Advance Copy

301-86-JB-60

NORTHROP

Northrop Research and Technology Center
Northrop Corporation
One Research Park
Palos Verdes Peninsula
California 90274 5471
Telephone 213 377 4811

9 May 1986

Dr. Herbert N. Berkow, Director
Standardization and Special
Projects Directorate
Division of PWR Licensing-B, NRR
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Dr. Berkow:

In response to the questions posed in your letter of February 28, 1986, we have reviewed our original data, assembled it into a form you will find easier to digest, and provided some explanatory text.

To insure that we are being completely responsive, we have organized our answers into two sections. Section I addresses the question regarding the response of the micro-R meter to the spectrum of gamma rays monitored in the course of our final survey. We show by means of analysis and supporting measurements that the response of the micro-R meter is accurate to well within the desired +20%. Section II addresses the initial survey measurements in the exposure room, resolution of the geometrical impact on our observations, and a comparison of the radiation levels from the concrete rubble with background. We find that the radiation from the concrete is the same as background within the precision of our measurements, or approximately 10% of background. This easily meets or surpasses the 5 μr/hr staff position.

We trust we have answered your questions satisfactorily. Early approval of our request for unrestricted use of our facility and our plan for disposal of concrete rubble at a local landfill are requested.

Sincerely yours,

J. Benveniste

J. Benveniste, Chairman
Corporate Radiation Committee

130036

DF02 1/1

SECTION I

JUSTIFICATION FOR USE OF SCINTILLATION DETECTOR

NRR QUESTION:

(1) Radiation measurements were obtained by Northrop Corporation using a sodium iodide crystal which is calibrated for a certain source type and strength. The methods and standards used for calibration of this survey instrument were not specified in the final report. Please provide a detailed description of your calibration procedure and justify use of a scintillation detector, which is an energy dependent instrument, to measure dose rate with reasonable accuracy (e.g. ±20%) over the wide range of energies expected in your surveys.

NORTHROP RESPONSE:

The roentgen is a unit of radiation exposure whose definition is based on the effect of X or gamma radiation on the air through which they pass. It is defined as the quantity of X or gamma radiation which produces 1 electrostatic unit of electricity of either sign per cubic centimeter of dry air at 0 deg C and 760mm Hg.

The Ludlum micro-R meter is a sodium iodide crystal - photomultiplier assembly which measures the pulse-rate generated by the interaction of a photon flux with the crystal. Ours are customarily sent to Ludlum Measurements Inc. for calibration. Certificates of calibration for two recent episodes are provided in Attachments 1 and 2. Note that a Cs-137 source is used as the standard and the calibration is extended to the lower ranges by means of a pulse generator. The meter reading (M) may be related to the rate of charge generation in air (and hence to roentgens per unit time) through the relation

$$M = r(e)E \quad (1)$$

where E is the radiation exposure in roentgens, and r(e) is an energy-dependent meter response factor. The scale of the micro-R meter is calibrated so that for the 662 keV gamma rays from cesium-137 r(662)=1 and

$$M_c = E_c \quad (2)$$

see ref. 1.

The factor r(e) is plotted as a function of photon energy in Figure 1 (ref.2)

For a flux of photons of energy e_i, Equation 1 is written

$$M_i = r(e_i)\, E_i \qquad \text{or} \qquad E_i = \frac{M_i}{r(e_i)} \tag{3}$$

Thus, for a complex spectrum, the total exposure may be written

$$\Sigma E_i = \Sigma \left[\frac{M_i}{r(e_i)} \right] \tag{4}$$

where the M_i are the individual meter readings which would be contributed by the components of the complex spectrum.

If we divide Equation (4) by Equation, (2) we write

$$\frac{\Sigma E_i}{E_c} = \frac{1}{M_c} \Sigma \left[\frac{M_i}{r(e_i)} \right] \tag{5}$$

and if we consider the case where the composite meter reading contributed by the complex spectrum is the same as that given by the same flux of Cs-137 gamma rays (i.e., $\Sigma M_i = M_c$), Equation (5) becomes

$$\frac{\Sigma E_i}{E_c} = \frac{\Sigma \left[\frac{M_i}{r(e_i)} \right]}{\Sigma M_i} \tag{6}$$

