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UCRL - 75864
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CONF-741213--3

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**"TERRESTRIAL GAMMA-RAY SURVEYS AT PREOPERATIONAL NUCLEAR POWER
PLANTS USING AN IN-SITU GE(LI) SPECTROMETER"**

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December 5, 1974

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This paper was prepared for publication in
The Proceedings of the 1974 IEEE Nuclear Science Symposium,
Washington, D.C. Dec. 11-13, 1974

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"TERRESTRIAL GAMMA-RAY SURVEYS AT PREOPERATIONAL NUCLEAR POWER PLANTS USING AN IN-SITU $\text{Ge}(\text{Li})$ SPECTROMETER"

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Summary

As a prelude to in-situ measurements of gamma exposure rates from reactor plumes, baseline terrestrial gamma-ray surveys have been run at five preoperational nuclear power stations: Fort St. Vrain, Colorado; Fort Calhoun, Nebraska; Cooper Nuclear Station, Nebraska; Rancho Seco, California; and Diablo Canyon, California. A pressurized ion chamber was used to measure the total exposure from cosmic rays and terrestrial radionuclides. A portable $\text{Ge}(\text{Li})$ spectrometer was used to make in-situ measurements of the radionuclide soil concentrations and of the individual external gamma exposure rates at the TLD sites. Subsequent measurements after start-up will enable accurate determinations of deposition and build-up of reactor produced fission products to be made. The application of the in-situ $\text{Ge}(\text{Li})$ spectrometer for real-time plume dose measurements is being investigated.

Introduction

Environmental radiation measurements near nuclear power reactors have already shown that pressurized ion chambers and thermoluminescent dosimeters can measure noble gas plume exposure rates down to 1 mR per year. It has also been demonstrated that in-situ $\text{Ge}(\text{Li})$ detectors are capable of measuring the concentrations and exposure rates of trace amounts of fallout radionuclides in the soil.^{2,3} This baseline study was the first phase of the laboratory's program to develop a technique for semiquantitative determination of the individual plume radionuclide doses in real time. The combination of ion chamber and $\text{Ge}(\text{Li})$ detector was to accomplish a total exposure rate measurement simultaneously with the terrestrial exposure rate.

The primary concern in the baseline measurements was to quantitate the concentration of fallout fission products before reactor start-up. Since the measurements were mostly carried out at the reactor TLD stations, variations in natural and man-made radionuclides were determined around the power plant and compared to the TLD readings.

Instrumentation and Method

The field system, which has been described previously,^{4,5} consists of a tripod-mounted coaxial 70 cm^3 $\text{Ge}(\text{Li})$ detector and an argon-filled high pressure steel-walled ionization chamber mounted in a mobile van along with complete electronic support equipment. Auxiliary equipment consists of anemometers mounted on a 20-foot mast for measuring wind direction and speed. The spectral data were processed in a 4096-channel pulse-height analyzer and recorded on magnetic tape. Preliminary exposure determinations were done in the field, however, the final calculations were done on the LLL computers. The ion chamber and anemometers output to scalars and onto paper-punch tape. Figure 1 shows the field spectrometer system.

The methodology used to analyze the field gamma-ray spectra for soil concentrations and dose rates were the same as that described by Beck et al.² and Anspaugh et al.³ The general equation used is

$$\frac{N_f}{S} = \frac{N_0}{S} \frac{N_f}{N_0} \frac{1}{S}, \quad (1)$$

where N_0/S is the counting rate in the photopeak of interest per unit of soil radioactivity; N_f/S is the number of counts in the photopeak per incident photon/cm² when a point source is placed at ∞ from the detector axis and sufficiently far away that the flux striking the detector can be considered parallel; $1/S$ is the flux of unscattered photons incident at the detector per unit of soil radioactivity; and N_f/N_0 is a correction factor that must be applied if the response of the detector is not uniform as a function of angle from the detector axis. All factors are energy dependent.

For naturally occurring radionuclides we assume a uniform distribution with depth, and N_0/S is expressed in terms of activity per unit weight of soil. For aged fallout radionuclides we assume an exponential distribution with depth, and N_0/S is expressed in terms of activity per unit area of soil integrated to infinite depth. Since the results depend on soil density and the slope of the exponential distribution,² soil cores were taken at each detector site at the corners and center of a 10 foot square centered at the detector. The cores were each cut into 0-2, 2-5, 5-10, 10-15, 15-20, and 20-25-cm sections, blended and counted. The ¹³⁷Cs distributions were determined by fitting the results by least squares to an exponential function

