



Department of Energy

Oak Ridge Field Office

P.O. Box 2001

Oak Ridge, Tennessee 37831 —

March 19, 1993

Sandra Waldron
Technical Assistant
U.S. National Regulatory Commission
101 Marietta Street 2900
Atlanta, Georgia 30323

Dear Ms. Waldron:

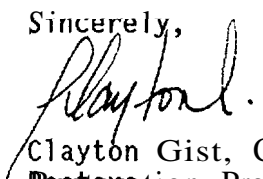
PRELIMINARY SITE SURVEY REPORT OF THE EL VERDE RESEARCH STATION

Per your request, enclosed is a copy of the Preliminary Site Survey Report of the El Verde Research Station, Center for Energy and Environment Research in Puerto Rico.

Additional soil and vegetation samples were collected recently, the results will be submitted to your office upon my receipt.

Should you have any questions or need additional information, please do not hesitate to contact me at (615) 576-6821 or Mildred Ferré at (615) 576-8018.

Sincerely,


Clayton Gist, Chief
Restoration Program
Integration Branch

Enclosure

PRELIMINARY SITE
SURVEY REPORT OF THE
EL VERDE RESEARCH STATION,
CENTER FOR ENERGY
AND
ENVIRONMENT RESEARCH,
IN THE LUQUILLO FOREST,
LUQUILLO, PUERTO RICO
(PRE001)

R. D. Foley
L. M. Floyd

DRAFT

HEALTH AND SAFETY RESEARCH DIVISION

**Waste Management Research and Development Programs
(Activity No. AH 10 05 01 0, EW202001)**

**PRELIMINARY SITE SURVEY REPORT
OF THE EL VERDE RESEARCH STATION,
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH,
IN THE LUQUILLO FOREST, LUQUILLO,
PUERTO RICO (PRE001)**

R. D. Foley and L. M. Floyd

Date of Issue - March 16, 1990

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MARTIN MARIETTA ENERGY SYSTEMS, INC
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under contract DE-AC05-84OR21400**



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Research for this project was sponsored by the Division of Facility and Site Decommissioning Projects, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc. The authors wish to acknowledge the support of J. E. Baublitz, Acting Director, Office of Remedial Action and Waste Technology; J. J. Fiore, Director, Division of Facility and Site Decommissioning Projects; and members of their staffs. The authors also appreciate the contributions of J. L. Rich of the Publications Division; T. R. Stewart of the Measurement Applications and Development Group; N. E. Irizarry, Center for Energy and Environment Research, University of Puerto Rico; and J. A. Foley for participation in the collection, analyses, editing, and reporting of data for this survey.

ABSTRACT

At the request of the **U.S.** Department of Energy (DOE), a group from Oak Ridge National Laboratory conducted a preliminary radiological survey at the El Verde Research Station, Center for Energy and Environment Resaerch, in the Luquillo Forest, Luquillo, Puerto **Rico** (PRE001), in 1988. The **purpose** of the survey **was** to determine whether the site **was** contaminated with radioactive residues from project sponsored in the 1960s by the Atomic Energy Commission and the U. **S.** Department of Agriculture, Forest Service. The scope of this preliminary survey primarily covered the **six** main outdoor study areas (2-5, 7, and 8) and the old laboratory building areas **A**, B, and C. The survey included gamma scans, **indoors** and outdoors; direct measurements of alpha radiation levels and transferable measurements of beta-gamma radiation levels, indoors; and soil and vegetation sampling for radionuclide analyses.

Results of the survey demonstrated radionuclide concentrations in **excess** of the current **DOE** criteria for ^{137}Cs in **soil** at study area **4**. **Based** on the results of this radiological assessment, it **is** recommended that a **Follow-up**, detailed radiological survey of both surface and subsurface **environs** be performed to more precisely define the extent of the contamination from possible radionuclide migration and areal spread of ^{137}Cs in study area **4**.

**PRELIMINARY SITE SURVEY REPORT
OF THE EL VERDE RESEARCH STATION,
CENTER FOR ENERGY AND ENVIRONMENT RESEARCH,
IN THE LUQUILLO FOREST, LUQUILLO,
PUERTO RICO (PRE001)***

INTRODUCTION

In the early 1960s, the Atomic Energy Commission (AEC) sponsored the development of the Puerto Rico Nuclear Center (PRNC) near San Juan, Puerto Rico (Fig. 1), launching a comprehensive program for research and training in nuclear science and engineering, with applications of nuclear energy in medicine, agriculture, and industry.¹ In 1964, AEC and the U. S. Department of Agriculture, Forest Service (USFS) signed a memorandum of agreement, separating 156 acres of the Luquillo Forest (the El Verde Rain Forest) into an experimental area for the El Verde Research Station (EVRS), shown in Fig. 1.

In 1976, PRNC became the Center for Energy and Environment Research (CEER), and control transferred from the Energy Research and Development Administration (ERDA), formerly AEC and presently the U. S. Department of Energy (DOE), to the University of Puerto Rico (UPR), terminating the agreement with USFS. UPR placed responsibility for EVRS under CEER and continued use of the EVRS area under permit from USFS.

The main study areas (2-5, 7, and 8) were located on the northwestern side of the Rain Forest, with the research station built on the site of a former coffee plantation (Fig. 2). A plot plan of the laboratory building and residence is shown in Fig. 3. The AEC and USFS conducted detailed ecological studies in this area on radioactive fallout in tropical forests and on the effects of sealed, point sources of ⁶⁰Co and ¹³⁷Cs. These gamma emitting point sources were later removed, and several study areas were developed east of the Sonadora River for researching the subsequent mineral cycling and forest metabolism (Fig. 4). The follow-up studies used ¹³⁴Cs, ¹³⁷Cs, ⁵⁴Fe, ³H, ⁵⁴Mn, ³²P, ⁸⁶Rb, ⁷⁵Se, ⁸⁸Sr, and ⁶⁵Zn as radiotracers. Designated areas of vegetation and/or soil were either sprayed or injected with the tracers. Access to these areas was controlled by fencing and dog patrols.

The first investigative survey and decontamination of the EVRS buildings and study areas were performed by the Health and Safety Division of CEER and reported in 1983.¹ A later survey of study area 4 by the USFS was reported to CEER by correspondence in 1989.² The letter discussed continuing ¹³⁷Cs contamination above background levels in two trees in that area.

*The survey was performed by members of the Measurement Applications and Development Group of the Health and Safety Research Division at Oak Ridge National Laboratory under DOE contract DE-AC05-84OR21400.

Because the contamination reported by USFS was apparently related to AEC activities, verification of these findings was needed to determine whether the site met current radiological guidelines, then, if necessary and appropriate, to correct these conditions. The principal radionuclide of concern is ^{137}Cs and its naturally occurring decay products.

On June 14 and 15, 1989, the preliminary radiological survey at the EVRS site was conducted by a member of the Measurement Applications and Development Group of the Oak Ridge National Laboratory at the request of DOE. Outdoor surveys of study areas 2-5, 7, and 8 are shown in Figs. 5 through 10. Soil and vegetation samples were taken for further analyses during that time. Indoor surveys for the old section of the laboratory building, areas A-C, are shown in Figs. 11 through 13. Smear samples were also taken from the laboratory for assessment.

SURVEY METHODS

The radiological survey of the EVRS site included: (1) outdoor gamma scans of six study areas 2-5, 7, and 8, and (2) collection of surface soil and vegetation samples; as well as (3) indoor gamma scans of the old laboratory areas A-C, and (4) direct alpha and transferable beta-gamma activity levels in the laboratory areas. No exterior surveys were performed around the immediate buildings. Three indoor laboratory areas were not surveyed: the new section, a storage room A in area B, and shop II in area C. The new section of the laboratory was constructed in 1976, and no records were found of radioisotope usage in this area. The storage room A and shop II were filled with vegetation samples and stored equipment. The survey methods followed the basic plan outlined in a correspondence from W. D. Cottrell to A. J. Whitman.