Primordial Radioactive Source in Concrete

Normal concrete contains primordial sources of radiation (ref. 3). The gamma spectrum from potassium-40, uranium-238 series, and thorium-232 series are extremely complex. But the measurements of the attenuation of this gamma field, utilizing lead attenuators, indicate the spectrum can be represented by a two component photon field. The meter reading for this two component spectrum may be represented by

$$M(x) = M_1 \exp\left(-\frac{x}{x_1}\right) + M_2 \exp\left(-\frac{x}{x_2}\right)$$

where x is the thickness of the attenuator. The experimental data corresponding to this expression appears in Table III and Figure 2. After normalizing so that $M_1 + M_2 = 1$, we find from Figures 1, 2 and 3:

M_1 = .667

M_2 = .333

x_1 = 1 gm/cm^2

x_2 = 19 gms/cm^2

e_1 = 200 KeV

e_2 = 1500 KeV

$r(e_1)$ = 6.00

$r(e_2)$ = 0.35

Returning to Equation (6) yields

$$\frac{\Sigma E_i}{E_c} = \frac{.667}{6.00} + \frac{.333}{.35} = 1.06$$

That is, a given meter reading corresponds to a 6% greater exposure from the primordial radioactive source in concrete than from a Cs-137 source---the meter is underestimating the exposure by 6%.

Neutron Activated Concrete Source

The gamma exposure from the neutron activated concrete in the facility is treated in a related, but somewhat different, way. This is because the emitted gamma flux is dominated by the natural, primordial radioactivity to the extent that the neutron induced gamma rays could not be measured directly. Thus, we rely on a calculation of the spectral composition of the emitted gamma rays, relate this to the exposures contributed by each element of the spectrum, and finally make the connection to the meter readings as in the previous example.

The isotopic composition of the neutron activation induced radioactivity .t depth in the concrete is known to be (ref. 3).

Fe - 55	81 percent of disintegrations
Co - 60	4
Eu - 152	13.9
Eu - 154	1.1

Since Fe-55 emits very low energy gamma rays (less than 10 keV) that, to a large extent, are self-absorbed in the concrete and are below the cut-off energy of the detector, Fe-55 need not be included in the analysis of the gamma rays emitted from the concrete. The remaining isotopic source terms, S_j after normalization, are:

$$S_{60} = 0.21$$

$$S_{152} = .73$$

$$S_{154} = .06$$

There are approximately eighty different photon energies emitted by these sources. All of these photon types were arranged into five energy groups, each with a calculated emission probability, N_i, and a radiation length in concrete, x_i. The probability of each photon energy group being represented in the emitted flux is given by

$$\phi_o(e_i) = \sum_j S_j N_i x_i \tag{7}$$

There is an implicit assumption in using this functional representation that the neutron activation is rather uniform in the concrete, and that the neutron relaxation length is large compared to the gamma radiation length. The function $\phi_o(e_i)$ is tabulated for each energy group in Table IV. This information is normalized and summarized in Table V, column (2), and plotted in Figure 4. However, this is not quite the whole story for equation (7) is derived from an assumption that the gamma rays are absorbed exponentially without producing secondary photons prior to emerging from the concrete. In fact, however, some of the interactions are Compton scatters in which the photon is not absorbed, but only degraded in energy. This feature is estimate this build-up by adding 10% of the flux in each energy group to each of the lower energy groups as in Table V, Columns 3 and 4, and in Figure 4. $\phi(e_i)$ designates the flux with the build-up included.

The flux in each of these energy groups is related to the corresponding exposure through the relation

$$\phi(e_i) = f(e_i)E_i \tag{8}$$

where the function f(e), flux-exposure factor, is plotted in Figure 1, and normalized to 1 for the Cesium gamma ray. Using this expression the values for exposure associated with each of the photon groups were calculated in Table V, column (7). Finally, using Equation (3) the meter readings corresponding to these exposures were calculated and listed in column (8). Summing the meter readings from each energy group

$$\Sigma M_i = \Sigma r(e_i)E_i \tag{9}$$

yields the meter reading for the entire complex spectrum. Dividing Equation (9) by Equation (2) gives

$$\frac{\Sigma M_i}{M_c} = \frac{\Sigma r(e_i) E_i}{E_c} \tag{10}$$

and if we consider the case where the total exposure due to the complex spectrum is the same as that from a flux of Cs-137 gamma rays (ie. $E_c = \Sigma E_i$) Equation (10) becomes

$$\frac{\Sigma M_i}{M_c} = \frac{\Sigma r(e_i)E_i}{\Sigma E_i} = 1.13 \tag{11}$$

That is, a given exposure yields a 13% higher meter reading by the complex spectrum from the neutron activated concrete than from a Cs-137 source.

