	392	293	---	1.22 (5.9)
	5	352	303	---	.12 (38)
	10	509	434	---	---
	15	485	385	---	---
124	2.5	389	336	---	0.97 (6.5)
	5	278	243	---	7.35 (2.0)
	10	486	388	---	0.30 (17.)
	15	436	402	---	---
131	2.5	282	195	1.23 (6.5)	14.8 (1.9)
	5	373	157	0.56 (14.)	3.76 (4.5)
	10	596	446	0.34 (16.)	.16 (31.)
	15	476	330	0.29 (29.)	---

¹Concentrations at points where none of the increments were above the upper limit are left blank.

²Errors in parentheses are one standard deviation in percent; concentrations with 100% error are upper estimates.

Table 3. - Continued

	Eu-152		Eu-154		Eu-155		Am-241	
14	---		---		---		---	
	---		---		---		---	
	---		---		---		---	
	---		---		---		---	
30	35.7	(1.2)	1.72	(13.)	1.62	(20.)	4.02	(15.)
	30.3	(1.3)	1.11	(26.)	0.33	(100)	0.38	(100)
	93.9	(0.9)	4.12	(9.5)	---		---	
	72.2	(1.1)	3.37	(11.)	---		---	
43	211	(0.9)	11.2	(6.8)	4.92	(12.)	13.4	(12.)
	284	(0.6)	17.8	(3.8)	3.74	(15.)	5.45	(17.)
	307	(0.9)	16.9	(4.3)	0.54	(100)	1.21	(100)
	246	(0.8)	12.1	(6.5)	---		---	
48	5.35	(2.2)	---		1.22	(9.4)	---	
	1.55	(4.3)	---		0.27	(36.)	---	
	1.17	(6.2)	---		0.29	(24.)	---	
	0.37	(20.)	---		---		---	
56	1.83	(15.)	---		---		---	
	---		---		---		---	
	---		---		---		---	
	---		---		---		---	
85	31.8	(1.2)	1.74	(11.)	1.18	(22.)	---	
	35.6	(1.4)	1.41	(23.)	0.25	(100)	---	
	26.7	(1.2)	1.00	(23.)	---		---	
	18.7	(1.4)	0.73	(20.)	---		---	
94	2.60	(3.8)	---		2.06	(7.0)	2.46	(14.)
	1.16	(6.8)	---		0.86	(11.)	0.50	(23.)
	0.42	(17.)	---		0.51	(20.)	0.23	(100)
	0.13	(100)	---		0.15	(100)	---	
101	---		---		---		---	
	---		---		---		---	
	---		---		---		---	
	---		---		---		---	
124	---		---		---		---	
	---		---		---		---	
	---		---		---		---	
	---		---		---		---	
131	3.49	(4.5)	---		1.50	(9.9)	1.04	(36.)
	4.12	(3.8)	---		0.67	(32.)	0.31	(100)
	5.40	(2.1)	---		0.17	(100)	---	
	3.81	(2.7)	---		---		---	

Table 4. Inverse relaxation lengths
(Results expressed as $\text{cm}^{-1} \pm 1$ standard deviation)

Point	Co-60	Cs-137	Eu-152	Eu-154	Eu-155	Am-241
14	---	.4 $\pm$.3	---	---	---	---
30	.15 $\pm$.04*	.32 $\pm$.01	.036 $\pm$.001*	.036 $\pm$.004*	.7 $\pm$.3	1.0 $\pm$.4
43	.15 $\pm$.01*	.3 $\pm$.1	.06 $\pm$.02*	.06 $\pm$.03*	.3 $\pm$.1	.39 $\pm$.06
48	.50 $\pm$.06	.4 $\pm$.1	.26 $\pm$.05	---	.28 $\pm$.07	1.0 $\pm$.4
56	---	.43 $\pm$.03	---	---	---	---
85	.142 $\pm$.001	.8 $\pm$.1	.10 $\pm$.01*	.125 $\pm$.001	.7 $\pm$.3	---
94	.3 $\pm$.1	.32 $\pm$.02	.30 $\pm$.02	---	.24 $\pm$.03	.45 $\pm$.09
101	---	.9 $\pm$.1	---	---	---	---
124	---	.3 $\pm$.4	---	---	---	---
131	.19 $\pm$.05	.73 $\pm$.01	.057 $\pm$.004*	---	.40 $\pm$.05	.8 $\pm$.4

*Values are overestimates due to insufficient sampling depth.

Table 5. Plutonium and strontium concentrations in soil samples
(Results expressed in pCi/g ± 2 standard deviations in percent)

Point	Aliquot	Sr-89	Sr-90	Pu-239+240	Am-241	Cs-137	Pu/Am	Sr/Cs
30	10	<42.7	16.9 $\pm$ 7.1	30.4 $\pm$ 7.1	6.59 $\pm$ 17	11.0 $\pm$ 12	4.55 $\pm$ 13	1.67
	100	<46.4	22.1 $\pm$ 22	30.8 $\pm$ 13	6.85 $\pm$ 12	12.3 $\pm$ 9.2		
43	10	<135.	96.9 $\pm$ 15	157. $\pm$ 6.1	25.4 $\pm$ 12	51.0 $\pm$ 9.5	5.49 $\pm$ 9.3	1.40
	100	<75.4	41.1 $\pm$ 17	103. $\pm$ 8.2	22.0 $\pm$ 9.7	47.3 $\pm$ 8.7		
94	10	<149.	108. $\pm$ 14	33. $\pm$ 16	---	22.6 $\pm$ 10	---	4.64
	100	<130.	90.3 $\pm$ 15	29.8 $\pm$ 8.0	---	20.1 $\pm$ 8.8		

the first and second sample increments. The former estimate of the error is preferred since it not only includes the statistical error due to counting, but also indicates how closely the profile really fits an exponential distribution.

In the calculations, we have assumed that all activity in these samples exists in the fine fraction, although the activities were corrected to the total wet weight of the sample. This assumption was tested and found to be true for all radionuclides of interest except Eu-152 and Eu-154, which were assumed to be distributed uniformly between the fine and coarse fractions. Eu-152 and Eu-154 are soil activation products. To get a better estimate of their depth distributions, unpublished data (summarized in Brady and Church, 1975) from profile samples taken at the Galileo ground zero were reviewed. Eu-152 was found to be typically present in the 60 cm sample and in some cases the 90 and 120 cm samples. The mean inverse relaxation length for Eu-152 in 11 of these profiles was $.023 \pm .015 \text{ cm}^{-1}$.

2.4 Radiochemical Analyses

The fine fraction of the top 2.5 cm sample from three sampling locations was submitted to the REECo laboratory to be analyzed for Sr-89, Sr-90, and Pu-239+240. Aliquots of 10 g and 100 g were taken from each sample, totally dissolved, and chemically analyzed. The results are reported in Table 5. The Am-241 and Cs-137 results were obtained by gamma-ray spectroscopy before dissolution. The activity reference date is October 15, 1982. The average Pu/Am ratio is 5.0 ± 0.5 , which agrees with the 5.0 obtained by Brady and Church (1975) in Area 1. The Sr/Cs ratios are not as encouraging: Either there is something wrong with the Sr-90 measurement at point 94 or the ratio cannot be assumed to be constant. If the result at point 94 is ignored, the average Sr/Cs ratio is 1.5 ± 0.2 . This is consistent with the value

of 1.2 ± 0.3 near the Kepler ground zero in Area 4 (McArthur and Kordas, in preparation) and with the values of 1.9 at Little Feller II in Area 18 and 0.93 at Palanquin/Cabriole in Area 20 (Gilbert, 1983).

3. Field Measurements

3.1 Gamma-ray Measurement System

The in situ gamma-ray measurement system consisted of four major components:

1. A high-purity germanium detector and collimator shield.
2. A spectrometric amplifier and power supply.
3. A 4096-channel pulse-height analyzer.
4. A desktop computer and printer.

The detector measured the gamma rays emitted by the radionuclides in the surface and near-surface soil. It was a planar model originally designed to detect low-energy gamma rays, with resolution on the order of 900 eV at low energy (60 keV) and 2.0 keV at higher energy (1332 keV). The detector thickness (16 mm) and large surface area (19 cm²) resulted in good efficiency at low energy and reduced Compton scattering, but poor efficiency at higher energy. A lead and cadmium collimator shield limited the detector field of view (Section 3.3). The two detectors used in the Galileo area were individually calibrated for in situ spectrometry as outlined in Section 3.2.

Pulses from the detector were fed through the amplifier into the pulse-height analyzer, which sorted them to produce an energy spectrum. At the end of each measurement, the spectrum was transferred to the computer for processing and storage on tape cartridges. A typical spectrum from the Galileo ground zero area is shown in Figure 2.

Figure 2. Gamma-ray spectrum collected at point 43.

The instruments were carried in a small tracked vehicle (Figure 3). The detector and shield were attached to a telescoping mast which could raise them from ground level to a height of 7.4 m. A 4-kW generator provided power for the system. During field operations, the position of the vehicle was determined with a microwave ranging system consisting of a console inside the vehicle, a receiver/transmitter on top of it, and two or more remote reference stations with accurately known locations. The system was capable of locating a point within 37 km of the references with an accuracy of about 3 m. Because of an equipment failure, the microwave system was used for only 55 sampling points in the Galileo area; the rest were located by surveying teams.

After the vehicle had been positioned near a measurement point, the detector was raised and cantilevered out. The operator entered information describing the site into the computer and began the spectrum acquisition. During the 15-minute acquisition period, a pressurized ionization chamber was set up 1 m above the ground under the detector to measure the external exposure rate. At the end of the acquisition time, the mast was retracted and the vehicle moved to the next location.

The energy calibration of the detector was checked three times daily and was adjusted, if necessary, using a calibration source containing Am-241, Cs-137, and Co-60 located 30 cm from the detector. An energy calibration of .375 keV/channel was used.

Measurements in the Galileo area were made between August and December, 1981.

3.2 Detector Calibration

The following discussion of the detector calibration is greatly simplified. For additional details, see Anspaugh (1976), Beck et al. (1972), or Tipton et al. (1978).

Figure 3. Vehicle containing the in situ measurement system.

The conversion factor C to convert counts in a photopeak to radionuclide activity in nCi/m^2 can be expressed (using the notation of Beck et al.) as

$$C = (N_O/\phi)(N_f/N_O)(\phi/S)$$

where the factors in parentheses are as defined below.

- N_O/ϕ is the detector response to a unit flux perpendicular to the detector surface. It can be determined directly using calibrated gamma-ray sources at distances large enough that the detector can be considered a point detector. Table 6 lists the energies and branching intensities of the sources used to determine this parameter.