Results and Analyses

Figure 2 shows the in-situ gamma-ray spectrum recorded at a permanent pasture site (LLL-K) 4.5 miles SSE of Cooper Nuclear generating station on Aug. 15, 1973 in a 4000 sec. count. The spectrum includes gamma-rays from daughters of ²³⁸U and ²³²Th, ⁴⁰K, and ¹³⁷Cs. For the ²³⁸U and ²³²Th results, 8-10 photopeaks were individually analyzed and the results for each series were self-consistent. Secular equilibrium was therefore assumed for the calculations of pCi/gm and $\mu\text{R/hr}$. The total exposure rate for site LLL-K was 10.6 R/hr with the breakdown as follows:

²³⁸ U series	1.96	0.06 $\mu\text{R/hr}$
²³² Th series	2.05	.08 $\mu\text{R/hr}$
⁴⁰ K	2.05	.05 $\mu\text{R/hr}$
¹³⁷ Cs	0.70	.02 $\mu\text{R/hr}$

The cosmic contribution was 3.0 $\mu\text{R/hr}$. The ¹³⁷Cs depth distribution was exponential with a slope of $0.33 \pm 0.01 \text{ cm}^{-1}$. The variation in total terrestrial and ¹³⁷Cs external exposure rates around Cooper is shown in figures 3 and 4. The variation in terrestrial exposure rates was small, 6.1 to 7.6 $\mu\text{R/hr}$, however, the variation in the ¹³⁷Cs exposure rate was significantly larger, 0.16 to 0.70 $\mu\text{R/hr}$. The large variation is due to the different histories of the sites, which include permanent pastures, plowed fields, lawns, undisturbed areas, and sites which had been disturbed for construction, road grading etc. Figure 5 shows the depth distributions for some of the permanent pasture sites around Cooper.

Table I shows the variation in ¹³⁷Cs deposition around Cooper. Also included are other fission products when they were observed. Sites LLL-X, 52, 33 are permanent pasture sites.

Table II summarizes the ^{137}Cs deposition at some permanent pasture sites for each power plant investigated. The depositions at Rancho Seco and Diablo Canyon are consistent and definitely lower than the power plants in the Midwest. Table III summarizes the external gamma exposure rates for the 5 reactor sites measured. The total exposure rate is the measurement taken from the ion chamber, the terrestrial exposure rate is the measurement taken from the Ge(Li) detector including natural as well as fallout activities. The column labelled fallout is the exposure rate calculated from the ^{137}Cs activities as measured with the Ge(Li) detector. The total exposure rates around Cooper and Fort Calhoun vary little with the terrestrial contributions tightly grouped. The ^{137}Cs exposures vary over a wide range, but since they are a small percentage of the total, the ^{137}Cs variations have little effect. On the other hand, the total exposures at Rancho Seco and Diablo vary over a factor of two due to relatively large variations in natural soil radionuclides. The high values of terrestrial exposures at Fort St. Vrain are due to large amounts of ^{238}U and ^{232}Th in the soil. Table IV includes a comparison of the ion chamber readings taken around the power plants by LLL to the TLD readings taken by the utilities. It must be noted that there is no necessary correlation between the TLD and ion chamber readings, that is, the sites are not necessarily the same. Considering that the ion chamber measurements were of 4000 second duration and the TLD readings were of 1 or 3 month duration the agreement is quite good in general. Fort Calhoun and Cooper are the most logical ones to compare since they have the smallest variations. We agree with Fort Calhoun's data much better than with Cooper's data. There seems to be a systematic difference between our measurements and those at Cooper. Fort St. Vrain shows the largest differences, however, the large variation in natural radionuclides could account for these differences.

Our investigations and those of HASL and others have shown that one can measure ambient exposures to the low levels of current interest with ion chambers and TLD's. One should note, however, that in routine practice significant differences between ion chambers, TLD's and Ge(Li) spectrometers are often noted. These differences can usually be resolved by careful investigation, e.g. of calibration and operational techniques, site selection, or site anomalies. These investigations require considerable effort. With a reactor lifetime of many years one would expect similar disagreements and these may not be resolved due to the time span. In such a case only a detector such as the Ge(Li) spectrometer can verify that no buildup of fission products has occurred. For this purpose the in situ measurement requires significantly less effort than soil sampling and represents a better overall average of the location. We conclude that such spectrometric measurements should be made of a few sites on a periodic basis, perhaps once a year, to supplement the routine methods such as TLD's. In addition some research on better ways to handle the spectrometric data would be useful.