Using a portable Victoreen gamma scintillation meter, ranges of measurements were recorded in all six study areas and inside the old section of the laboratory. (Gamma values are given in $\mu\text{R/h}$.) The detector was held approximately three inches above the ground surface or floor. If the gamma levels were elevated, a biased sample was taken near the point showing the highest gamma radiation level. Systematic samples were taken at various locations outdoors, irrespective of gamma radiation levels. Soil samples taken outdoors from 0 to 15 cm in depth. One vegetation sample was taken from study area 8. Soil and vegetation samples were analyzed for all gamma emitting radionuclides, with results reported for ^{137}Cs , ^{232}Th , and ^{238}U content. In addition, samples were collected from areas 2 and 3 for analysis of ^3H content.

Indoors, direct alpha activity levels were determined using a Geiger-Müller (GM) pancake type probe with an alpha scintillation meter. Smears from 100 cm^2 areas were obtained from various surfaces in the three old laboratory areas to establish transferable beta-gamma activity levels. All samples were handled through the appropriate signed Quality Assurance chain of custody and transported to Tennessee under permit to Oak Ridge Associated Universities (ORAU). ORAU followed the U. S. Department of Agriculture's requirements for soil sterilization, etc., and then returned the samples to ORNL. Comprehensive descriptions of all survey methods and instrumentation have been presented in another report.

SURVEY RESULTS

Applicable DOE guidelines are summarized in Table 1.^{5 and 6} These data are provided for comparison with survey results presented in this section. All direct measurement results presented in this report are **gross** readings; background radiation levels have not been subtracted. Similarly, background concentrations have not been subtracted **from** radionuclide concentrations measured in soil and vegetation samples. Transferable radioactivity levels (smears) are reported **as** net counts with background subtracted.

Outdoor Survey Results

Gamma Radiation Levels

Gamma radiation levels measured during a gamma scan at each of the **six** study areas (2-5, 7, and 8) are given in **Figs. 5** through 10. Gamma exposure rates over the major portions of five study areas (2, 3, **5**, 7, and 8) ranged from **2** to **3 $\mu\text{R/h}$** . Study area **4** measured **2** to **14 $\mu\text{R/h}$** on the perimeter but **contained two** trees with elevated gamma levels (Fig. 7). Both **trees** had previously **been** injected with ^{137}Cs . Tree #1 measured **15 $\mu\text{R/h}$** at the base of the tree, **10 $\mu\text{R/h}$** at the injection site of **15 m** above **ground**, **9 $\mu\text{R/h}$** at **2 m** of elevation, and **170 $\mu\text{R/h}$** at the bottom of a partially excavated hole under this tree. Biased soil sample **4B1** **was** taken from this excavated hole. Tree #2 measured **5 $\mu\text{R/h}$** both at its **base** and **1 m** above **ground**. No other elevated levels were discovered in any of the study areas.

Systematic and Biased Soil Samples

Systematic **soil** samples were taken for radionuclide analyses **from** various locations at each of the **six** study areas. As mentioned above, one biased **soil** sample **was** taken from the hole beneath tree #1 in area **4** (Fig. 7). **Locations** of the systematic (S) and biased (B) samples are **shown** in Figs. 5 through 10, with results **of** analytical assessment provided in Table 2. Concentrations of cesium, thorium, and uranium in the systematic samples ranged from **0.29** to **2.53 pCi/g**, **0.22** to **0.35 pCi/g**, and **0.67** to **1.60 pCi/g**, respectively. Concentrations of cesium, thorium, and uranium in the biased sample were **370 pCi/g**, **0.29 pCi/g**, and **2% pCi/g**, respectively. **None** of the **soil** samples were above **DOE** guideline values (Table 1), with the possible exception of biased sample 4B1 for cesium.

Soil samples (2S1, 2S2, and 3S1) from study areas 2 and 3 were also analyzed for the radionuclide, tritium. All three samples **contained** minimal concentrations for ^3H of less than **135 pCi/g**. With the exception of ^{137}Cs and ^{134}Cs , none of the isotopes used for injections **or** spraying were detected in any of the soil samples. **Soil** sample 4B1 **was** the only sample with elevated ^{137}Cs . Samples 5S2 and 8S1 contained very low but detectable concentrations of the ^{134}Cs , with values of **1.35 pCi/g** and **0.66 pCi/g**, respectively.

Vegetation Sample

One vegetation sample (V) was taken from study area 8, near the fence on the western side of the enclosure, as shown in Fig. 10. In Table 2, concentrations of cesium, thorium, and uranium for this sample (8V1) were 1.10 pCi/g, 0.56 pCi/g, and 8.41 pCi/g.

Indoor Survey Results

Gamma Radiation Levels

Gamma radiation levels measured during a Scan of the floor inside the old laboratory building areas A, B, and C are given in Figs. 11 through 13. Gamma exposure rates generally ranged from 2 to 5 $\mu\text{R/h}$ in all three areas: none were elevated.

Alpha and Beta-Gamma Measurements

Measurements of direct and transferable radioactivity levels were taken from floor surfaces in each of the three laboratory areas A, B, and C (Figs. 11 through 13). All 21 direct alpha measurements were below the minimum detectable amount (MDA) of $<30 \text{ dpm}/100 \text{ cm}^2$. Twenty one smear samples were obtained from the same three areas A, B, and C. Analyses of the smears showed all measurements of transferable beta-gamma radiation from a 100-cm^2 area were below the MDA of 120 dpm.

SIGNIFICANCE OF FINDINGS

Measurements and results of soil and vegetation sample analyses taken at EVRS, Puerto Rico indicate that the property contained elevated levels of ^{137}Cs , found at study area 4 and possibly migrating from the base of one previously injected tree. Biased soil sample (4B1) was taken from under this tree and contained 370 pCi/g of ^{137}Cs ; its location is shown in Fig. 7. The concentrations of all other radionuclides on this site were below applicable DOE criteria (Table 1) and basically in agreement with the findings reported by N. E. Irizarry, CEER-X-115.¹

RECOMMENDATIONS

Based on the results of this radiological assessment, it is recommended that a follow-up, detailed radiological survey of study area 4 be performed to:

- determine the areal spread of ^{137}Cs (if any),
- determine the depth of possible contaminant migration,
- take vegetation samples from the trees in question to determine leaf content and estimate annual dispersion, and
- take samples from other vegetation in the vicinity to determine secondary uptake.

REFERENCES

1. N. E. Irizarry and A. V. Cruz, *Radiological Survey Report for El Verde Research Station, Center for Energy and Environment Research*, Health and Safety Division, University of Puerto Rico, CEER-X-115 (Rev. May 1983).
2. A. E. Lugo, U. S. Department of Agriculture, Forest Service, Rio Piedras, PR, to N. E. Irizarry, Center for Energy and Environment Research, Health and Safety Division, Mayaguez, PR, correspondence in reply to 1350 (March 7, 1989).
3. W. D. Cottrell, ORNL, to A. J. Whitman, DOE/HQ, correspondence, "Radiological Survey of Private Properties in Lodi, New Jersey" (August 15, 1984).
4. T. E. Myrick, B. A. Berven, W. D. Cottrell, W. A. Goldsmith, and F. E. Haywood, *Procedures Manual for the ORNL Radiological Survey Activities (RASA) Program*, Oak Ridge National Laboratory, ORNL/TM-8600 (April 1987).
5. U.S. Department of Energy, *Guidelines for Residual Radioactive Material at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites* (Rev. 2, March 1987).
6. Nuclear Regulatory Commission, *NRC Guidelines for Decontamination at Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-Product, Source, or Special Nuclear Material* (May 1987).