- N_f/N_O is a correction factor necessary if the detector response varies with angle. It depends upon the calculated differential flux with angle and the measured angular response of the detector. The angular response was also measured with the sources listed in Table 6. Figure 4 shows the angular response of a collimated planar detector at three energy levels. Note that the collimation is incomplete at higher energies.

Table 6. Sources used for detector calibration

	Energy (keV)	Branching Intensity (γ/decay)
Am-241	59.5	0.359
Cd-109	88.0	0.0372
Eu-152	121.8	0.286
	244.7	0.0751
	344.3	0.266
	778.9	0.130
	964.0	0.146
	1408.0	0.208
Cs-137	661.6	0.85
Co-60	1173.2	1.00
	1332.5	1.00

Figure 4. Angular response of a collimated planar detector.

- ϕ/S is the incident flux at the detector of unscattered photons of the desired photopeak energy per unit of soil activity. It is calculated from the air attenuation, soil attenuation, soil density, and the depth distribution of the radionuclide.

The conversion factors were computed on the CDC 7600 at LLNL by the FLUX code of Anspaugh and Kordas (1984), which fits a hermitian spline to the angular response data and calculates ϕ/S and N_f/N_0 as functions of soil density and depth distribution. Table 7 summarizes the parameters used in the computations. The attenuation coefficients are those of Beck *et al.* (1972); the soil coefficients are adjusted for the soil moisture content and therefore differ slightly from those for dry soil in Table 2. The air density is that of dry air at 20° C and 760 mm Hg. Since the soil density and moisture are within one standard deviation of the measured values (Section 2.1), we did not recompute the conversion factors using the measured values. Doing so would have changed the conversion factor for a planar detector and a gamma-ray energy of 60 keV by less than 3.0%, and the change becomes smaller as the gamma-ray energy increases.

As noted above, the conversion factor depends on the linear attenuation coefficient μ_s and the inverse relaxation length α ; it is extremely sensitive to the latter, especially at low energies. Figure 5 shows the percent error in the estimated activity as a function of the ratio of the "true" μ_s to the μ_s assumed in the calibration (derived from the mass attenuation coefficients in Table 7). A positive error represents an overestimate. Figure 6 shows the ratio of the true activity to the calculated activity as a function of α at three energy levels. The α 's for which the ratio equals 1.0 are those given in Table 7 for Am-241, Cs-137, and Co-60.

The inverse relaxation lengths in Table 7 were chosen to minimize the errors in the calculated activities. For this purpose, the area was divided into a region containing the

Table 7. Parameters used to compute conversion factors

Air density	0.001204 g/cm ³	
Soil wet density	1.5 g/cm ³	
Soil moisture	10%	

Mass attenuation coefficients (cm ² /g)		
	<u>Air</u>	<u>Soil</u>
60 keV	0.177	0.248
662 keV	0.0770	0.0781
1332 keV	0.0550	0.0558

Inverse relaxation lengths (cm ⁻¹)		
	<u>GZ area</u>	<u>Other</u>
Co-60	0.4	0.4
Cs-137	0.4	0.4
Eu-152	0.05	0.3
Eu-154	0.05	0.3
Eu-155	0.6	0.6
Am-241	0.6	0.6
naturals	uniform	uniform

measurement points within a 3200-foot square centered on the GZ and a region containing the other points; different α 's were used for each region. The α 's chosen for Co, Cs, and Am reflect the "hot spot" discussion in Section III.5.1. Also, an α of 0.05 cm⁻¹ for Eu-152 and Eu-154 results in the same activity as a uniform distribution integrated to 30 cm.

3.3 Detector Field of View

A lead and cadmium collimator shield limited the detector field of view to a restricted solid angle and circular area on the ground. The physical angle of the cone was 50° from the vertical; however, the cut-off angle at which gamma rays could not enter the detector was approximately 60° for

Figure 5. Error in estimated activity as a function of linear attenuation coefficient.

Figure 6. Error in estimated activity as a function of inverse relaxation length.

rays with energies between 0 and 300 keV. The field of view is a function of the collimation and the gamma-ray attenuation, both of which are energy-dependent. Figure 7 shows the cumulative response of a collimated planar detector 7.4 m above the ground as a function of the angle from a line perpendicular to the face of the detector. (An inverse relaxation length of 0.4 cm^{-1} was assumed.) The field of view for 90% response has a radius of about 10 m at 60 keV, 12 m at 662 keV, and 21 m at 1332 keV.

3.4 Data Processing

After each measurement, a computer program analyzed the spectrum for radionuclides of interest. The program uses a sliding interval filter to scan preselected regions of a spectrum for peaks, then uses a first moment calculation to determine the peak energy and computes the net counts by setting up background regions on each side of the peak. The widths of the peak and background regions depend on the peak energy. The radionuclide activity is calculated using predetermined conversion factors stored in a library. The activity of radionuclides with more than one prominent gamma ray is calculated as an average, with the counts in each peak weighted by the reciprocal of the variance. The conversion factors of Beck (1980) are used to compute an external exposure rate for comparison with the measured exposure rate. The printout (Figure 8) can be inspected by the operators in the field to ensure that the system is functioning properly.

All spectra were transferred to magnetic tape at DRI and sent to LLNL to be processed through a version of GAMANAL (Gunnink and Niday, 1971), a sophisticated gamma-ray analysis package which performs background delineation, peak search, peak fitting, and radionuclide identification. GAMANAL has been modified for in situ spectrometry by eliminating the detector efficiency and source geometry calculations, and by

Figure 7. Cumulative response of a collimated planar detector 7.4 m above the ground.

SITE: GAL STAKE: S 43 43 0 0 RUN: PS 362
 DATE: 11301 TIME: 1459 DAY: 332 RAIN: NO VEHICLE: 2
 DETECTOR: 496 COLLIMATOR: ON DETEC HEIGHT (m): 7.4
 SHADOW %: 4 BRUSH COVER %: 1 ION CHAMBER (uR/Hr): 0
 COUNT TIME: 900 CLOCK TIME: 972 CHANNELS: 4096 PRGM: 11181

COMMENTS: GAL STK43

RADIO- NUCLIDE *****	*****CONCENTRATION***** (pCi/g) (mCi/km ²) *****	EXPOSURE RATE (uR/Hr) *****
K- 40	20.9 +/- 2.2	
Rn 241		3.7 +/- 0.4
Co 60	12600 +/- 176	1.3 +/- 0.0
Cs 137	27726 +/- 187	571.2 +/- 3.9
Eu 152	18611 +/- 208	93.1 +/- 1.0
Eu 154	23578 +/- 400	134.4 +/- 2.3
Eu 155	2145 +/- 423	12.4 +/- 2.5
Ru 106	2937 +/- 125	1.5 +/- 0.1
	2574 +/- 848	4.9 +/- 1.6
Rn-241 CORRECTED FOR Eu-155: 12495 +/- 179		

ENERGY CAL: OK

SUBTOTAL EXTERNAL EXPOSURE RATE DUE TO
 NATURALLY OCCURRING RADIONUCLIDES (uR/Hr): 3.7 +/- 0.4

TOTAL EXTERNAL EXPOSURE RATE (uR/Hr): 822.4 +/- 11.7

Figure 8. Sample field printout.

replacing the branching intensities in the library with the detector conversion factors. It uses a Gaussian curve with an exponential tail for peak fitting and can separate overlapping peaks. The six detector dependent peak shape parameters needed for peak fitting are obtained from the daily field energy calibration spectra. If the peaks associated with selected radionuclides are not found, upper limit values are calculated from the equation

$$U.L. = 2 \sqrt{B/(tC)}$$

where B is the integrated background in the peak region,
 t is the count time, and
 C is the detector conversion factor.

Figure 9 shows a typical output of the peak identification and quantitation portion of GAMANAL, while Figure 10 shows a typical radionuclide summary output.

3.5 Confirmatory Measurements

As a quality control, additional measurements were made at several points with an uncollimated coaxial detector facing down at a height of 1 m. The cumulative response of this detector (again assuming an inverse relaxation length of 0.4 cm^{-1}) is shown in Figure 11. The radius of the field of view for 90% response is approximately 12 m at 60 keV and 16 m at 662 and 1332 keV. Table 8 shows that the measurements made with this detector compare very well with those made by the collimated planar detector at 7.4 m. The average deviation of the measurement pairs from their means is 8.6%. This includes the deviations at points close to the GZ, where we would expect to see differences in the measurements because of the different fields of view and the rapidly changing radionuclide activities, and the deviations of pairs of measurements that are close to their detection limits.

SAMPLE D496GALILEO 431130. DELTAT = 1460.005 DAYS. 15 MIN COUNT BEGAN 111.333 () ON DETECTOR-P4
LIVE-TIME OF COUNT (TAKEN FROM CHANNEL 1) = 15.00 MINS

SUMMARY OF ENERGY CALIBRATION

INPUT DATA		CALCULATED FIT	**BASED ONLY ON EXTERNAL DATA **
CHANNEL	ENERGY	ENERGY	DELTA E
159.768	59.500	59.526	0.026
1765.238	661.600	661.550	-0.050
3554.585	1332.500	1332.524	0.024

GAIN = APPROX. 0.375 KEV/CHANNEL

AVG. DEVN. = NOT VALID.