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TABLE I

DEPOSITION FROM FALLOUT RADIONUCLIDES COOPER NUCLEAR STATION

Site	^{137}Cs (nCi/m ²)	^{95}Zr (nCi/m ²)	^{95}Nb (nCi/m ²)	^{144}Cs (nCi/m ²)	^{125}Sb (nCi/m ²)
3	134±8	1.5±.7	1.3±.4		
6	82±3				
23	139±5	2.8±.6	2.1±.5		
27	108±3	2.6±.8	3.1±.4	76±50	
38	99±5	2.2±.7	0.9±.5		
45	126±3	2.9±.7			
62	136±5	1.2±.4			24±9
33	143±5	3.1±.6			
2	148±5				
LLL-S	107±3	2.3±.8			
31	151±4				
LLL-K	157±4	1.8±.8	1.0±.3		
39	135±5				
5	133±5				
56	94±4				
40	153±7				
52	122±2				

TABLE II

 ^{137}Cs EXTERNAL GAMMA EXPOSURE RATES ($\mu\text{R/hr}$) PERMANENT PASTURE SITES

<u>Power Station</u>	<u>No.</u>	<u>Slope</u> (cm ⁻¹)	<u>CUNC</u> (nCi/m ²)	<u>Exposure Rate</u> ($\mu\text{R/hr}$)
Fort Calhoun	GM-L	0.42	94 ± 3	0.47 ± .01
Nebraska	GM-G	0.14	140 ± 5	0.47 ± .02
Fort St. Vrain	F14	0.39	98 ± 4	0.47 ± .02
Colorado	A32	0.37	72 ± 3	0.33 ± .01
Cooper Nuclear	33	0.13	143 ± 5	0.45 ± .02
Nebraska	LLL-K	0.33	157 ± 4	0.70 ± .02
52	52	0.34	122 ± 2	0.56 ± .01
Rancho Seco	11	0.29	48 ± 2	0.18 ± .01
California	8	0.64	53 ± 3	0.27 ± .01
Diablo Canyon	2	0.15	56 ± 3	0.19 ± .01
California	8	0.12	47 ± 4	0.15 ± .01
	7	0.092	56 ± 4	0.17 ± .01

TABLE III

EXTERNAL GAMMA EXPOSURE RATES ($\mu\text{R/hr}$)

	Sites	Total	Terrestrial	Fallout
Rancho Seco	15	5.8 - 9.8	2.9 - 7.1	.69 - .27
Fort. St. Vrain	17	14.2 - 18.7	5.6 - 15.3	.69 - 2.67
Fort Calhoun	19	9.2 - 10.9	6.2 - 8.1	.63 - .75
Cooper	17	9.4 - 10.6	6.1 - 7.6	.16 - .79
Diablo Canyon	15	5.8 - 11.6	2.1 - 9.2	(.02 - .26)

TABLE IV

Total External Gamma Exposure Rates ($\mu\text{R/hr}$)^{*}

<u>Power Plant</u>	<u>LLL Ion Chamber*</u>	<u>Utilities Exposure Time (mos)</u>	<u>Utilities TLD Exposures</u>
Rancho Seco	5.8 - 9.8	3	7.5 - 12.8
Fort St. Vrain	14.2 - 18.7	1	21.6 - 27.6
Fort Calhoun	9.2 - 10.9	3	9.2 - 14.9
Cooper	9.4 - 10.6	3	6.3 - 8.1
Diablo Canyon	5.8 - 11.6	1	11.6 - 15.9

* Ion Chamber measurements taken for 1 hour at each site

* TLD exposures and ion chamber readings are not necessarily at the same sites

Figure Legends

- Fig. 1. Tripod-mounted Ge(Li) detector and electronic support equipment housed in van. Pressurized ion chamber and wind-measuring devices (not shown) and support equipment are also housed in van.
- Fig. 2. In-situ terrestrial gamma-ray spectrum taken with portable Ge(Li) spectrometer at site LLL-K at Cooper Nuclear Station. Counting time was 4000 sec. Terrestrial dose was $7.6 \mu\text{R/hr}$. Fallout dose (^{137}Cs) was $0.70 \mu\text{R/hr}$ (157 nCi/m^2).
- Fig. 3. External gamma exposure rates from terrestrial radionuclides measured August 13-16, 1973 around Cooper Nuclear Generating Station.
- Fig. 4. External gamma exposure rates from fallout ^{137}Cs measured August 13-16, 1973 around Cooper Nuclear Generating Station.
- Fig. 5. Depth distributions of ^{137}Cs at three permanent pasture sites around Cooper Nuclear Generating Station. The slopes were 0.33 ± 0.01 , 0.36 ± 0.01 , and $0.15 \pm 0.01 \text{ cm}^{-1}$ for sites LLL-K, 52, and 33, respectively. The solid lines are least-square fits to an exponential function.

NOTES

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Fig. 1
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Fig. 2
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COOPER NUCLEAR STATION
TERRESTRIAL EXTERNAL GAMMA EXPOSURE RATES
($\mu\text{R/hr}$)

Fig. 3
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COOPER NUCLEAR STATION TERRESTRIAL EXTERNAL GAMMA EXPOSURE RATES (MR/M)

Fig. 4
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Fig. 5

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