ORNL-DWG 89-10883

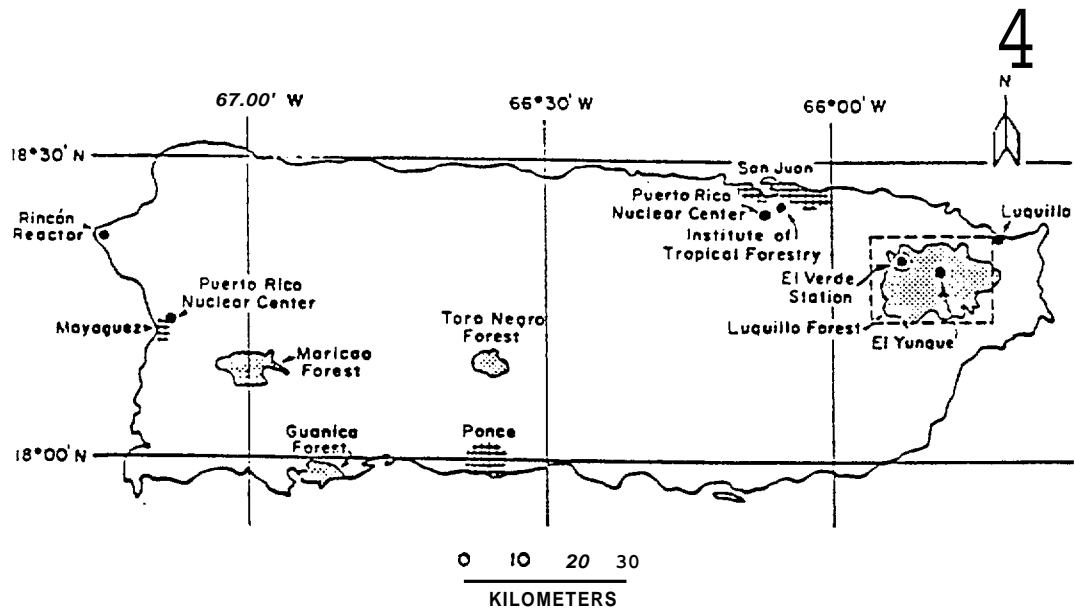
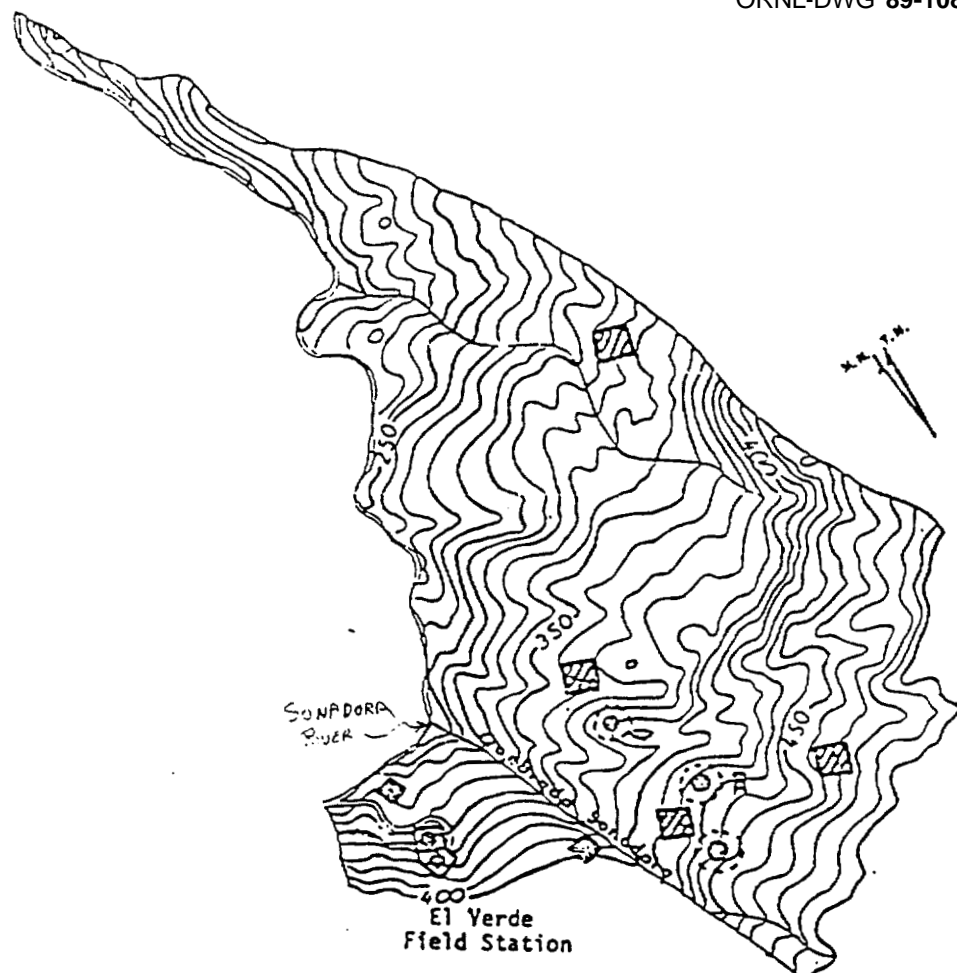


Fig. 1. Map of Puerto Rico showing the locations of EVRS, Luquillo Forest, and PRNC. (Figures are duplicated from an earlier report by N. E. Irizarry, ORNL-X-115.)

ORNL-DWG 89-10884







-  Meteorological tower
-  Cycling and Transport study sites
-  U. S. Forest Service long term growth plots
-  AEC Experimental sites (1964-1970)

Fig. 2. Approximate boundaries to the 156 acres of the EL Verde Rain Forest allocated to EVRS, Puerto Rico (PRE001). (Figures are duplicated from an earlier report by N. E. Irizarry, CEER-X-115.¹)