SUMMARY OF PEAKS WITH SIGNIFICANT NET TOTALS IN SPECTRUM NO. 010046

INDEX	CHANNEL	KEV	(+/-)	- PEAK -	CALC.	PROP.	COUNTS/MIN	PCT	QFIT	FWHM	PCT	INDEX
				START END	COUNTS	COUNTS		ERROR		USED	DIFF	
1	63.173	23.305	0.035	60.0 67.0	2904	2562	1.822E+02	12.22	1.3	0.892	-8.7	1
2	71.257	26.336	0.079	68.0 74.0	1175	1117	7.637E+01	21.69	1.0	0.956	-2.5	2
3	87.027	32.250	0.030	82.0 92.0	3674	3681	2.452E+02	9.17	1.0	1.062	7.7	3
4	98.341	36.493	0.090	96.0 103.0	909	887	5.987E+01	29.47	1.0	0.905	-8.7	4
5	107.909	40.080	0.024	103.0 112.0	5170	5049	3.407E+02	6.54	1.0	1.111	11.8	5
6	115.598	42.963	0.060	113.0 118.0	1381	1306	8.955E+01	17.28	1.0	0.911	-0.7	6
7	122.373	45.504	0.071	120.0 126.0	1277	1225	8.339E+01	20.01	1.0	0.913	-8.7	7
8	160.123	59.660	0.005	149.0 165.0	22799	23623	1.547E+03	3.04	1.0	0.923	-8.7	8
9	226.952	84.719	0.146	222.0 228.0	751	758	5.031E+01	40.74	1.0	0.948	-8.7	9
10	232.023	86.621	0.021	228.0 236.0	5300	5485	3.595E+02	6.07	1.0	-	-	10
11	282.113	105.404	0.030	276.0 287.0	3836	3926	2.588E+02	10.69	1.0	1.000	-5.6	11
12	326.088	121.894	0.016	321.0 333.0	9865	9952	6.606E+02	4.68	2.0	0.981	-8.7	12
13	653.830	244.791	0.044	650.0 657.0	1503	1481	9.678E+01	11.80	1.0	1.083	-8.7	13
14	789.683	295.733	0.215	786.0 794.0	262	279	1.804E+01	53.14	1.0	1.145	-6.9	14
15	853.878	319.806	0.210	851.0 857.0	235	233	1.561E+01	47.39	1.0	1.167	-6.6	15
16	860.615	322.332	0.236	858.0 863.0	141	124	8.846E+00	72.27	1.0	1.142	-8.7	16
17	919.139	344.277	0.018	912.0 924.0	3540	3492	2.347E+02	4.97	1.0	1.209	-4.7	17
18	976.197	365.673	0.249	973.0 980.0	202	205	1.357E+01	52.66	1.0	1.279	-8.6	18
19	982.560	368.059	0.139	980.0 986.0	284	286	1.901E+01	34.04	1.0	1.176	-8.7	19
20	1098.027	411.357	0.197	1095.0 1101.0	193	178	1.237E+01	40.77	1.0	1.207	-8.7	20
21	1184.984	443.965	0.127	1181.0 1190.0	346	339	2.202E+01	32.75	1.0	1.229	-8.7	21
22	1765.401	661.611	0.007	1757.0 1771.0	11280	11274	7.518E+02	1.30	1.0	1.398	-7.0	22
23	2078.138	778.882	0.047	2074.0 2082.0	922	929	6.167E+01	8.32	1.0	1.496	-5.4	23
24	2313.809	867.254	0.148	2307.0 2319.0	303	325	2.094E+01	30.52	1.0	1.593	-2.7	24
25	2329.627	873.186	0.273	2327.0 2332.0	105	105	7.021E+00	53.44	1.0	1.498	-8.7	25
26	2545.655	954.192	0.356	2543.0 2551.0	95	118	7.101E+00	74.21	1.0	1.543	-8.7	26
27	2571.498	963.883	0.057	2564.0 2576.0	969	991	6.533E+01	10.21	1.0	1.743	2.8	27
28	2896.396	1085.714	0.069	2890.0 2903.0	656	670	4.422E+01	13.22	1.0	1.695	-4.1	28
29	2907.125	1089.737	0.295	2903.0 2911.0	119	101	7.320E+00	55.14	1.0	1.616	-8.7	29
30	2966.414	1111.970	0.063	2960.0 2976.0	796	825	5.405E+01	12.60	1.0	1.791	0.5	30
31	3129.707	1173.202	0.009	3118.0 3140.0	12598	12722	8.440E+02	1.39	1.5	1.759	-3.2	31
32	3236.032	1213.072	0.251	3232.0 3243.0	83	95	5.926E+00	42.12	1.0	1.792	-2.6	32
33	3399.807	1274.485	0.130	3394.0 3404.0	117	121	7.921E+00	21.44	1.0	1.710	-8.7	33
34	3466.293	1299.416	0.188	3461.0 3471.0	93	100	6.426E+00	25.72	1.1	1.883	-0.3	34
35	3554.421	1332.462	0.011	3543.0 3563.0	11248	11330	7.526E+02	1.45	2.1	1.897	-0.4	35
36	3755.609	1407.904	0.025	3746.0 3763.0	1171	1191	7.074E+01	3.40	1.0	1.869	-3.9	36
37	3896.572	1460.763	0.116	3891.0 3904.0	80	92	5.726E+00	19.30	1.0	1.801	-8.7	37

PROGRAM ENTERING IDENTIFY ROUTINE AFTER 0.662 SEC. (CPU:1/0:SYS=52:47:00) CLOCK READS 17:15:12 U 11/08/83
123.140 KEV GAMMA RAY COULD NOT BE FOUND IN LIBRARY FOR 63154

Figure 9. Peak identification and quantitation output of GAMANAL.

GE GAMMA ANALYSIS OF D496GALILEO 431130

DATE OF CALCULATION

EXPERIMENT NO. 43

17:15:12 11/08/83

SAMPLE NUMBER 30

ZERO TIME 111.333

SAMPLE WEIGHT = 1.000E+00

MIDTIME OF COUNT 111.338

SPECTRUM NO. 010046

NORMALIZATION WEIGHT = 1.000E+00

NORMALIZATION FACTOR = 1.000E+00

DECAY TIME IS 1460.005 DAYS

DETECTOR P SYSTEM 4

GEOMETRY IS 0.01 CM

LIVE-TIME OF COUNT (TAKEN FROM CHANNEL 1) = 15.00 MINS 20BY 7 / 10BY 2

** MLR LEAST-SQUARES RESULTS **

NUCLIDE	NCI/M2 OR COUNT TIME	PCI/G AT	PCT ERROR	SET NO.	QFIT	IDENTIFICATION CONFIDENCE VALUE
K 040	1.439E+01		19.3	1	1.0	0.50
CO 060	3.057E+04		1.1	2	1.0	0.99
CS 137	2.037E+04		1.6	3	1.0	0.79
EU 152	2.994E+04		4.8	4	2.8	1.00
EU 154	2.398E+03		20.6	5	1.0	0.35
EU 155	2.419E+03		5.6	6	1.0	0.96
AM 241	1.200E+04		5.7	6	1.0	0.73

** THE FOLLOWING ARE UPPER LIMIT VALUES ONLY **

TH 232 1.785E+00 1.785E+00 1.895E+16

U 238 2.061E+00 2.061E+00 7.032E+15

Figure 10. Summary output of GAMANAL.

Figure 11. Cumulative response of an uncollimated coaxial detector 1.0 m above the ground.

Table 8. Radionuclide activities measured by two detectors
(Results expressed in nCi/m²)

Point	Detector	Co-60	Cs-137	Eu-152	Eu-154	Eu-155	Am-241
37	Coaxial	16,700	11,800	40,500	2,480	1,220	6,920
	Planar	17,900	11,800	41,300	2,730	1,210	5,390
43	Coaxial	27,400	18,300	24,700	1,380	1,770	8,570
	Planar	30,600	20,400	29,900	2,400	2,420	12,000
44	Coaxial	544	567	17,400	962	<90	<200
	Planar	1,010	765	19,300	1,520	<95	255
85	Coaxial	438	1,830	11,600	643	111	<121
	Planar	595	1,710	13,400	597	204	<84
88	Coaxial	49	676	111	<58	52	<58
	Planar	46	659	85	<67	<30	<29
89	Coaxial	27	257	652	<60	<26	<59
	Planar	<23	291	743	<255	<34	<39
90	Coaxial	64	469	2,190	151	32	<71
	Planar	72	446	2,070	<330	<41	<45
94	Coaxial	92	1,290	195	<66	80	<64
	Planar	90	1,200	150	<60	85	<32

III. Data Analysis

1. Introduction

The in situ data set contained 165 measurements made at 134 locations (27 locations were measured twice, one location was measured six times). The data were analyzed using the average measurements from each repeated point. Maps showing the observed activities of the six man-made radionuclides are presented in Figures 12 through 17. Note that many of the measurements were reported as upper limit values, indicating a level of activity less than the detectable minimum. A list of the data is given in the Appendix.

The analysis of the data has two separate, although closely related, objectives: the estimation of the total inventory of each radionuclide and the mapping of its distribution. If we let $Z(x)$ denote the activity of a radionuclide at a point x , a graph of $Z(x)$ as x varies over the plane forms a surface representing the distribution of the radionuclide. We can use isopleths of activity to show the shape of the surface in the same way that contour lines on a topographic map show the shape of a mountain. The volume under the surface represents the inventory.

We have observed $Z(x)$ at n distinct points; let $Z_i = Z(x_i)$, $i = 1, \dots, n$, denote the observed data. There are two general aspects of the function Z which we will need to estimate: the value at an unsampled location and the average value over an area. The estimators Z^* we will consider will all have the form of a linear combination of the data:

$$Z^* = \sum_{i=1}^n l_i Z_i$$

Different estimation methods are basically just different procedures for choosing the weights l_i .

Figures 12 through 17. Measured radionuclide activities (nCi/m²) in the Galileo area.

The orientation is the same as in Figure 1, with north at the top of the page. The solid rectangle indicates the boundary of the Galileo area as defined for inventory estimation: E658588 to E669788 by N832780 to N844780.

+ = points with measurable activity
o = points without measurable activity (values shown are upper limits)

In Figures 12 through 14, the solid line through the area shows the partitioning of the data set into two parts for kriging. The dashed lines outline the regions of above-background activity within which the inventory was estimated (Section 3).

Figure 13. Measured Cs-137 activities.

Figure 14. Measured Eu-152 activities.

Figure 15. Measured Eu-154 activities.

Figure 16. Measured Eu-155 activities.

It was assumed almost from the beginning of the RIDP that kriging would be used in the data analysis. Kriging is an estimation method based on the assumption that $Z(x)$ is a random variable with a mean and variance which do not depend on x . The surface representing the distribution is thus a realization of a stationary random process. For two points x and y , $Z(x)$ and $Z(y)$ have a covariance which is assumed to depend only on the vector h between x and y and not on the points themselves. The covariance structure of $Z(x)$ is characterized by the variogram function $g(h)$.

Any estimate Z^* will be different from the true value Z . Under the above assumptions the estimation error, $Z - Z^*$, has a mean and variance which can be expressed in terms of the weights l_i and the variogram. Kriging involves choosing the l_i so that the mean error is zero (that is, the estimate is unbiased) and the error variance is as small as possible. It turns out that the weights so chosen and the resulting error variance depend only on the variogram and the locations of the sampled points, and not on the observations themselves.

If the process under consideration is not stationary, i.e., if the mean of $Z(x)$ depends on x , kriging is more complicated. A non-stationary process is usually modeled as a random process superimposed on a non-random drift with a known functional form, typically a low-order polynomial. The coefficients of the drift are then estimated along with the kriging weights by the procedure known as universal kriging. Often, however, ordinary kriging can be used with a non-stationary process, if the drift is sufficiently small that it can be ignored on the scale on which estimates are to be made.

Further details about kriging may be found in Journel and Huijbregts (1978).