In summary then, we have seen that with respect to the Cs-137 source for which the micro-R meter has been calibrated, the micro-R meter underestimates the exposure from primordial concrete gamma rays by 6% and overestimates the exposure from neutron activated concrete by 13%. Our measurements in the exposure room indicate that the radiation exposure due to neutron activation is less than 10% of the total (primordial plus activation gamma rays) since this is the precision of the background measurements. Thus, the weighted meter response underestimates the exposure from the entire spectrum of gamma rays by about 4%. We may conclude, therefore, that the micro-R meter readings we took in performing our final survey were reliable to well within ±20%

This result has been confirmed by representatives of NRC-Region V who conducted an independent survey of the residual radioactivity in the facility using a Reuter-Stokes pressurized ion chamber.

SECTION II

SURVEY OF CONCRETE

NRR QUESTION:

(2) Your report indicates that your survey of the Exposure room was hampered by the small dimensions of the room, which resulted in your providing 4 pi readings versus measurements which would directly demonstrate satisfaction of the requirements of 5 uR/hr, at one meter from any planar surface. Your calculations indicated that the readings were close to background. However, because of the geometry problem, you dismantled the room and placed the resulting biological shield concrete rubble in a pile. Your survey of this pile also indicated readings close to background. However, during its final survey of your facility, the Region V staff found that the configuration of the concrete rubble pile precluded their obtaining the required final survey measurements with the available instrumentation.

Accordingly, we request that Northrop Corporation: (a) provide all the readings that were taken of the Exposure Room walls prior to dismantling, with and without shielding, (b) discuss the method used to determine "background" radiation and provide the respective data, (c) show from your measurement techniques and data that the contribution of dose rate from the surrounding walls could be subtracted from the relevant planar wall to provide the "close-to-background" dose rate from the planar wall, (d) physically redistribute the concrete rubble pile into a homogeneous configuration with as uniform and even a surface as possible and not more than about 1 foot deep. Measure the radioactive contamination levels at the surface and the radiation levels at one meter from the surface at a suitable number of locations.

NORTHROP RESPONSE:

Since the exposure room was classified as a "high potential" area the walls, floor, and ceiling were marked off in one-meter grids and 75% of the squares were selected for measurement by means of a random number generator. Figures 5a-e show schematic representations of the manner in which all surfaces were sectioned for the survey. Data on the west wall is missing because this is the wall which is shared by the pool and it was essentially eliminated when the window was removed.

Tables VIa-e contain the recorded readings from a Ludlum Model 19 μR-meter at 1 meter and 1 centimeter above the surface. Background measurements were taken at 30 locations in 16 different areas in and around the Northrop complex. These locations are identified in Figure 6 and the data is summarized in Table VII. It shows that the average of 30 readings is 11.6 $\pm$ 0.8 μR/hr at 1 meter.

When the μR-meter was set up in the exposure room at 1 meter from the walls we read much higher levels (e.g. an average of 18.4 μR/hr for 71 readings, with a maximum of 24 μR/hr). This was easily understood to be due to the "4π" geometry to which the detector was exposed; that is, the detector was completely surrounded by activated wall as opposed to being above a planar surface as for the background measurements. To illustrate this fact, we performed a couple of simple experiments. A 2 inch thick by 8 inch wide by 16 inch long layer of lead was placed below the detector, with the center of the detector at 1.375 inches above the center of the surface. The meter read 14 R/hr. The detector was placed below the layer of lead at 1.875 inches below the surface. The meter read 15.5 R/hr. For the detector completely surrounded by 2 inches of lead, the meter read zero. See Figures 7a,b & c for illustrations of the shielding arrangements. The solid angle for this geometry was calculated from

$$S = 4[\pi - (\arctan A + \arctan B - 2 \arctan C)] \qquad (12)$$

where,

$$A = \left[\frac{X^2}{Y^2 + Z^2}\right]^{.5}$$

$$B = \left[\frac{Y^2}{Z^2 + X^2}\right]^{.5}$$

$$C = \left[\frac{Z^2}{X^2 + Y^2}\right]^{.5}$$

x and y are the distances from the meter detector to the outside edges of the layer of lead brick, and z is the height of the detector above or below the brick layer.