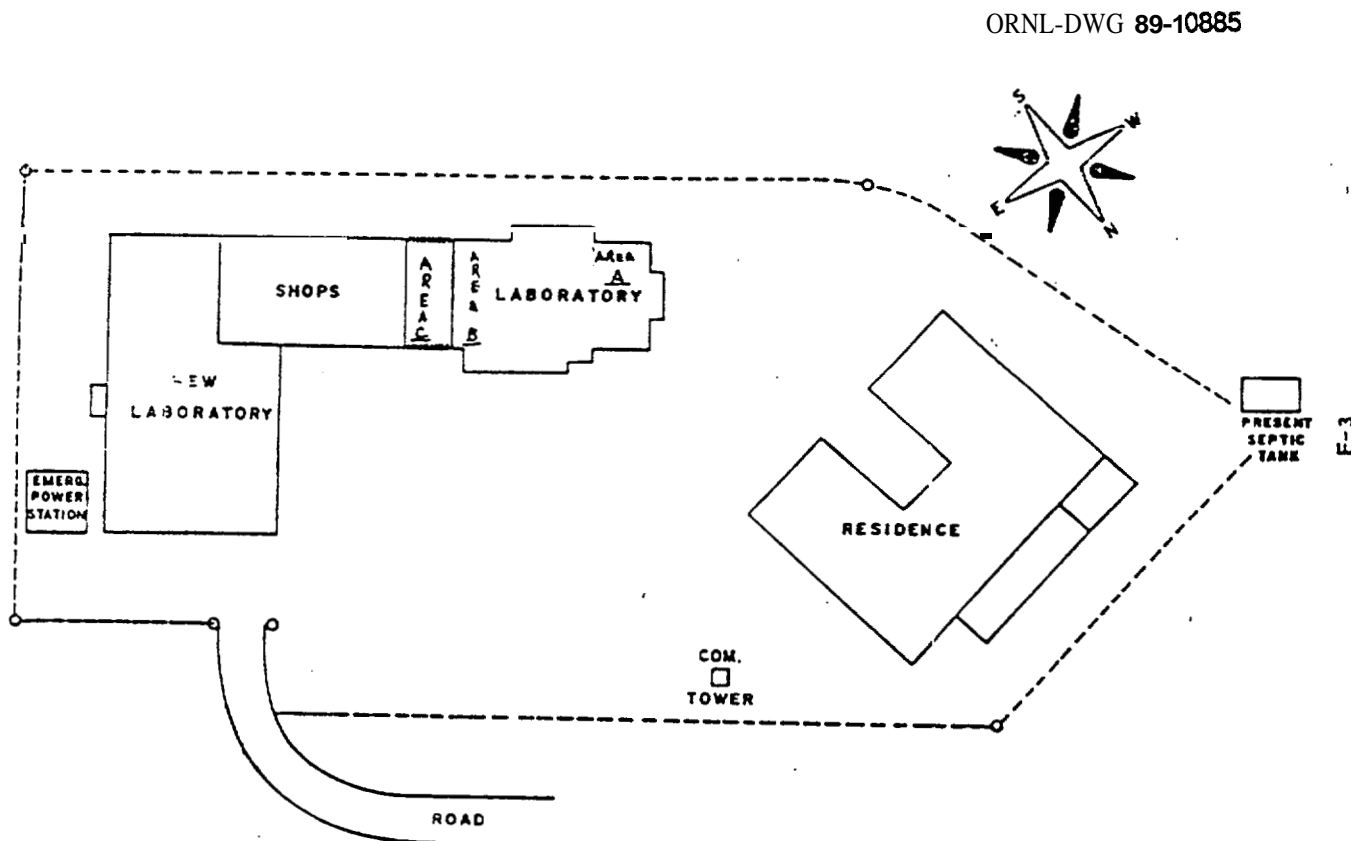


Fig. 3. Plot plan of the laboratory building and residence at EVRS, Puerto Rico (PRE001). (Figures are duplicated from an earlier report by N. E. Irizarry, CEER-X-115.¹)

ORNL-DWG 89-10886

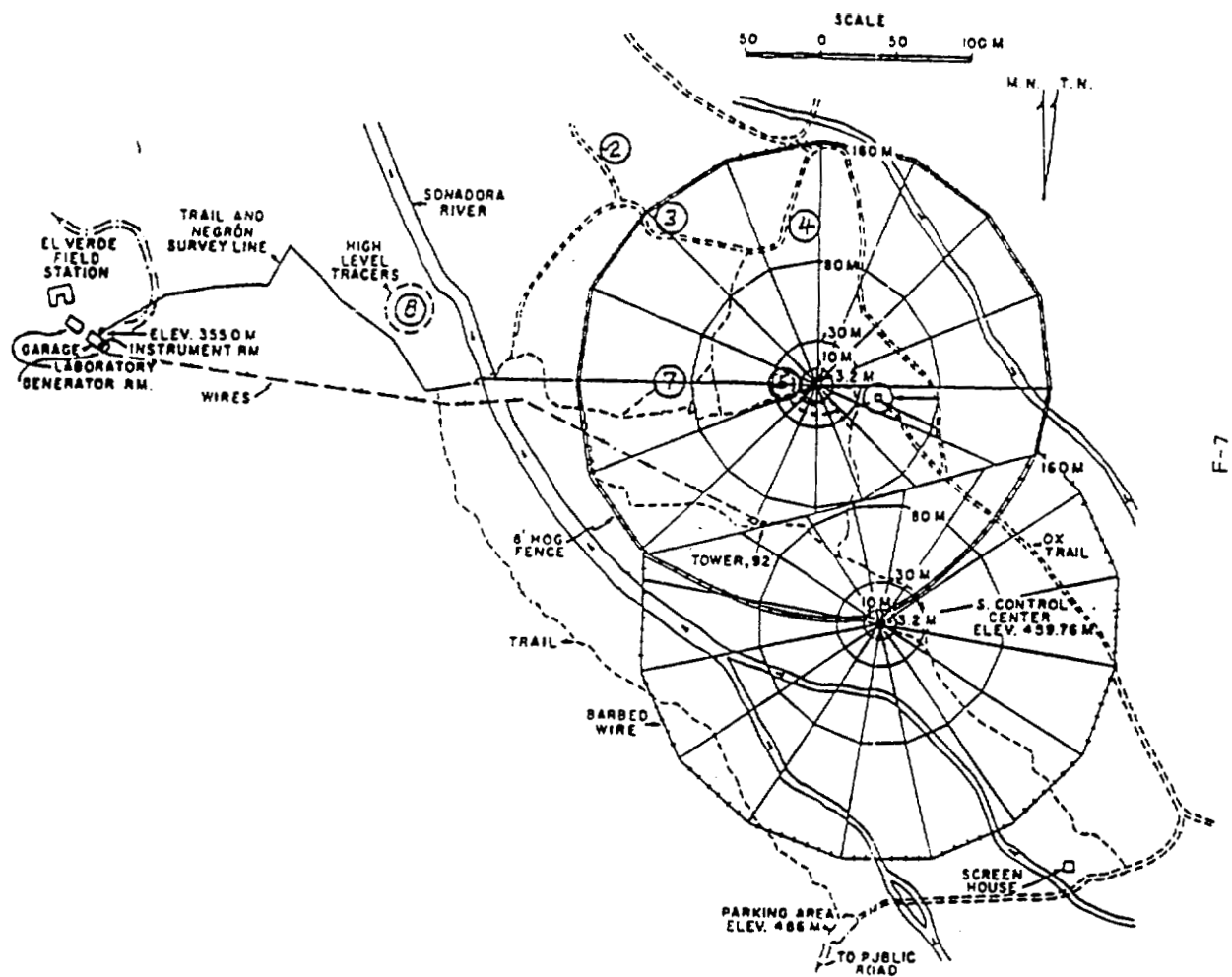


Fig. 4. Diagram showing the six study areas surveyed at EVRS, Puerto Rico (PRE001). Numbered circles show the locations of the six radiotracer sites surveyed. The 160-m radii show the approximate radiation centers for the point source sites of ^{137}Cs . (Figures are duplicated from an earlier report by N. E. Irizarry, CEER-X-115.¹)

El Verde Rain Forest

2-2-VS

Area #2

Back Ground 2.0 μ R

2.6 Count

CONT. 2-3V 2.0 μ R
C-2-4SV 2.0 μ R
C-2-5 2.0 μ R
C-2-6 2.0 μ R
C-2-7 2.0 μ R
C-2-8 2.0 μ R
C-2-9 2.0 μ R
C-2-10 1.5 μ R