2. Variograms

In general, the variogram function is not known and must be estimated from the data. The first step is calculation of the sample variogram. Each point $g^*(h)$ of the sample variogram is the average of the squared differences of all pairs of measurements at points separated by h . Because the inclusion of "less than" values from regions of background activity would make the process appear less variable than it actually is, only the points with measurable activity were used in the variogram computations. For $g^*(h)$ to be a reliable estimate of the true variogram, a fairly large number of observations is required; Journel and Huijbregts recommend at least 30 to 50 pairs. Only Co, Cs, and Eu-152 had more than 30 pairs of observations at each point of the sample variogram, so variograms were estimated only for these three radionuclides.

The GAMMA program of Chiles (1975) was used to compute sample variograms in four directions (N-S, NE-SW, E-W, and SE-NW). The four variograms appeared to be the same, so the process was assumed to be isotropic. The variogram is thus a function only of the length h of the vector h and not its direction, and it can be estimated by the average of the four individual variograms. The average sample variograms are shown in Figures 18 through 20.

Variogram 1 for each radionuclide was calculated using all the data (excluding the points without detectable activity). Since the only places where samples were taken close together were in regions where the activity was rapidly changing (Section II.1), the sample variograms give a distorted picture of the true variogram at small distances. To reduce this bias, the variograms were recalculated with the 13 points not on the 800-foot sampling grid omitted (Variogram 2). Note that the large peak at about 400 feet has disappeared and that the scale of the variability has been greatly reduced. Even these sample variograms are not

Figure 18. Co-60 variograms. The dashed lines connect the points of the sample variogram, while the solid line shows the fitted model.

Figure 19. Cs-137 variograms. The dashed lines connect the points of the sample variogram, while the solid line shows the fitted model.

Figure 20. Eu-152 variograms. The dashed lines connect the points of the sample variogram, while the solid line shows the fitted model.

completely unbiased, though, since the unsampled points of the grid tend to be in regions of fairly constant activity. Once the sample variogram has been calculated, a continuous model must be fitted to it. The form of the model is somewhat arbitrary and apparently has little effect on the resulting estimates if the parameters of the model are estimated accurately. We have in all cases used a spherical model, which expresses the variability of $Z(x)$ as a function of h and 3 parameters:

1. The nugget effect, $g(0)$, which represents the variance of repeated measurements at the same point.
2. The range, the distance beyond which $Z(x)$ and $Z(y)$ are statistically independent.
3. The sill, $g(\infty)$, which equals the variance of $Z(x)$.

The nugget effect was estimated from the repeat measurements made at 28 points. The range and sill were estimated by eye, with greater weight given to the points at shorter distances, since the sample variogram becomes an increasingly poor representation of the true variogram as the distance increases. The models shown with Variogram 2 were the ones used for kriging. The values of the parameters are given below.

	<u>nugget</u>	<u>range</u>	<u>sill</u>
Co-60	1,100	1,000	1×10^7
Cs-137	1,000	1,100	1.4×10^6
Eu-152	81,000	1,500	6.5×10^8

The adequacy of the models was checked by eliminating each point from the data set in turn, estimating the value at that point by kriging, and comparing the observed value with the estimate. All three models performed fairly well except at the points near the GZ (we were unable to find any model which accurately reproduced the results in the GZ area). We repeat, however, that the sample variograms from which the models are derived are biased, and the sills used are probably greater than the true sills. Furthermore, the

ranges are very poorly known: any value between 0 and 1600 feet would give a reasonably good fit to the data, and of course it is impossible to detect a range of less than 800 feet with data from an 800-foot grid. The uncertainty in the choice of variogram model should be kept in mind when the results of kriging are evaluated.

Kriging estimates for Eu-154, Eu-155, and Am were obtained using a generalized polynomial covariance model fitted to the full data set by the kriging program BLUEPACK (Delfiner et al., 1976). The best-fitting models were:

Eu-154 $k(h) = (3.908 \times 10^7)\delta$, where δ is the
Dirac delta function

Eu-155 $k(h) = -25.18h$

Am-241 $k(h) = -645.8h$

Details about these covariance models may be found in Delfiner et al. and the references given there.

3. Inventory Estimates

The sampling plan for the Galileo area was developed assuming that kriging would be used in the data analysis, but exactly how kriging should be applied to produce inventory estimates is not clear. In previous radionuclide studies, such as Barnes et al. (1980), kriging seems to have been used mainly as an interpolant, and its suitability for use in estimating total inventory has not been demonstrated. Since there is no standard method, we have used three techniques to estimate inventories in the Galileo area. Research on this question is continuing, and we leave open the possibility that some other method may eventually prove more suitable than the three used here.

For the purposes of inventory estimation, the Galileo area was defined as the 11,200-foot by 12,000-foot rectangle defined by NV Grid Coordinates E658588 to E669788 by N832780

to N844780. Within this rectangle, we have limited the inventory estimation to the region with above-background activity. While large areas of background activity may contribute a large fraction of the total inventory of some radionuclides, we cannot adequately measure this contribution from "upper limit" data.

The three estimation methods are similar in that they involve a partitioning of the rectangle into subregions in which the mean activity of a radionuclide is estimated. This mean is then multiplied by the area of the subregion to give an inventory for that subregion. The individual estimates are then added to give an estimate of the total inventory. The methods differ in how the region is partitioned and how the mean is estimated.

a) Kriging of small blocks

In this method, the area was divided into a 15 x 14 array of 800-foot square blocks, and the mean and standard deviation of the activity in each block were estimated by kriging. The inventories of all blocks in the area of detectable activity (outlined in Figures 12 through 17) were then added to get an estimate of the total inventory. The results are shown in Table 9.

The estimation of block means is a standard application of kriging. Each block is estimated using both the sampled points in the block and nearby points outside the block. This use of surrounding data points is one of the theoretical advantages of kriging, but it means that some of the same points are used to estimate the mean in adjacent blocks. The estimates are therefore not statistically independent, and the individual error estimates cannot easily be combined into an overall error term.

Since kriging uses nearby points in the estimation of each block, excluding the upper limit values would bias the results even in blocks with high activity. The entire data file was therefore used for the kriging estimates. There is little agreement on how to deal with "less than" values

Table 9. Inventory estimates for the Galileo area
(Areas are in 10^4 square feet; inventories and
standard deviations are in Curies)

	Kriging		
	Inventory		Area
	<u>800' blocks</u>	<u>territories</u>	
Co-60	2.9	2.6 <u>+</u> 1.3*	5,632
Cs-137	5.0	6.1 <u>+</u> 0.9	12,672
Eu-152	20.7	20.1 <u>+</u> 6.1	4,096
Eu-154	1.3	---	832
Eu-155	0.25	---	2,112
Am-241	0.73	---	3,264

	Polygons of Influence		
	All data	Upper limit data excluded	Area
	Inventory	Inventory	
Co-60	2.8	$2.7 \pm .018^\dagger$	4,665
Cs-137	4.8	$4.8 \pm .037$	12,280
Eu-152	21.3	21.0 ± 0.11	4,246
Eu-154	2.2	$1.1 \pm .066$	648
Eu-155	0.57	$0.26 \pm .014$	1,963
Am-241	1.0	$0.73 \pm .026$	3,121

*Kriging standard deviation

†Measurement standard deviation

statistically. When they are included in the computations in this study, they are treated in the same manner as the other data. The resulting estimates are of course greater than they would be if the true values were known. To check the size of the difference, the estimate for Co was recalculated with the upper limit values set at one-half their original values. The inventory estimate decreased by 0.017 Curies, a change of less than 0.7%.

b) Kriging over the whole territory

This method is similar to the first, except that the entire region is treated as one block. There is no combining of individual estimates, so there is no problem with the error term. The disadvantages of this approach are its assumption that the random function is stationary on a larger scale than is assumed when kriging smaller blocks, and its relatively large cost in terms of computer time and memory.

Unfortunately our version of BLUEPACK can only handle 100 points at a time when calculating the mean over a territory. The area was therefore divided into two territories, and within each territory a region of detectable activity was defined which excluded as many upper limit values as possible while including the above-background measurements. The average activity for each region was estimated by kriging, and the two resulting inventories were added to get a total inventory. Since the two estimates were made from different subsets of the data, the error terms were also additive.

Inventories of Eu-154, Eu-155, and Am were not estimated with this method since good variogram estimates could not be obtained.

c) Polygons of influence

In the polygons of influence method, each point in the plane is associated with the sampled point to which it is closest, resulting in the partitioning of the plane into polygons. The activity at all points within a polygon is assumed to be the same as that of the sampled point; hence for each polygon there is an inventory equal to the area of the polygon times its activity. The total inventory is the sum of these individual inventories.

This method is an intuitively natural way to estimate the volume under a surface. It requires none of the assumptions which form the basis for kriging, and can be used even with a small number of data points. On the other hand, it does not provide an estimation error term, and is difficult to compute if data have not been taken on a regular grid.

Figure 21 shows the partitioning of the Galileo area into polygons of influence. Two estimates were computed for each isotope. The first used only the polygons for which the measurement was above background. These estimates are comparable to the kriging estimates, although the areas over which the inventory was estimated are somewhat different. The second used all 134 data points, and is included to give some idea of the inventory in the background areas.

Associated with the first method is a standard error derived from the counting error of each measurement. The counting error (% error x measured value) was assumed to represent one standard deviation, and the measurements were assumed to be independent. This error term represents measurement error; that is, it reflects the variability to be expected if the measurements were repeated at the same sampling points. It is not comparable to the kriging error, nor does it reflect sampling variability (the variability involved with measuring at a different set of sampling points).

4. Distribution Patterns

The distributions of the radionuclides were determined by using kriging to estimate the activity on a 27 x 29 array of points on a 400-foot grid centered on the GZ. Kriging is used here as an interpolant, in contrast to its use as an estimator of block averages to calculate inventories. The initial interpolation results were not satisfactory. For example, the estimated Co-60 activity 1200 feet east of the GZ was -3270 nCi/m², and a value of -80 nCi/m² was interpolated at a point 26 feet away from a measured value of 17.5. Such problems were largely eliminated by using only the 4 closest data points to interpolate each grid point. The few negative estimates which remained were set equal to 10 nCi/m².

Figure 21. Polygons of influence.

The array of interpolated values was then used as the input to the NCAR subroutine CONREC (Wright, 1977), which drew the isopleths shown in Figures 22 through 27. In all these figures, north is at the top of the page, the lower left corner represents point #107 (E658988, N833180), and the size of the increments around the rectangle is 400 feet. In addition, three-dimensional representations of the surfaces were drawn by the EZSRFC subroutine. The Eu-152 surface, as viewed from the southwest, is shown in Figure 28. The surfaces for the other radionuclides were similar.

Figure 22. Isopleths of Co-60 activity (nCi/m^2).

Figure 23. Isopleths of Cs-137 activity (nCi/m^2).