The data is summarized below:

MEASUREMENT ANGLE	x (	y inches	z)	S (st'rad)	EXPOSURE ($\mu R/hr$)	E/S ($\mu R/hr/sr$)
ENTIRE SPHERE	-	-	-	12.57	21.3	1.69
UPPER SPHERE	4	8	1.375	7.62	14.0	1.84
LOWER SPHERE	4	8	1.875	8.15	15.5	1.90
AVERAGE						1.81
BACKGROUND	-	-	-	6.28	11.6 ± 0.8	1.85 ± 0.13

By calculating the exposure per steradian we are able to eliminate the solid angle effect and combine the results of the three observations in the exposure room. We see that the average is 1.81$\mu R/hr/sr$. The corresponding number for the background is 1.85 $\mu R/hr/sr$ and the difference is 0.04 $\mu R/hr/sr$. This means that if we were able to remove the surrounding walls and ceiling to infinity, the exposure measured at 1 meter from a plane surface in the exposure room would be essentially background, and therefore, well within the 5 $\mu R/hr$ staff position.

When the NRC was reluctant to accept this kind of evidence in fulfillment of the requirements, we decided to eliminate the "4π" geometry by eliminating the exposure room. This was done by cutting a swath through the concrete shield from the hot cell on the north through the south wall of the exposure room. This left large, planer surfaces for us to work with. Most of the concrete rubble was taken to an enclosed area in the middle of the Johnson property parking lot.

The rubble which came from immediately around the exposure room was stored separately in anticipation of further interest on the part of the NRC. This rubble was eventually moved to the Johnson property storage yard and distributed homogeneously over an area such that the depth of material was nowhere more than about one foot. Prior to this move, however, background background measurements were made in the storage yard in the vicinity of the proposed laydown area. The storage yard was marked off in a grid with 3-meter grid size and readings were taken at 1 meter above the center of each square. The squares to be read were selected by means of a random number generator. Figure 8 shows the results of these measurements graphically and Figure 9 shows the distribution of the readings and an analysis of the data.

Figures 10 and 11 show the outline of the area over which the rubble from the exposure room was distributed and the exposure meter readings obtained at 1 meter above the rubble and at the surface of the rubble, respectively. Comparison of the exposure readings at 1 meter above the surface yields:

DESCRIPTION	AVERAGE R/hr	NUMBER OF MEASUREMENTS	SURVEY RATE
RUBBLE (from exposure room)	8.63 + 0.38	30	MARCH 86
RUBBLE (from exterior walls)	8.77 + 0.26	39	JANUARY 86
BACKGROUND (of storage yard)	9.08 + 0.36	30	JAN & MAR 86

The difference is zero within the precision of the measurements.

Thus, we have demonstrated that:

1. Our technique for treating the data obtained in a confined space like the exposure room so that they might be directly compared with readings obtained above a planar surface is correct and reliable.

2. Radiation emanating from the concrete rubble is essentially at background levels and easily meets the 5 R/hr criterion.

ATTACHMENT 1

MAKERS MANUFACTURERS OF
Scientific and Industrial
INSTRUMENTS

LUDLUM MEASUREMENTS, INC.
915 · 235-5494 TELEX No.
POST OFFICE BOX 810
501 OAK STREET
SWEETWATER, TEXAS, U.S.A. 79556

CERTIFICATE OF CALIBRATION

Customer *Northrop Corp.*

Order No. *85-0111*

Mfg *Ludlum* Model *19* Serial No. *37438*

Mfg *"* Detector Model *—* Serial No. *PR*

Cal. Date *3-12-85* Cal. Due *3-12-86* Temperature *75°*

Cal. Interval *1 yr* Procedure: In accordance with Mfg. Specs. Humidity *42* %

INSTRUMENT RECEIVED	INSTRUMENT RETURNED
☐ Within tolerance	☑ Input sensitivity threshold set for *40* MV
☐ Out of tolerance	☑ Detector operating voltage = *800* volts
☐ Requiring repair	☑ See comments

COMMENTS *NEW*

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Bureau of Standards, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants, or have been derived by the ratio type of self-calibration techniques. The calibration system conforms to the requirements of MIL-STD-45662A and ANSI N323-1978.

CALIBRATION EQUIPMENT

Manufacturer	Model Number	Serial Number	Accuracy
Ludlum	500	*13663*	Mfg. Specs.
B&K	VOM	—	Mfg. Specs.
B&K	Oscilloscope	—	Mfg. Specs.