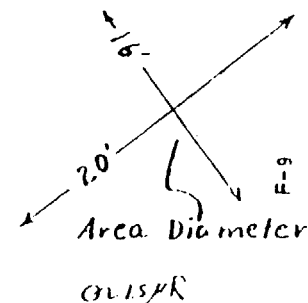
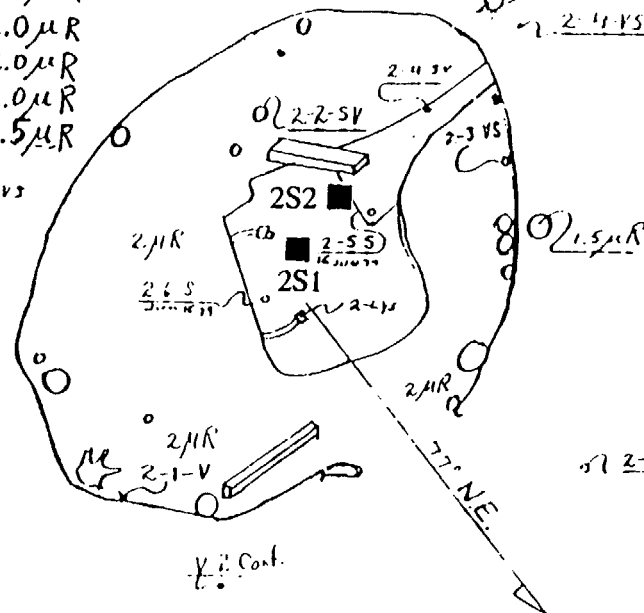
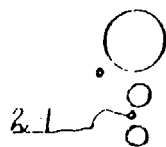
2-8-VS

2-5-SV
2.0 μ R

2-4-VS

2-3-SV Count

2-9-VS



2-2-VS Count

2.0 μ R

2-1-Count

Tree #1 1.5 μ R
Tree #5 1.5 μ R
Soil 1.5 μ R

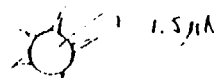


Fig. 5. Diagram of previous EVRS surface gamma radiation levels (μ R/h) measured at study area 2, EVRS, Puerto Rico (PRE001), and locations of ORNL soil sampling (■). ORNL gamma scan range was 2 to 3 μ R/h. (Figures are duplicated from an earlier report by N. E. Irizarry, CEER-X-115.)

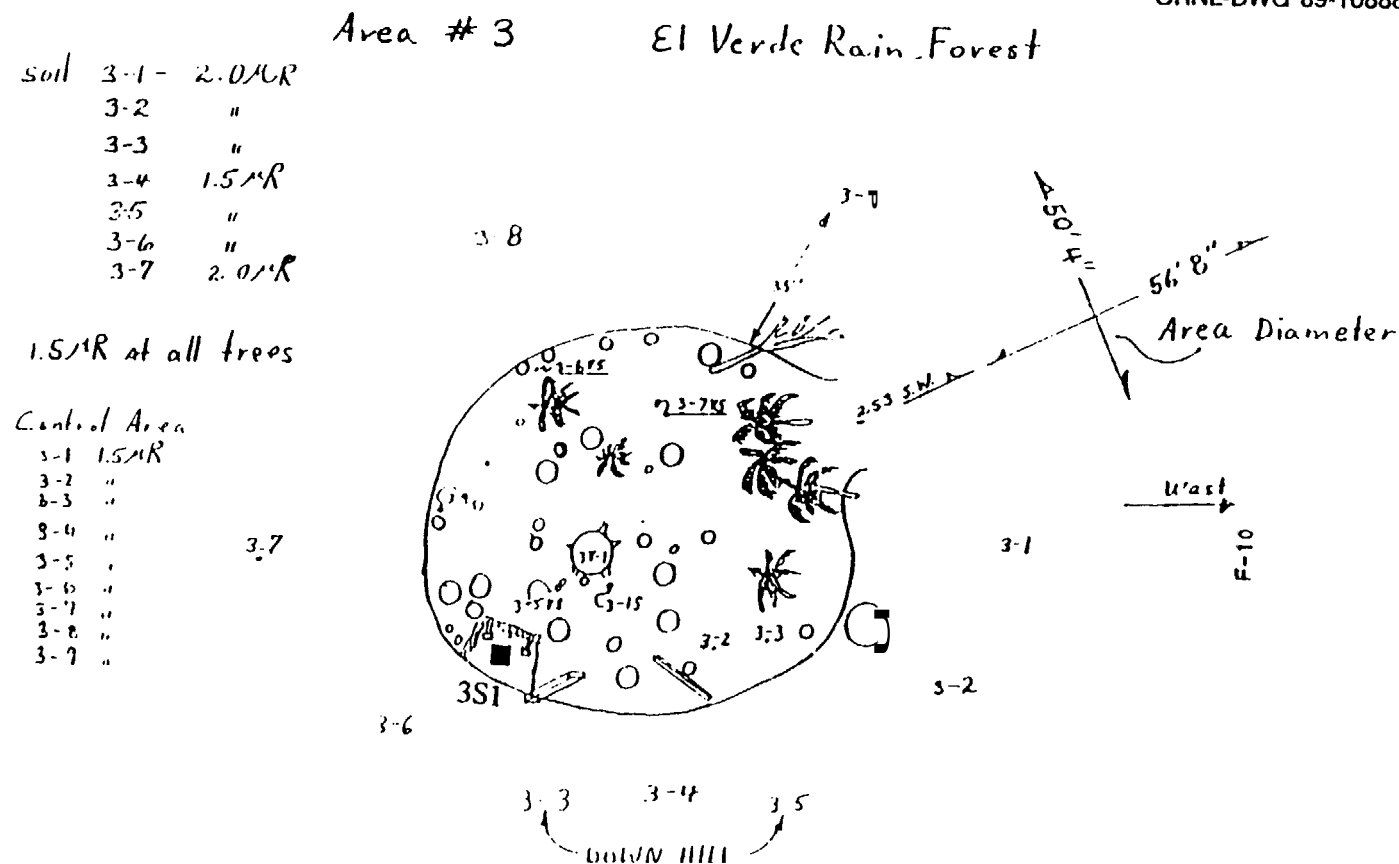


Fig. 6. Diagram of previous EVRS surface gamma radiation levels (μ R/h) measured at study area 3, EVRS, Puerto Rico (PRE001), and location of ORNL soil sampling (■). ORNL gamma scan range was 2 to 3 μ R/h. (Figures are duplicated from an earlier report by N. E. Irizarry, CEER-X-115.)

AREA (DIAMETER

Tree #1 at 1M height 7 AR

Hand-drawn map of a coastal area with various points labeled with codes and measurements. The map includes a central area with a grid labeled 4S1 and 4B1. A note at the bottom reads: "Time (min:sec) 2μR? Negra hora at 16 meters distance."

Labels on the map include:

- C-4-10 2.0μR
- C-4-11 2.0μR
- C-4-12 2.0μR
- C-4-13 2.0μR
- C-4-14 2.0μR
- C-4-15 2.0μR
- C-4-16 2.0μR
- C-4-17 2.0μR
- C-4-18 2.0μR
- C-4-19 2.0μR
- C-4-20 1.5μR
- C-4-21 2.0μR
- C-4-22 2.0μR
- C-4-23 2.0μR
- C-4-24 2.0μR
- C-4-25 2.0μR
- C-4-26 2.0μR
- C-4-27 2.0μR
- C-4-28 2.0μR
- C-4-29 2.0μR
- C-4-30 2.0μR
- C-4-31 2.0μR
- C-4-32 2.0μR
- C-4-33 2.0μR
- C-4-34 2.0μR
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- C-4-43 2.0μR
- C-4-44 2.0μR
- C-4-45 2.0μR
- C-4-46 2.0μR
- C-4-47 2.0μR
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- C-4-83 2.0μR
- C-4-84 2.0μR
- C-4-85 2.0μR
- C-4-86 2.0μR
- C-4-87 2.0μR
- C-4-88 2.0μR
- C-4-89 2.0μR
- C-4-90 2.0μR
- C-4-91 2.0μR
- C-4-92 2.0μR
- C-4-93 2.0μR
- C-4-94 2.0μR
- C-4-95 2.0μR
- C-4-96 2.0μR
- C-4-97 2.0μR
- C-4-98 2.0μR
- C-4-99 2.0μR
- C-4-100 2.0μR