Figure 24. Isopleths of Eu-152 activity (nCi/m^2).

Figure 25. Isopleths of Eu-154 activity (nCi/m^2).

Figure 26. Isopleths of Eu-155 activity (nCi/m^2).

Figure 27. Isopleths of Am-241 activity (nCi/m^2).

Figure 28. Surface representing the Eu-152 distribution.

5. Supplemental Studies

5.1 In situ versus Soil Measurements

Since soil samples were taken at several locations where field measurements were made, it is natural to compare the activities measured by in situ spectrometry with those obtained by integrating the soil data. The results of four such comparisons are shown in Table 10. Except for Eu-152 and Eu-154, all soil activity was assumed to be in the fine soil fraction, and the measured inverse relaxation lengths were used for the integration. The two europium isotopes were assumed to be equally distributed between the fine and coarse fractions, and an inverse relaxation length of 0.05 cm^{-1} was used.

Note the differences between the estimates from in situ measurement and soil sampling for Co-60, Cs-137, and Am-241, especially at point 43. This point is 400 feet east of the GZ and is the only soil sampling location within 800 feet of the GZ. The in situ 1 m to soil ratios at point 43 are 6.2 for Co, 8.9 for Cs, and 17 for Am. Since the original soil sample at point 43 may not have been truly representative of the field of view of the detector, five additional surface samples were taken, one in the original location, the others 2 meters in each direction. These results, shown in the bottom part of Table 10, did not completely explain the difference. The ratios of the in situ 1 m measurements to the average soil total integral are 3.7 for Co, 5.4 for Cs, and 7.2 for Am.

To further investigate the discrepancy, the soil surface around point 43 was scanned with a μR meter. No large pieces of shot debris were found, but localized "hot spots" were observed which were always associated with the base of a plant or clump of grass. Such a "hot spot" about 300 ft east of the GZ pegged the μR meter on the 5 mR/hr scale in a typical field of about 500 $\mu\text{R/hr}$. Upon further investigation, the

Table 10. Radionuclide activities from soil and in situ measurements.
(Results expressed in nCi/m²)

Point		Co-60	Cs-137	Eu-152	Eu-154	Eu-155	Am-241	calculated μR/hr ¹
43	<u>In situ</u> 1m	27,400	18,300	24,700	1,380	1,770	8,570	730
	<u>In situ</u> 7.4m	30,600	20,400	29,900	2,400	2,420	12,000	823
	Soil							
	Top 5 cm	2,150	1,730	17,200	1,010	207	434	
	15 cm integral	3,990	2,060	56,100	3,040	233	490	
	Total integral	4,460	2,060	106,000	5,770	234	490	408
30	<u>In situ</u> 7.4m	1,540	1,910	52,800	2,840	150	<105	208
	Soil total integral	1,070	472	27,500	1,230	51	117	102
85	<u>In situ</u> 1m	438	1,830	11,600	643	111	<120	
	<u>In situ</u> 7.4m	596	1,720	13,400	597	204	<84	
	Soil total integral	340	330	10,900	458	38	<34	
94	<u>In situ</u> 1m	92	1,290	195	<66	80	<64	
	<u>In situ</u> 7.4m	90	1,200	150	<60	85	<32	
	Soil total integral	120	1,210	180	---	126	91	
<u>Additional surface 5 cm samples</u>								
	Point 43	2,800	2,310	19,000	1,110	226	705	
	2 m West	3,680	2,650	16,600	954	286	1,150	
	2 m East	6,100	4,890	18,500	1,050	500	1,970	
	2 m South	3,450	2,870	19,000	1,160	304	1,020	
	2 m North	1,740	1,510	12,500	570	167	424	
	Average	3,550	2,850	17,100	970	297	1,050	
	Average total integral	7,370	3,390	105,000	5,540	336	1,190	

¹ Measured exposure rate at point 43 was 690 μR/hr.

activity appeared to be associated with pieces of black opaque debris typically 1 to 5 mm in diameter held in the humus under the grass clump. A sample was counted and found to contain high levels of Co-60, Cs-137, and Am-241, but very little Eu-152. It appears that these localized "hot spots" could be responsible for up to 90% of the Am-241, 80% of the Cs-137, and 70% of the Co-60 in the Galileo GZ area. The Eu-152 appears to be more uniformly distributed as would be expected for a soil activation product. This phenomenon may be typical for tower shot areas in Yucca Valley.

Therefore, we believe that the activities in the Galileo ground zero area derived from the in situ data are a much better estimate of the true activity than those derived from soil sampling.

5.2 Influence of Variogram on Inventory Estimates

Recall (Section 2) that the variogram models derived from the Galileo data are highly uncertain. To determine how great an influence the variogram has on the inventory estimates, we estimated the Cs-137 inventory by kriging (method b) using variogram models with different sills and ranges. The results (Table 11) show that the inventory estimates are independent of the sill and inversely related to the range in the models considered.

The dependence on the range is at least in part a result of the biased sampling plan. Since there are no pairs of points less than 200 feet apart, a variogram with a range of 200 feet is nearly equivalent to a pure nugget effect, and all points get the same kriging weight. The kriging estimate of the mean is therefore essentially equal to the sample mean of the data, and is a very biased estimate of the true mean because of the higher sampling density around the GZ. As the range increases, the weights move toward the values they would be given by the polygons of influence method, where

Table 11. Inventory estimates using different
variogram models
(Results expressed in Curies)

		range (feet)							
		<u>200</u>	<u>400</u>	<u>600</u>	<u>800</u>	<u>1000</u>	<u>1100</u>	<u>1500</u>	<u>2000</u>
<u>Estimates</u>									
	1	9.7	8.6	7.6	6.7	6.4	---	---	---
sill	14	9.7	8.6	7.6	6.7	6.4	6.1	5.6	5.0
x10 ⁵	30	9.7	8.6	7.6	6.7	6.4	---	---	---
	55	9.7	8.6	7.6	6.7	6.4	---	---	---
<u>Standard deviations</u>									
	1	.32	.31	.29	.27	.25	---	---	---
sill	14	1.1	1.2	1.1	.99	.92	.90	.85	.73
x10 ⁵	30	1.7	1.7	1.6	1.4	1.4	---	---	---
	55	2.6	2.3	2.2	2.0	1.8	---	---	---

points that are close together get relatively smaller weights. The important thing to note about Table 11 is that the inventory estimates can change by a factor of two with a 10-fold increase in the range, the variogram parameter which is most poorly known in the present situation.

IV. Conclusion

The Galileo study has resulted in more than just a table of inventory estimates and some contour maps: it has led to findings which may affect the future efforts of both the RIDP and other inventory projects. An example is the large difference between the activities estimated from in situ spectrometry and from the more traditional soil sampling. It appears that soil samples, taken as they usually are in fairly open areas, may be missing a large fraction of the radioactivity which is associated with vegetation. The in situ method in a sense averages the gamma-ray radiation over an area of several hundred square meters, and thus gives a much better indication of local radioactivity levels.

On the other hand, there remain unresolved problems with regard to the analysis of the data. The results of kriging with the Galileo data are rather disappointing. In the first place, the inventory estimates are highly dependent on the variogram, in contradiction to the often-assumed robustness of kriging. Fortunately we were able to estimate the inventories with another method and so have some confidence that the kriging estimates are reasonable. The performance of kriging as an interpolant is even more troubling, since kriging produced negative estimates at points which clearly have high activity. This is especially surprising since kriging is primarily used as an interpolant.

Part of the problem, of course, is our inability to get reliable variogram estimates. The strategy of sampling at short distances only near the GZ will always produce biased sample variograms. We cannot give up sampling at short distances, since we then have no idea of the variogram range, which was seen to be the parameter with the greatest influence on the inventory estimates. It therefore seems necessary to also sample points close together in areas where the activity is fairly constant, which seems a waste of resources. It should also be noted that the Galileo data set

is very small from the standpoint of variogram estimation. Many of the examples in Journel and Huijbregts (1978) have several hundred data points.

Even more fundamental, though, is the question of how well our situation fits the kriging model. In other words, are we really dealing with a stationary random process? Perhaps the first thing to note is that it is not possible to tell from a single realization whether a process is stationary or not. We have an area of very high activity around the GZ, but this is not enough -- any process, stationary or not, will have areas of high activity and areas of low activity. It is not valid to look at the contour maps and conclude that the process is non-stationary. As Journel and Huijbregts point out, stationarity is largely a matter of scale. If we look at all of Yucca Flat, for example, the stationarity assumption is probably reasonable: the situation seems similar to an ore field with a few "nuggets" (GZ's) scattered about. If we look closely at one GZ, the assumption is clearly not reasonable, since we know that the activity will increase as we move toward the GZ.

The scale of the Galileo area, unfortunately, falls between these extremes, and the question of stationarity is not easily resolved. It seems clear that we do not have a "drift" in the sense of a slowly changing trend which can be modeled by a linear or quadratic polynomial. In the Galileo area, we have a region of high activity concentrated over perhaps 10% of the surface, and this feature cannot be reasonably approximated by a low-order polynomial. On the other hand, it also seems clear that the assumption of stationarity is not met in the area near the GZ.

A logical approach would be to model the area as a non-stationary random process in the vicinity of the GZ and a separate stationary process in the outlying areas. This is theoretically sound, but it cannot be done with the Galileo data, since there are only about 35 points within what might be defined as the GZ area.

It seems unlikely that we will be able to improve significantly on the kriging results obtained here. It would seem worthwhile, then, to investigate alternatives to kriging. The polygons of influence method is one alternative. Another would be to use some other interpolation method, such as that of Foley (1981), to produce an estimate of the surface, then compute the volume under the surface (the inventory) by numerical integration. One drawback of these alternatives is that they provide no estimate of error. Whether this is a serious problem is arguable: in light of the large degree of uncertainty about the variogram model, the kriging error estimates are probably little more than guesses anyway.

There are other aspects of the RIDP which we have not addressed in this report. One is the design of sampling plans for the in situ measurements to avoid the kinds of biases resulting from the preferential sampling scheme used in the Galileo area. Another involves an assessment of the overall precision of the project to see if the objective of "within a factor of two" for the inventory estimates is being met. Discussion of these issues, as well as continued reporting of the results from other areas, will be the subjects of future RIDP reports.

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APPENDIX: In situ Measurements

The measurement for each radionuclide is followed by the percent error. Measurements with 0 percent error are upper limit values.

Units for Co-60, Cs-137, Eu-152, Eu-154, Eu-155 and Am-241 are nCi/m².