CALIBRATION RANGE

☑ Cs137 Gamma traceable to NBS TFN 224006, Oct. 2, 1980, 142Mr/HR @ 1 meter

☐ Neutron Am-241/Be traceable to NBS Certification Test 223767, Aug. 21, 1980

☐ Electronic Calibration ☐ Alpha ☐ Beta

☐ Other

Calibrator *Robert Hill* Supervisor *Keith D. Brock*

Date *3-12-85* Quality Control *[signature] Smith*

Page ___ of ___

Form 3

DESIGNERS AND MANUFACTURERS
OF
Scientific and Industrial
INSTRUMENTS

LUDLUM MEASUREMENTS, INC.
915 · 235-5494 TELEX No. [illegible] UD
POST OFFICE BOX 8[illegible]0
5[illegible]1 OAK STREET
SWEETWATER, TEXAS, U.S.A. 79[illegible]

GAMMA DATA SHEET

CUSTOMER: Northrup Corp. ORDER NO. 85-0111

Model No. 19 S/N 37438

Detector Model No. — S/N —

Type of Source: Cs137

Size of Source: 150 mCi

Range	Calibration Point	Dial Reading
5000	4 mr/hr	38 3.8 mR
"	2 "	20 3.0 mR

500-250-50-25 Range(s) calibrated with a Ludlum Model 500 Pulser

Cs137 source traceable to NBS, 142 Mr/HR @ 1 meter TFN224008—Oct. 2, 1980.

Date 3-12-85 Signature [illegible]

Form 23

DESIGNER AND MANUFACTURER OF
Scientific and Industrial
INSTRUMENTS

LUDLUM MEASUREMENTS, INC.
915 - 235-5494 TELEX No. 488832 UD
POST OFFICE BOX 810
501 OAK STREET
SWEETWATER, TEXAS, U.S.A. 79556

GAMMA DATA SHEET

BEFORE ADJ. CAL READINGS

CUSTOMER: Northrop ORDER NO. R 10705

Model No. 19 S/N 37438

Detector Model No. — S/N —

Type of Source: Cs137

Size of Source: 150 mCi

Range	Calibration Point	Dial Reading (BEFORE ADJ. CAL READ)
5000	4 mr/hr	38
"	2 "	20
500	37K CPM =	20
"	18.5K "	10
250	39K "	20
"	19.5K "	10
50	3.9K "	20
"	1.95K "	10
25	3.9K "	20
"	1.95K "	10

500-250-50-25 Range(s) calibrated with a Ludlum Model 500 Pulser

Cs137 source traceable to NBS, 142 Mr/HR @ 1 meter TFN224008—Oct. 2, 1980.

Date 10-14-85 Signature RH

Form 13

DESIGNER AND MANUFACTURER OF
Scientific and Industrial
INSTRUMENTS

LUDLUM MEASUREMENTS, INC.
915 - 235-5494 TELEX No. 466832 UD
POST OFFICE BOX 810
501 OAK STREET
SWEETWATER, TEXAS, U.S.A. 79556

GAMMA DATA SHEET

CUSTOMER: Northrop ORDER NO. R 10705

Model No. 19 S/N 37428

Detector Model No. — S/N —

Type of Source: Cs137

Size of Source: 150 mCi

Range	Calibration Point	Dial Reading
5000	4 mr/hr	38
"	2 "	20
500	37K CPM	= 20
"	18.5K "	10
250	37K "	20
"	18.5K "	10
50	3.7K "	20
"	1.85K "	10
25	3.7K "	20
"	1.85K "	10

500-250-50-25 Range(s) calibrated with a Ludlum Model 500 Pulser

Cs137 source traceable to NBS, 142 Mr/HR @ 1 meter TFN224008—Oct. 2, 1980.

Date 10-14-85 Signature RH

Form D

DESIGNER AND MANUFACTURER OF
Scientific and Industrial
INSTRUMENTS

LUDLUM MEASUREMENTS, INC.
915 · 235-5494 TELEX No. 466832 UD
POST OFFICE BOX 810
501 OAK STREET
SWEETWATER, TEXAS, U.S.A. 79556

CERTIFICATE OF CALIBRATION

Customer Northrop Res + Tech Ctr

Order No. R 10705

Mfg. Ludlum Model 19 Serial No. 37438

Mfg. — Detector Model — Serial No. —

Cal. Date 10-14-85 Cal. Due 10-14-86 Temperature 76°

Cal. Interval 1 yr Procedure: In accordance with Mfg. Specs. Humidity 58 %

INSTRUMENT RECEIVED

- ☑ Within tolerance
- ☐ Out of tolerance
- ☐ Requiring repair

INSTRUMENT RETURNED

- ☐ Input sensitivity threshold set for ~~1.00~~ = 46 MV
- ☐ Detector operating voltage = 850 volts
- ☐ See comments

COMMENTS

Ludlum Measurements, Inc. certifies that the above instrument has been calibrated by standards traceable to the National Bureau of Standards, or to the calibration facilities of other International Standards Organization members, or have been derived from accepted values of natural physical constants, or have been derived by the ratio type of self-calibration techniques. The calibration system conforms to the requirements of MIL-STD-45662A and ANSI N323-1978.