Fig. 7. Diagram of previous EVRS surface gamma radiation levels ($\mu\text{R/h}$) measured at study area 4, EVRS, Puerto Rico (PRE001), and locations of ORNL soil sampling (■). ORNL gamma scan range was 2.5 to 14 $\mu\text{R/h}$ at the perimeter, 5 $\mu\text{R/h}$ at the base of tree #2, 15 $\mu\text{R/h}$ at the base of tree #1, and 170 $\mu\text{R/h}$ under tree #1. (Figures are duplicated from an earlier report by N. E. Irizarry, CEER-X-115.¹)

Area #5 El Verde

5-1 50 μ R
 5-1-VS 30 μ R
 5-2 VS 1.5 μ R

 5-1-V 1.5 μ R
 5-2 VS 2.0 μ R
 5-3 VS 2.0 μ R
 5-4 VS 2.0 μ R
 5-5 VS 1.5 μ R
 5-6 VS 1.5 μ R
 5-7 VS 2.0 μ R

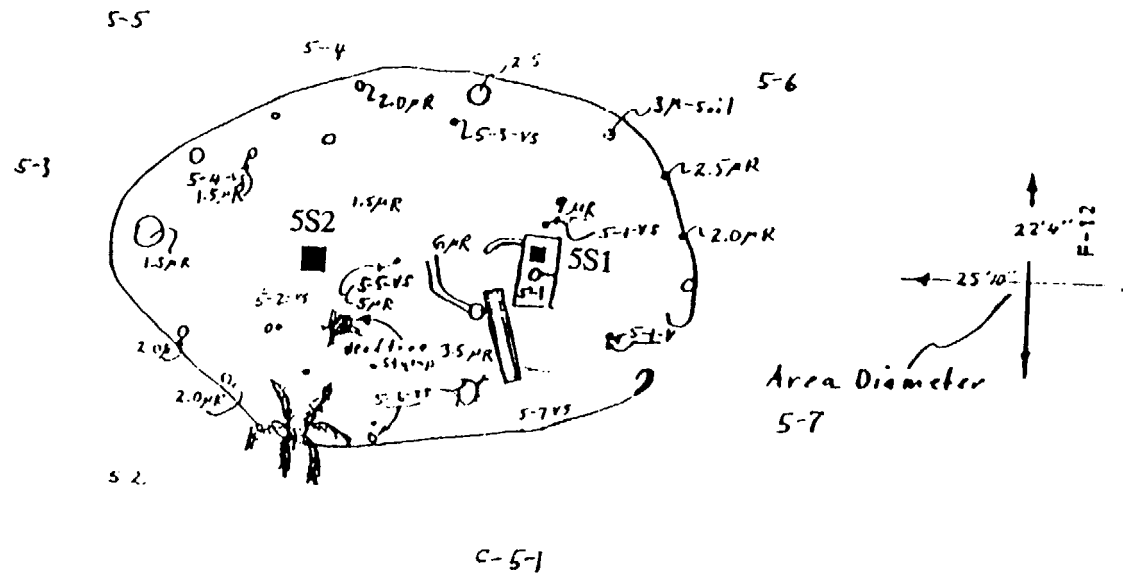


Fig. 8. Diagram of previous EVRS surface gamma radiation levels (μ R/h) measured at study area 5, EVRS, Puerto Rico (PRE001), and locations of ORNL soil sampling (■). ORNL gamma scan range was 2.5 to 3 μ R/h. (Figures are duplicated from an earlier report by N. E. Irizarry, CEER-X-115.)

Area #7 El Verde

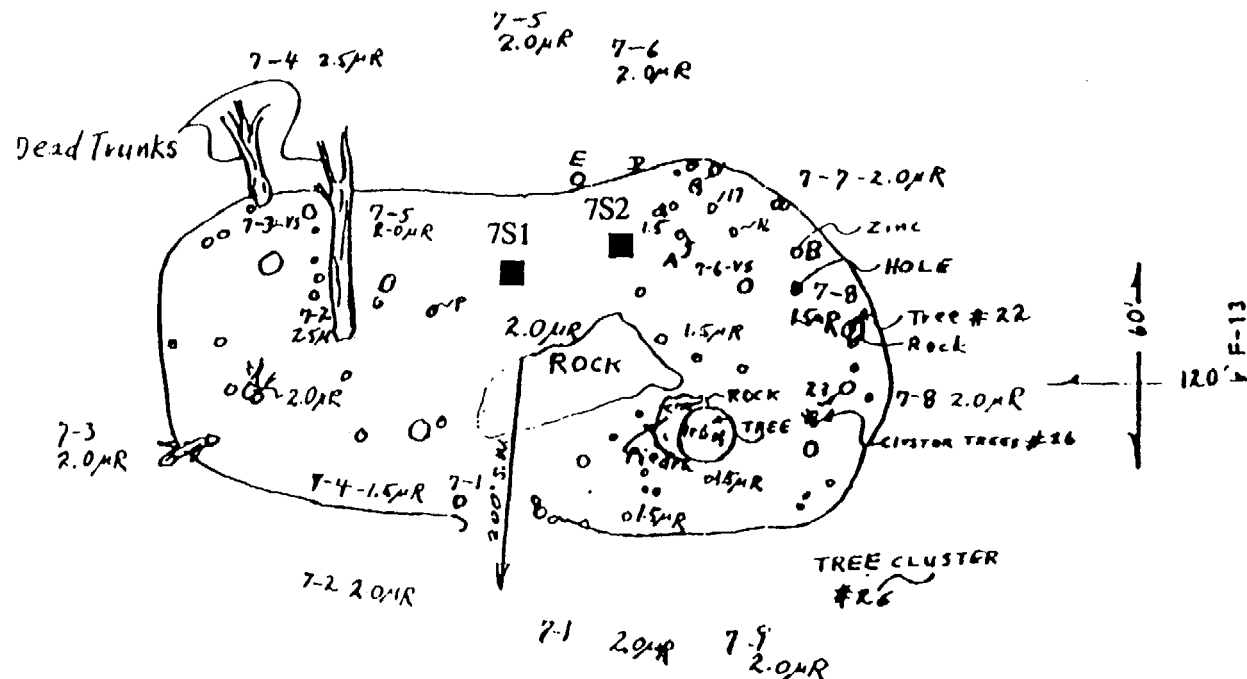


Fig. 9. Diagram of previous EVRS surface gamma radiation levels ($\mu\text{R/h}$) measured at study area 7, IVRS, Puerto Rico (PRE001), and locations of ORNL soil sampling (■). ORNL gamma scan range was 2.5 to 3 $\mu\text{R/h}$. Figures are duplicated from an earlier report by N. E. Irizarry, CEER-X-115.¹