Units for K-40, Th-232, and U-238 are pCi/g.

point	E	N	Co-60	Cs-137	Eu-152	Eu-154
1	659714	840393	5.698 .0	57.76 21.2	21.63 .0	32.69 .0
2	659768	841977	15.61 .0	107.30 17.3	27.34 .0	51.65 .0
2	659768	841977	23.20 53.0	130.20 11.3	21.48 .0	38.46 .0
3	659738	843577	71.00 18.0	185.70 11.8	30.04 .0	54.39 .0
3	659738	843577	69.32 22.4	174.00 8.6	22.01 .0	38.99 .0
4	660589	840399	13.37 .0	16.55 .0	110.70 20.5	46.23 .0
4	660589	840399	8.841 .0	27.00 50.0	110.60 16.7	36.26 .0
5	660601	841188	10.03 .0	93.20 18.9	31.83 .0	66.62 .0
5	660601	841188	9.497 .0	101.00 12.4	22.29 .0	42.52 .0
6	660596	843599	53.89 15.9	133.60 10.6	23.71 .0	40.03 .0
7	660529	844369	97.85 18.1	111.10 18.1	31.97 .0	60.13 .0
7	660529	844369	92.27 11.0	126.30 11.6	22.23 .0	39.52 .0
8	660962	840782	13.70 .0	99.61 19.2	33.66 .0	54.39 .0
8	660962	840782	9.305 .0	113.10 13.1	22.75 .0	36.82 .0
9	661389	838776	20.74 .0	46.18 38.9	43.67 .0	95.81 .0
9	661389	838776	12.56 .0	61.35 26.7	31.43 .0	65.44 .0
10	661376	839595	8.494 .0	81.66 15.4	23.35 .0	38.99 .0
11	661411	840392	17.82 .0	100.30 19.8	67.50 33.7	65.37 .0
11	661411	840392	17.44 57.1	110.80 14.8	56.45 45.5	47.11 .0
12	661384	840776	787.20 6.2	3124. 3.4	38130. 2.1	2563. 18.5
12	661384	840776	805.60 6.9	3206. 4.2	39020. 1.7	2647. 11.5
13	661415	841184	14.57 .0	80.64 21.4	34.16 .0	58.56 .0
13	661415	841184	12.50 .0	101.50 20.9	33.89 .0	67.84 .0
14	661414	841983	10.23 .0	103.40 15.1	25.69 .0	44.87 .0
15	661388	842780	24.54 .0	91.78 24.4	40.54 .0	82.04 .0
16	661388	843580	26.75 .0	106.30 21.1	41.27 .0	65.44 .0
17	661778	840789	6660. 2.7	1333. 6.7	3541. 6.2	755.90 .0
17	661778	840789	6760. 2.0	1239. 5.3	3534. 4.6	289.00 54.0
18	662155	839582	14.21 .0	71.57 25.1	34.93 .0	66.62 .0
18	662155	839582	9.869 .0	66.20 17.7	64.17 32.3	44.41 .0
19	662206	840377	14.57 .0	103.00 19.0	39.71 .0	76.35 .0
19	662206	840377	10.91 .0	117.30 12.6	36.60 59.0	49.65 .0
20	662183	841187	13.70 .0	76.81 20.5	36.60 .0	65.37 .0
20	662183	841187	9.452 .0	90.70 15.6	25.87 .0	45.78 .0
21	662208	841980	14.21 .0	22.80 .0	35.82 .0	62.81 .0
21	662208	841980	14.10 61.0	59.65 22.7	24.80 .0	43.48 .0
22	662188	842780	26.23 .0	93.63 23.6	40.63 .0	83.42 .0
23	662606	840381	93.39 17.3	187.40 16.2	3610. 5.3	307.90 .0
23	662606	840381	92.19 13.1	193.50 14.3	3815. 3.3	317.90 37.1
24	662625	840773	13.78 .0	64.51 25.1	152.10 18.1	82.09 .0
24	662625	840773	9.598 .0	62.39 19.4	143.30 14.2	56.98 .0
25	663007	838783	28.84 .0	205.60 14.5	845.50 15.1	304.60 .0
25	663007	838783	38.10 34.0	185.80 12.9	954.30 9.1	216.70 .0
26	662970	839504	22.15 .0	136.50 18.4	2106. 5.5	252.90 .0
26	662970	839504	51.93 17.7	150.30 13.8	2101. 3.9	180.40 .0
27	663012	840366	37.68 24.0	71.90 19.4	689.20 8.0	154.00 .0
28	662979	841977	15.19 .0	54.12 28.7	33.91 .0	67.84 .0
28	662979	841977	9.497 .0	70.21 18.9	24.76 .0	43.48 .0
29	662988	843580	70.70 36.0	100.30 24.8	43.39 .0	73.16 .0
30	663797	838766	1572. 4.2	1961. 7.4	52990. 1.2	2985. 14.7
30	663797	838766	1540. 3.2	1919. 4.9	52820. .9	2841. 9.5
31	663794	839570	573.80 4.1	761.50 6.0	14480. 1.3	528.30 22.4
32	663801	840378	233.50 12.0	216.40 11.9	1488.00 7.7	266.50 .0
32	663801	840378	214.30 7.1	206.30 9.2	1456.00 5.5	195.60 .0
33	663796	841167	134.40 12.0	126.00 16.2	79.61 30.8	69.04 .0
33	663796	841167	135.30 10.2	128.40 13.8	81.74 22.9	50.88 .0

	Eu-155			Am-241			K-40			Th-232			U-238		
1	20.20	.0		15.57	.0		17.26	6.9		1.436	7.9		1.168	10.1	
2	20.17	.0		20.67	.0		21.50	7.3		1.201	11.3		1.174	12.2	
2	20.20	.0		16.16	.0		22.03	5.7		1.179	8.5		1.131	14.1	
3	24.68	.0		25.12	.0		19.77	8.7		1.462	10.9		1.220	15.8	
3	16.97	.0		23.30	56.5		20.15	6.0		1.426	7.6		1.136	12.5	
4	22.74	.0		22.17	.0		18.07	9.2		1.305	12.1		1.147	16.7	
4	16.14	.0		16.03	.0		18.65	6.3		1.285	7.8		1.158	10.8	
5	23.72	.0		23.25	.0		20.35	9.0		1.567	10.5		1.188	16.3	
5	16.84	.0		16.33	.0		19.91	6.1		1.552	7.0		1.285	11.8	
6	17.25	.0		23.80	56.0		18.38	6.3		1.608	7.3		1.273	10.7	
7	23.74	.0		24.59	.0		20.71	8.8		1.565	13.1		1.114	16.7	
7	16.92	.0		29.80	47.0		20.25	6.3		1.537	8.6		1.310	9.7	
8	25.00	.0		25.20	.0		17.16	10.6		1.134	12.4		1.240	14.9	
8	17.22	.0		18.23	.0		16.92	6.6		1.225	8.1		1.274	9.7	
9	30.80	.0		33.46	.0		21.93	12.0		1.626	16.6		1.724	17.7	
9	22.00	.0		23.78	.0		20.77	7.5		1.500	11.9		1.610	13.0	
10	26.80	50.0		16.42	.0		20.29	6.2		1.501	12.4		1.487	8.5	
11	27.65	.0		28.86	.0		20.77	10.7		1.081	38.8		1.231	15.4	
11	19.66	.0		20.37	.0		18.61	6.4		1.332	8.9		1.283	10.8	
12	111.70	.0		101.60	.0		18.15	10.9		.9068	.0		1.022	.0	
12	79.19	.0		275.50	30.9		18.67	7.9		.6367	.0		2.003	23.0	
13	26.15	.0		26.29	.0		15.16	10.1		1.545	10.6		1.286	13.3	
13	25.67	.0		26.91	.0		16.09	9.9		1.416	10.3		1.254	14.3	
14	18.65	.0		18.49	.0		16.88	7.0		1.307	9.7		1.300	13.6	
15	27.29	.0		30.44	.0		20.77	11.3		1.247	19.6		.9385	20.9	
16	28.69	.0		32.82	.0		21.46	9.8		1.470	13.7		1.272	18.5	
17	66.25	.0		188.80	36.5		16.27	10.2		.6999	.0		.9185	.0	
17	47.03	.0		153.40	30.2		16.57	7.6		1.033	28.8		1.183	29.0	
18	24.67	.0		24.85	.0		14.80	11.2		.8234	35.6		.8970	20.2	
18	17.49	.0		17.44	.0		15.97	7.3		1.148	9.9		1.098	15.0	
19	28.24	.0		28.01	.0		17.37	9.8		1.132	14.4		1.282	16.0	
19	19.92	.0		19.95	.0		17.95	6.4		1.112	10.1		1.185	13.6	
20	27.45	.0		27.04	.0		20.16	11.4		1.538	12.3		.9595	18.0	
20	19.10	.0		19.43	.0		18.07	7.8		1.325	8.7		1.037	13.1	
21	25.82	.0		25.77	.0		18.81	8.8		1.204	12.5		1.219	14.7	
21	18.28	.0		18.15	.0		19.07	6.7		1.229	9.6		1.214	10.5	
22	28.72	.0		40.10	53.0		21.54	9.4		1.471	13.7		1.117	18.2	
23	39.61	.0		38.81	.0		18.26	9.9		1.430	14.7		1.301	24.5	
23	27.80	.0		27.26	.0		19.18	8.2		1.182	12.3		1.351	14.1	
24	29.17	.0		29.93	.0		16.49	9.3		1.145	15.9		1.222	19.8	
24	20.58	.0		21.03	.0		18.34	6.4		1.090	10.8		1.179	16.3	
25	42.49	.0		48.35	.0		18.67	12.1		1.191	17.1		1.450	33.0	
25	30.14	.0		31.60	67.0		17.79	8.1		1.267	11.8		1.314	16.4	
26	32.29	.0		32.33	.0		17.60	10.2		1.135	16.7		1.191	21.1	
26	25.97	.0		26.06	.0		17.32	6.8		1.197	11.3		1.136	14.9	
27	21.63	.0		21.77	.0		19.50	6.7		1.369	11.2		1.278	13.5	
28	26.12	.0		25.37	.0		18.37	9.4		1.173	12.9		1.356	14.5	
28	18.57	.0		17.94	.0		18.77	6.3		1.427	9.0		1.350	12.9	
29	29.10	.0		32.58	.0		25.06	9.1		1.429	19.1		1.303	16.6	
30	140.40	.0		148.90	.0		16.99	13.1		1.240	.0		1.336	.0	
30	153.60	32.6		105.10	.0		21.64	12.6		1.800	45.0		2.620	39.0	
31	108.10	28.4		49.64	.0		17.29	8.4		1.281	21.7		1.253	24.0	
32	36.17	.0		37.12	.0		16.72	9.6		1.015	19.8		.9649	22.3	
32	25.30	.0		65.76	30.0		17.75	6.7		1.246	11.0		1.168	14.0	
33	29.81	.0		31.16	.0		17.43	9.4		1.313	13.2		1.171	18.8	
33	21.30	.0		38.10	45.0		18.77	6.6		1.349	13.9		1.241	12.0	

point	E	N	Co-60		Cs-137		Eu-152		Eu-154	
34	663788	842780	164.90	12.1	151.70	20.0	43.72	.0	88.10	.0
35	663788	844380	348.80	8.4	255.50	13.1	48.17	.0	119.10	.0
36	664188	838780	6857.	2.1	4322.	4.3	94490.	.9	4916.	12.4
37	664788	838780	17850.	1.2	11812.	2.1	41260.	1.5	2728.	17.4
133	664388	838780	17250.	1.3	8590.	3.3	141800.	2.0	9628.	18.3
38	664588	839180	3039.	2.9	1338.	9.2	50310.	4.5	3399.	38.7
134	664588	838980	9094.	1.6	4429.	4.4	36550.	4.3	3516.	36.0
39	664594	839577	1796.	3.8	1975.	5.6	36610.	1.6	2169.	14.8
39	664594	839577	1785.	2.9	1837.	4.0	36840.	1.5	2044.	17.3
40	664600	840395	701.20	4.2	968.00	5.2	3255.00	4.9	352.00	.0
40	664600	840395	717.30	3.2	894.00	4.0	3195.00	3.7	243.10	.0
41	664588	841980	364.80	8.1	300.60	14.2	48.40	.0	104.80	.0
42	664588	843580	416.00	7.1	321.50	11.4	49.16	.0	73.16	.0
43	664988	838780	30570.	1.1	20423.	1.6	29940.	4.8	2398.	20.6
44	665375	838795	1179.	5.3	884.00	9.7	20280.	2.3	968.50	24.8
44	665365	838806	1248.	4.2	957.00	10.2	20840.	2.8	869.10	.0
44	665365	838806	1340.	4.0	859.00	10.6	21310.	2.7	1060.	27.1
44	665388	838780	1206.	3.7	891.00	7.2	20890.	2.3	932.80	25.0
44	665388	838780	1132.	4.4	820.00	8.7	20740.	2.5	1174.	27.3
44	665388	838780	1013.	5.2	767.00	10.9	19260.	2.3	1515.	18.4
45	665374	839170	1171.	4.5	1721.	5.9	29870.	1.8	2053.	14.3
46	665380	839585	735.50	6.8	1246.	6.5	16000.	2.2	976.40	25.7
47	665395	840385	206.40	13.6	655.00	7.2	2313.00	6.1	325.20	.0
48	665400	841196	251.20	10.3	1329.	5.0	564.80	7.8	111.00	.0
49	665388	842780	339.70	8.1	802.40	6.9	52.90	65.0	89.61	.0
50	665388	843580	366.30	7.8	1000.	5.1	52.27	.0	103.50	.0
51	665388	844380	331.90	13.4	586.00	7.5	49.52	.0	96.79	.0
52	666183	838842	242.40	10.4	1637.	4.6	2880.00	5.9	365.80	.0
53	666188	839580	98.36	19.3	613.00	7.2	2115.00	6.5	331.80	.0
54	666188	840380	29.71	.0	602.00	7.1	1282.00	10.8	254.40	.0
55	666188	841980	21.42	.0	280.50	13.8	191.00	36.0	71.31	.0
56	666188	842780	16.93	.0	146.00	19.0	41.59	.0	81.80	.0
57	666188	843580	37.00	50.0	327.00	12.4	44.56	.0	86.57	.0
58	666188	844380	93.06	20.3	559.40	7.2	45.89	.0	85.01	.0
59	666988	839580	22.72	.0	152.50	19.6	134.90	20.9	89.61	.0
60	666988	840380	22.72	.0	204.80	13.3	178.00	30.0	80.15	.0
61	666988	841180	16.92	.0	272.50	11.2	94.17	31.1	85.01	.0
62	666988	841980	19.54	.0	87.93	26.6	70.30	42.0	80.15	.0
63	666988	843580	16.93	.0	77.53	38.2	40.66	.0	71.31	.0
64	666988	844380	16.06	.0	70.65	35.6	40.25	.0	83.42	.0
65	667790	838727	22.08	.0	102.70	23.8	63.80	54.0	69.97	.0
66	667788	840380	16.93	.0	207.80	16.9	76.10	47.0	74.97	.0
67	667788	841180	16.06	.0	77.60	28.7	68.50	49.0	86.57	.0
68	667788	842780	19.31	.0	64.17	31.4	40.69	.0	83.42	.0
69	668588	839580	16.06	.0	76.61	31.3	40.42	.0	65.45	.0
70	668588	843580	17.76	.0	26.31	.0	40.98	.0	85.01	.0
71	669388	841980	17.76	.0	25.03	.0	40.01	.0	76.73	.0
72	669388	843580	17.76	.0	26.31	.0	42.08	.0	71.31	.0
73	670188	839580	17.76	.0	22.27	.0	41.73	.0	74.97	.0
74	664588	834780	13.70	.0	134.80	15.5	33.30	.0	66.62	.0
75	664588	835580	14.71	.0	209.40	14.7	33.86	.0	55.88	.0
76	664588	836380	28.06	.0	432.20	8.6	134.00	32.7	99.51	.0
77	664578	837177	198.00	17.3	1288.	5.2	2937.00	5.5	374.60	.0
78	664607	837968	1872.	3.7	7333.	2.6	42370.	1.3	1967.	15.0
79	665388	833180	14.21	.0	73.57	21.9	29.29	.0	49.00	.0
80	665388	833980	11.40	.0	72.83	23.4	31.59	.0	49.65	.0

	Eu-155		Am-241		K-40		Th-232		U-238	
34	30.56	0	34.97	0	20.74	12.3	1.234	18.0	1.636	16.0
35	32.03	0	114.30	25.1	23.06	10.2	1.343	23.7	1.486	20.6
36	306.20	38.1	1577.	15.8	16.47	13.9	1.608	0	1.822	0
37	1213.	13.6	5391.	6.5	17.09	13.1	1.626	0	1.871	0
133	810.10	22.1	4414.	8.5	18.63	14.5	2.253	0	2.577	0
38	150.70	0	431.50	36.5	17.25	16.8	1.353	0	1.529	0
134	307.90	31.2	1356.	11.9	18.37	12.1	1.490	0	1.701	0
39	109.80	0	426.30	25.3	17.16	9.9	8549	0	9679	0
39	185.50	37.2	388.70	36.0	20.30	12.7	5994	0	6884	0
40	77.02	31.8	244.10	17.3	16.77	10.2	1.212	22.2	9519	31.9
40	76.85	23.7	217.10	11.8	19.12	6.5	1.108	25.2	1.263	17.8
41	33.53	0	138.80	23.5	18.35	11.8	1.543	14.5	1.520	32.0
42	32.43	0	99.28	34.7	20.48	19.3	1.755	14.7	1.448	19.3
43	2419.	5.6	12000.	5.7	14.39	19.3	1.785	0	2.061	0
44	93.65	0	105.50	0	12.96	28.0	1.989	29.6	1.640	46.0
44	104.90	0	204.60	32.8	18.04	12.4	2.060	58.0	1.031	0
44	105.70	0	315.10	39.0	22.11	11.6	1.440	54.0	1.037	0
44	80.41	0	150.70	36.5	15.63	12.1	1.360	47.0	1.509	30.0
44	79.63	0	156.50	43.5	16.44	10.6	1.318	33.2	1.180	38.0
44	94.90	0	255.10	37.4	17.54	14.6	863	71.0	1.410	35.0
45	194.00	37.0	219.00	50.0	24.92	16.5	1.280	49.0	1.073	0
46	85.03	0	167.70	36.2	18.24	12.3	1.765	29.2	2.240	38.7
47	63.00	68.1	52.89	0	20.76	12.2	1.342	21.0	1.296	24.0
48	86.26	32.3	97.22	45.3	20.94	11.6	1.303	21.6	1.550	40.0
49	35.59	0	108.80	27.9	17.16	11.8	1.102	22.5	9538	24.6
50	62.50	42.0	154.20	22.8	17.74	12.2	1.066	25.9	1.208	23.8
51	33.98	0	198.60	22.3	19.68	11.5	1.495	15.9	1.623	18.7
52	130.50	34.4	54.35	0	19.71	11.1	1.249	22.9	1.222	30.3
53	41.83	0	46.85	0	20.85	11.4	1.285	17.3	1.610	21.9
54	36.93	0	40.09	0	21.41	10.9	1.443	17.7	1.434	18.5
55	32.20	0	34.94	0	22.98	11.2	1.499	14.7	1.469	16.8
56	28.12	0	32.16	0	24.43	9.4	1.163	19.3	1.345	18.8
57	31.28	0	34.52	0	25.44	9.2	1.151	18.3	1.679	17.1
58	31.67	0	36.35	0	19.71	11.4	1.464	17.0	1.425	19.9
59	32.15	0	35.37	0	20.17	11.0	1.400	16.0	1.713	14.0
60	31.75	0	34.67	0	23.47	9.7	1.532	12.9	1.359	18.2
61	31.79	0	34.64	0	19.55	11.6	1.538	20.4	1.406	17.0
62	29.58	0	32.51	0	21.25	14.5	1.234	23.2	9751	23.5
63	27.80	0	31.51	0	22.61	9.5	1.281	18.4	1.102	19.3
64	28.30	0	31.28	0	20.62	14.7	1.244	24.0	1.487	14.8
65	32.34	0	64.87	35.7	19.20	11.0	1.459	13.7	1.266	22.3
66	28.79	0	33.66	0	21.52	11.4	1.267	17.3	1.159	17.8
67	27.57	0	30.41	0	21.05	10.4	1.308	14.2	1.124	18.9
68	27.42	0	31.35	0	20.51	11.6	1.441	12.9	1.327	16.0
69	27.92	0	32.17	0	18.39	12.1	1.241	15.1	1.204	16.8
70	27.84	0	31.60	0	19.87	11.5	1.192	15.3	1.119	20.3
71	27.75	0	31.66	0	15.33	18.1	1.459	13.9	1.509	14.5
72	27.98	0	32.02	0	17.83	11.1	1.488	19.6	1.523	18.6
73	28.65	0	32.19	0	20.68	10.7	1.336	21.8	1.540	16.1
74	24.32	0	24.17	0	24.66	7.7	1.580	9.8	1.099	17.7
75	26.00	0	25.97	0	21.01	0	1.120	30.0	9972	22.7
76	37.57	0	42.16	0	24.30	11.9	1.230	18.1	1.069	24.2
77	80.41	31.8	53.81	0	22.91	11.6	1.288	23.1	1.458	21.4
78	562.10	23.1	437.20	43.2	19.04	12.0	1.140	0	1.223	0
79	22.02	0	22.22	0	18.41	9.0	1.017	13.7	1.218	16.0
80	24.62	0	23.76	0	23.36	8.6	1.419	12.4	1.111	14.1