AREA #8 El Verde

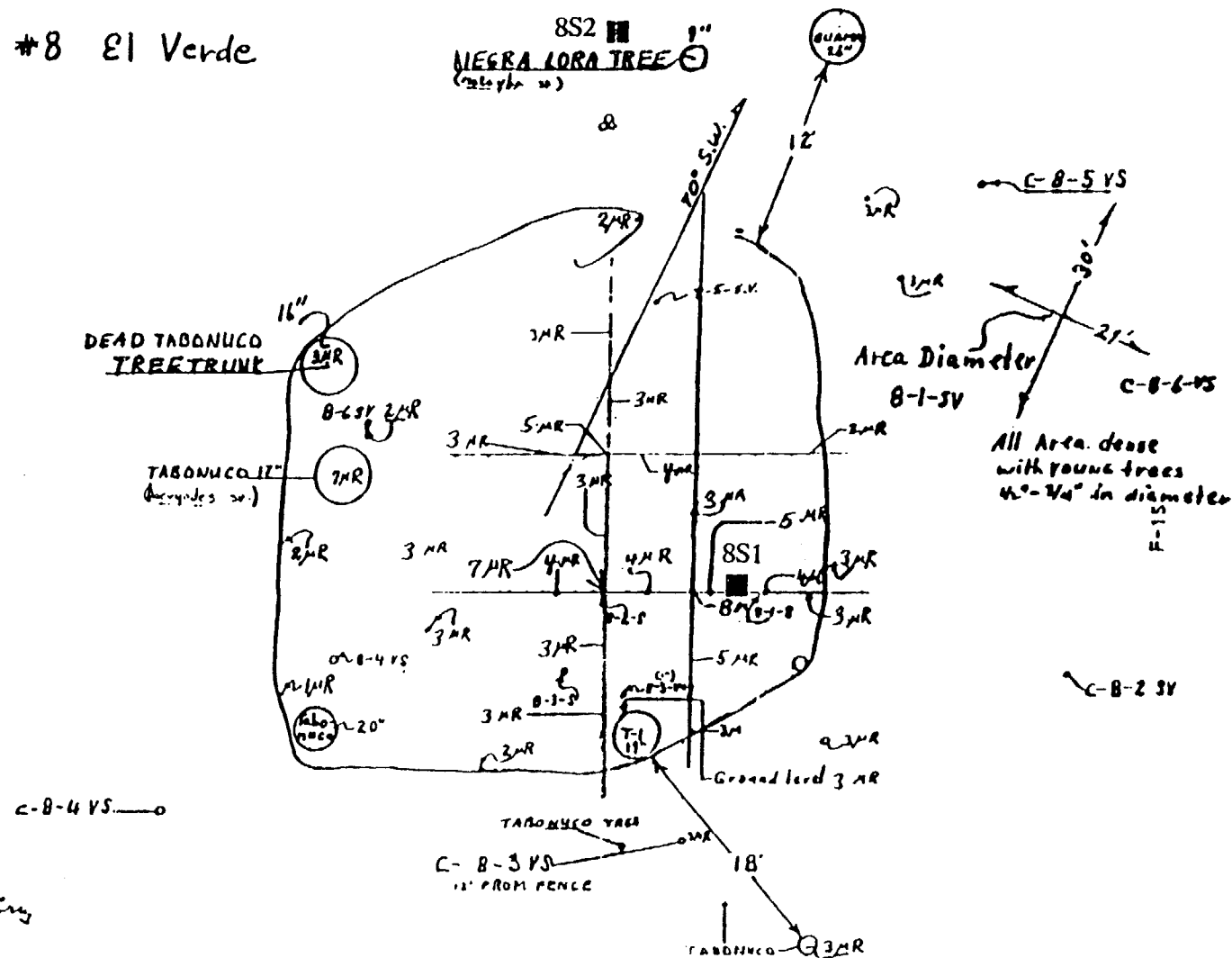


Fig. 10. Diagram of previous EVRS surface gamma radiation levels (μ R/h) measured at study area 8, EVRS, Puerto Rico (PRE001), and locations of ORNL soil (■) and vegetation sampling. ORNL gamma scan range was 2 to 3 μ R/h. (Figures are duplicated from an earlier report by N. E. Irizarry, CEER-X-115.)

ORNL-DWG 89-10893

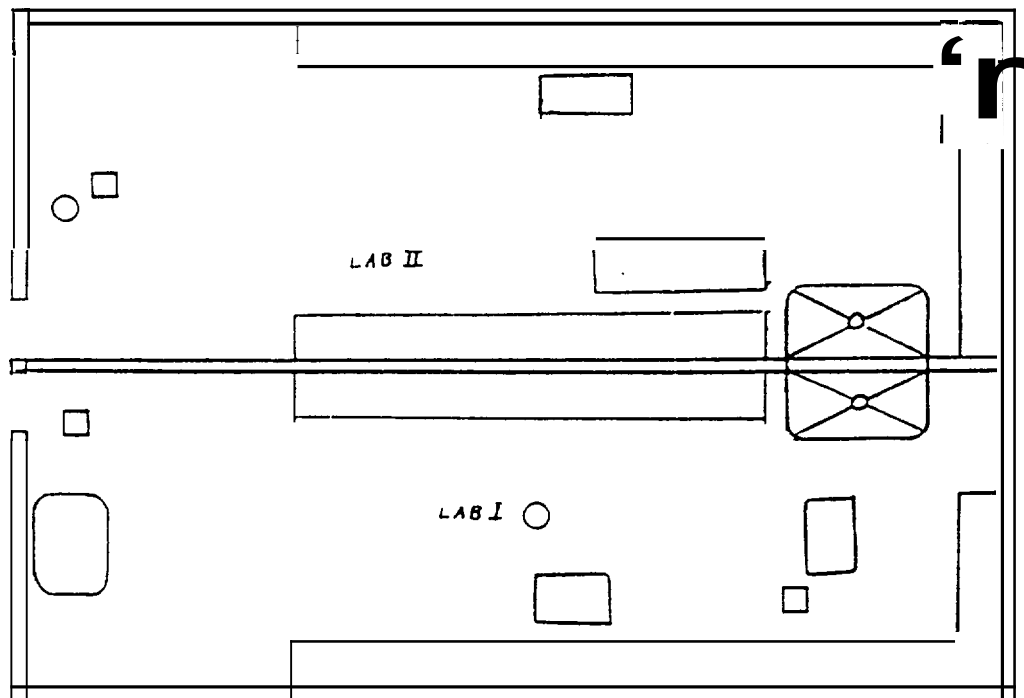


Fig. 11. Plot plan of laboratory building, area A, at EVRS, Puerto Rico (PRE001), showing indoor surface gamma radiation levels and locations of smear samples (\square) and direct alpha measurements (\circ). ORNL gamma scan range was 3 to 5 μ R/h.

ORNL-DWG 89-10894

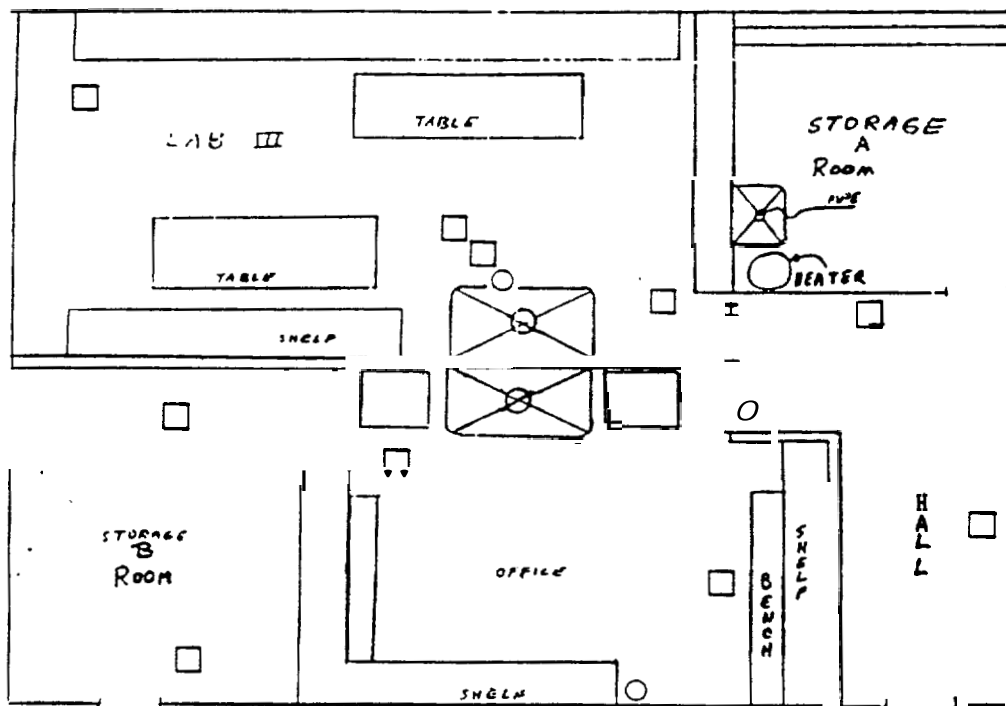


Fig. 12 Plot plan of laboratory building, area ③ at EVRS, Puerto Rico (PRE001), showing indoor surface gamma radiation levels and locations of smear samples (\square) and direct alpha measurements (\circ). ORNL gamma scan range was 25 to 5 $\mu\text{R/h}$.