point	E	N	Co-60	Cs-137	Eu-152	Eu-154
81	665388	834780	11.40 .0	145.30 16.1	33.25 .0	64.10 .0
82	665388	835180	13.16 .0	125.20 14.8	33.63 .0	66.62 .0
83	665388	836380	29.33 .0	628.60 12.9	57.94 .0	92.56 .0
84	665389	837187	89.44 21.9	458.00 8.9	1716.00 8.2	286.30 .0
85	665411	837983	595.90 6.4	1715. .5.6	13430. 2.2	597.10 29.5
86	666188	834780	13.16 .0	101.90 18.0	33.61 .0	64.10 .0
87	666188	835580	91.13 16.2	1387. .3.6	157.40 22.7	75.85 .0
88	666188	836380	45.80 40.0	659.30 5.6	85.00 32.4	66.62 .0
89	666177	837190	66.70 43.0	292.00 13.0	742.90 14.5	254.50 .0
90	666188	837985	71.80 47.6	446.00 10.4	2070.00 6.4	328.50 .0
91	666988	833980	10.05 .0	72.97 22.4	33.04 .0	69.04 .0
92	666988	834780	12.94 .0	102.80 18.2	32.50 .0	61.49 .0
93	666988	835580	43.90 47.0	453.40 7.0	71.17 33.2	57.34 .0
94	666988	836380	90.00 15.5	1198. .3.9	149.50 19.1	60.13 .0
95	666988	837981	31.47 38.4	436.40 9.3	186.80 19.6	82.04 .0
96	667788	833180	12.01 .0	62.40 25.2	30.32 .0	55.56 .0
97	667788	835180	12.60 .0	266.10 9.4	34.31 .0	66.62 .0
98	667788	836380	50.35 27.0	655.50 5.5	37.91 .0	58.75 .0
99	667788	837180	18.30 .0	476.30 6.4	110.80 23.3	61.49 .0
100	667797	837982	24.54 .0	395.30 9.0	261.70 15.7	85.69 .0
101	668588	834780	15.19 .0	228.10 10.8	5.57 79.0	62.81 .0
102	668588	835580	50.40 36.0	467.70 6.9	36.53 .0	54.39 .0
103	668588	837180	13.70 .0	252.60 10.9	34.14 .0	55.88 .0
104	669388	833980	13.70 .0	232.60 11.8	44.80 63.0	65.37 .0
105	669388	835580	43.42 28.8	529.40 6.5	37.73 .0	66.62 .0
106	669388	837980	10.57 .0	15.90 .0	30.26 .0	57.34 .0
107	658988	833180	16.06 .0	56.33 40.3	41.68 .0	71.31 .0
108	658988	836380	16.06 .0	62.95 28.0	35.31 .0	55.31 .0
109	659788	833980	17.76 .0	91.81 29.1	43.09 .0	51.73 .0
110	659788	835580	16.20 .0	21.38 .0	34.41 .0	61.21 .0
111	659788	837980	16.06 .0	48.69 42.2	39.53 .0	81.80 .0
112	660588	833180	14.17 .0	127.70 22.7	44.70 .0	81.80 .0
113	660588	833980	23.95 .0	401.00 9.7	43.80 .0	83.42 .0
114	660588	834780	19.60 76.0	299.50 10.5	38.72 .0	76.73 .0
115	661388	833180	20.74 .0	95.42 25.9	42.56 .0	85.69 .0
116	661388	834780	21.42 .0	173.80 14.5	40.72 .0	76.73 .0
117	661388	835580	22.08 .0	328.70 10.7	42.19 .0	74.97 .0
118	661394	837166	16.06 .0	45.80 50.0	45.91 .0	88.10 .0
119	661403	837969	16.93 .0	29.58 .0	46.09 .0	85.01 .0
120	662188	833980	16.06 .0	164.10 17.3	43.25 .0	81.80 .0
121	662188	834780	42.80 47.0	469.10 7.9	45.12 .0	74.21 .0
122	662165	836371	23.95 .0	124.80 23.3	47.32 .0	89.61 .0
123	662190	837968	11.97 .0	67.39 31.4	57.40 53.0	82.04 .0
123	662190	837968	12.56 .0	67.48 24.1	72.48 33.4	61.21 .0
124	662988	834780	18.92 .0	144.20 27.2	43.17 .0	91.09 .0
125	662968	835582	26.23 .0	846.10 5.4	53.69 .0	92.55 .0
126	662987	836371	23.34 .0	328.70 10.4	50.43 .0	100.80 .0
127	662885	837138	19.31 .0	95.20 28.0	128.10 24.3	89.61 .0
128	662998	837984	44.83 27.1	135.50 15.7	1391.00 6.0	217.90 .0
129	663788	833180	11.97 .0	120.60 22.0	44.00 .0	78.46 .0
130	663788	834780	20.04 .0	231.80 12.6	45.12 .0	74.97 .0
131	663801	837177	51.80 32.0	233.00 14.0	1567.00 9.9	301.10 .0
132	663757	837963	804.30 5.4	3017. .3.3	10270. 2.9	767.00 69.0

	Eu-155		Am-241		K-40		Th-232		U-238	
81	24.77	.0	24.45	.0	24.01	7.9	1.047	32.4	1.393	12.6
82	25.64	.0	25.18	.0	22.18	8.2	1.096	33.0	1.016	18.3
83	39.27	.0	42.48	.0	23.04	10.3	1.600	22.7	.730	49.0
84	41.27	.0	45.77	.0	19.09	11.1	1.529	19.0	1.520	36.0
85	203.80	25.0	83.94	.0	22.20	13.4	1.654	22.6	.7053	.0
86	24.41	.0	25.70	.0	22.37	8.0	1.429	12.8	1.217	15.4
87	116.00	17.0	79.87	36.7	23.17	8.1	1.268	14.5	1.197	18.0
88	45.80	45.0	29.26	.0	21.45	8.4	1.383	12.4	1.263	16.8
89	34.64	.0	38.84	.0	22.48	11.1	1.152	24.1	1.351	24.0
90	40.73	.0	45.21	.0	19.87	10.4	1.131	27.7	1.479	19.7
91	24.45	.0	24.17	.0	25.67	7.9	1.351	11.5	1.088	15.8
92	24.14	.0	25.01	.0	19.90	8.7	1.452	11.0	1.199	14.3
93	58.38	33.4	27.51	.0	23.07	8.7	1.401	12.2	1.333	18.6
94	85.10	24.1	32.43	.0	23.26	7.9	1.523	11.0	1.257	16.1
95	34.11	.0	37.99	.0	19.92	11.9	1.786	19.2	1.494	17.2
96	23.53	.0	49.20	51.0	23.03	7.8	1.377	10.9	1.131	14.4
97	24.74	.0	26.01	.0	22.29	8.4	1.519	10.8	1.132	27.9
98	58.40	37.0	35.50	51.0	19.61	10.9	1.371	12.8	.4476	48.2
99	28.12	.0	28.08	.0	21.43	8.5	1.458	11.7	1.226	15.0
100	33.54	.0	37.44	.0	21.48	10.2	1.273	18.7	1.351	18.3
101	37.70	43.0	43.30	58.0	22.94	8.4	1.416	11.8	1.170	14.4
102	27.50	.0	29.25	.0	22.65	8.0	1.303	14.2	1.153	23.3
103	65.20	33.5	25.80	.0	18.77	9.6	1.478	10.6	1.424	16.2
104	40.10	55.0	53.45	40.2	23.81	8.0	1.585	11.1	1.133	17.5
105	27.30	.0	62.60	45.0	19.95	8.9	1.535	11.3	1.195	17.7
106	23.04	.0	22.95	.0	19.33	9.2	1.624	8.9	1.135	15.2
107	28.79	.0	32.87	.0	20.09	10.8	1.859	14.6	1.540	16.0
108	23.63	.0	26.58	.0	13.61	15.1	1.006	17.7	1.027	17.0
109	29.07	.0	31.46	.0	20.87	11.3	1.232	15.8	1.349	15.7
110	24.28	.0	27.52	.0	17.40	13.6	.8602	18.4	.9391	21.4
111	27.13	.0	30.80	.0	26.03	9.6	1.457	13.4	1.354	17.3
112	30.15	.0	32.54	.0	24.68	10.0	1.772	13.1	1.382	17.7
113	31.79	.0	35.12	.0	22.31	9.8	1.332	15.2	1.599	17.2
114	29.26	.0	34.06	.0	21.99	11.7	1.238	18.1	1.324	16.3
115	30.00	.0	32.99	.0	21.73	11.8	1.746	19.5	1.626	16.7
116	27.95	.0	31.89	.0	19.41	14.4	.9224	24.3	1.208	20.9
117	30.33	.0	34.58	.0	24.02	9.4	1.307	16.8	1.638	15.5
118	31.04	.0	34.34	.0	23.20	10.5	1.619	12.0	1.429	17.5
119	31.80	.0	34.31	.0	25.83	12.8	1.413	14.4	1.320	18.7
120	30.58	.0	34.37	.0	25.41	10.3	1.841	14.6	1.599	15.0
121	31.74	.0	35.05	.0	20.81	9.8	1.510	14.6	1.268	22.2
122	32.36	.0	35.92	.0	26.71	9.3	1.582	14.7	.7604	27.5
123	32.79	.0	36.08	.0	20.42	11.8	1.559	15.1	1.453	17.1
123	23.14	.0	25.51	.0	21.24	6.9	1.280	14.0	1.253	12.6
124	30.36	.0	32.86	.0	20.17	10.6	1.444	18.8	1.329	16.5
125	38.11	.0	41.89	.0	22.09	10.4	1.133	26.3	1.072	23.8
126	43.60	58.0	39.39	.0	24.04	9.5	1.364	15.7	1.485	15.2
127	33.81	.0	46.50	52.0	23.98	11.8	1.431	16.3	1.797	15.6
128	28.66	.0	32.43	.0	21.43	8.0	1.144	14.2	1.240	15.1
129	29.14	.0	32.94	.0	22.00	35.1	1.349	16.8	1.576	15.3
130	30.79	.0	33.22	.0	24.11	12.2	1.876	12.6	1.180	19.4
131	42.36	.0	47.86	.0	21.52	12.8	1.275	23.1	1.510	18.3
132	168.70	34.7	208.80	37.4	21.23	10.9	1.648	29.9	.7522	.0

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