ORNL-DWG 89-10895

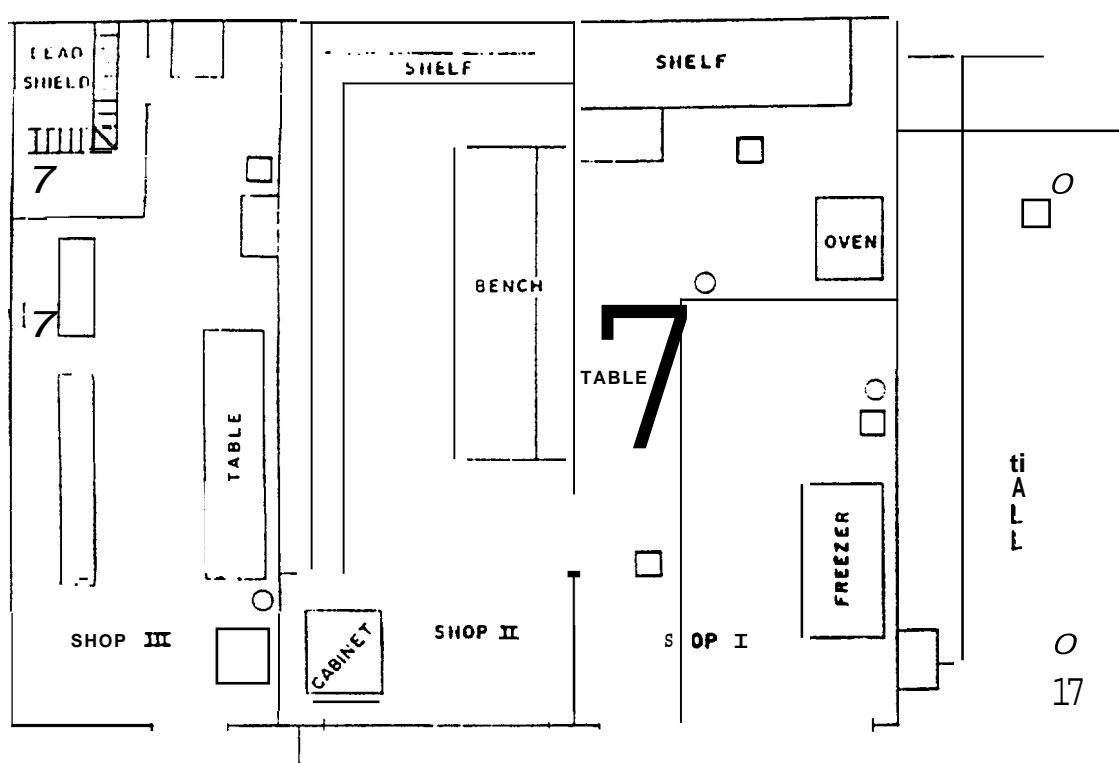


Fig. 13. Plot plan of laboratory building, area C, at EVRS, Puerto Rico (PRE001), showing indoor surface gamma radiation levels and locations of smear samples (□) and direct alpha measurements (○). ORNL gamma scan range was 25 to 5 $\mu\text{R/h}$.

Table 1. Applicable guidelines for protection against radiation'

Mode of exposure	Exposure conditions	Guideline value
Gamma radiation	Indoor gamma radiation level (above background)	20 μ R/h
Surface contamination ^b	²³⁸ U, U-natural(Alpha emitters),& Beta-gamma emitters ^c	
	Fixed on surfaces	5000 dpm/100 cm ²
	Removable	1000 dpm/100 cm ²
	²³² Th, Th-natural	
	Fixed on surfaces	1000 dpm/100 cm ²
	Removable	200 dpm/100 cm ²
	²²⁶ Ra	
	Fixed on surfaces	100 dpm/100 cm ²
	Removable	20 dpm/100 cm ²
Beta-gamma dose rates	Surface dose rate averaged over not more than 1 m ²	0.20 mrad/h
	Maximum dose rate in any 100 cm ²	1.0 mrad/h
Radionuclide concentrations in soil	Maximum permissible concentration of the following radionuclides in soil above background levels averaged over 100 m ² area	5 pCi/g averaged over the first 15 cm of soil below the surface; 15 pCi/g when averaged over 15-cm thick soil layers more than 15 cm below the surface.
	²³² Th	
	²³⁰ Th	
	²²⁸ Ra	
	²²⁶ Ra	
	²³⁸ U	Derived (site specific) ^d
	¹³⁷ Cs	Derived (site specific) ^e

^aReference 5.

^bDOE surface contamination guidelines are consistent with the Nuclear Regulatory Commission guidelines found in Reference 6.

^cBeta-gamma emitters (radionuclides with decay modes other than alpha emission or spontaneous fission) except ⁹⁰Sr, ²²⁶Ra, ²²⁸Ra, ²²⁷Ac, ¹³³I, ¹³¹I, ¹²⁹I, ¹²⁶I, ¹²⁵I.

^dDOE guidelines for uranium are derived on a site-specific basis. While none have been derived for this site, guidelines for ²³⁸U typically range between 35 and 150 pCi/g.

^eDOE guidelines for cesium are derived on a site-specific basis. None have been derived for this site.

Table 2. Concentrations of radionuclides in soil and vegetation at El Verde Research Station, CEER, Luquillo, Puerto Rico (PRE001)

Sample ^b	Depth (cm)	Radionuclide concentration (pCi/g) ^a		
		¹³⁷ Cs	²³² Th	²³⁸ U
<i>Systematic samples^c</i>				
2s1	0-15	1.47±0.04	0.34±0.04	0.80±0.62
2s2	0-15	0.29±0.02	0.31±0.03	0.92±0.78
3S1	0-15	1.58±0.03	0.22±0.03	0.85±0.58
4S1	5-13	2.53±0.03	0.32±0.03	0.69±0.44
5S1	0-15	1.02±0.02	0.33±0.02	1.02±0.57
5S2	0-15	1.39±0.03	0.35±0.03	1.60±0.74
7S1	0-10	0.89±0.02	0.24±0.02	0.99±0.61
7S2	0-15	1.75±0.04	0.29±0.03	1.13±0.76
8S1	0-13	0.82±0.02	0.31±0.02	1.34±0.41
8S2	0-15	1.23±0.03	0.27±0.02	0.67±0.28
<i>Biased sample^d</i>				
481	0-15	370 ±2.42	0.29±0.26	2.96±3.49
<i>Vegetation sample^e</i>				
8V1	N/A	1.10±0.14	0.56±0.21	8.41±2.51

^aIndicated counting error is at the 95% confidence level ($\pm 2\sigma$).

^bLocations of soil samples are shown on Fig. ?.

^cSystematic samples are taken at locations irrespective of gamma exposure rates.

^dBiased samples are taken from areas with elevated gamma exposure rates.

^eVegetation sample was taken from a variety of plants in area 8.

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