CALIBRATION EQUIPMENT

Manufacturer	Model Number	Serial Number	Accuracy
Ludlum	500	13663	Mfg. Specs.
B&K	VOM		Mfg. Specs.
B&K	Oscilloscope		Mfg. Specs.

CALIBRATION RANGE

- ☑ Cs137 Gamma traceable to NBS TFN 224008, Oct. 2, 1980, 142Mr/HR @ 1 meter
- ☐ Neutron Am-241/Be traceable to NBS Certification Test 223767, Aug. 21, 1980
- ☐ Electronic Calibration ☐ Alpha ☐ Beta
- ☐ Other

Calibrator Robert Hill Supervisor Keith D. Brock

Date 10-14-85 Quality Control Elaine Wyatt

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Form 3

TABLES

TABLE I

MEASUREMENT OF ATTENUATION
OF CS-137 RADIATION
BY LEAD ATTENUATORS

LEAD ATTENUATOR THICKNESS (gms/cm2) [1]	VICTOR METER READING (mR/hr) [2]	LUDLUM METER READING (mR/hr) [3]	NORMALIZED METER READINGS	NORMALIZED CALCULATED ATTENUATION FACTOR
0.00	-----	------	0.97500	1.00000
1.80	67.00	------	0.83750	0.83615
3.21	56.00	------	0.70000	0.72081
4.68	50.00	------	0.62500	0.61749
6.18	43.00	------	0.53750	0.52729
8.03	35.00	------	0.43750	0.43399
14.98	17.00	------	0.21250	0.20881
24.52	8.00	------	0.10000	0.07650
47.76	~0.60	0.600	0.00750	0.00663
53.98	~0.25	0.250	0.00313	0.00344
60.93	----	0.140	0.00175	0.00166
70.47	----	0.060	0.00075	0.00061
76.70	----	0.025	0.00031	0.00031
83.65	----	0.013	0.00016	0.00015
89.88	----	0.008	0.00010	0.00008

Note:

1] Lead attenuators were inserted at the source position.

2] The exposure from the Cs-137 source at 1 meter was 31,400 mR/hr. At 20 meters, the lead equivalent thickness of the intervening air was 1.8 grms/cm^2. The calculated exposure, without air attenuation, at 20 meters is 80 mR/hr.

3] The Victoreen 440 ion chamber was used for the higher flux roadings.

TABLE II

PARAMETERS USED IN THE
CALIBRATION OF THE MICRO-R-METER

PHOTON ENERGY (KeV) [e]	--PHOTON RELAXATION LENGTH-- (gms/cm^2) [x] [1] LEAD	CONCRETE	AIR	NaI	METER RESPONSE FACTOR [r(e)] [2]	FIELD REACTION FACTOR [f(e)] [3]
15	0.010	0.121	0.645	0.021	0.10	1.00
27	0.022	0.500	2.128	0.127	1.00	0.53
50	0.128	2.564	4.762	0.093	10.00	10.00
75	0.339	4.348	5.882	0.250	15.00	10.67
150	0.508	6.944	7.353	1.600	10.00	5.33
300	2.475	9.259	9.346	5.988	3.20	2.40
600	8.000	12.346	12.500	12.048	1.20	1.13
662	8.929	12.821	12.821	12.987	1.00	1.00
1200	13.699	16.949	16.949	18.182	0.50	0.63
1500	19.231	19.231	19.231	21.277	0.40	0.53
2400	22.727	24.390	24.390	25.641	0.20	0.39

Note:

1] Photon relaxation length data from Radiological Health Handbook (ref.3).

2] Meter-Exposure Response Factor data, r(e), from Eberline Micro-R-meter specifications (ref.2) (see figure 1). The factor, r(e), has the dimensions of (meter units)/(uR/hr).

3] Photon Field-Exposure Factor data, f(e), from Radiological Health Handbook - (ref.3) (see figure 1). The factor, f(e), has the dimensions of 0.77 ((Cs-137photons)/(cm^2/sec))/(uR/hr).

TABLE III

MEASUREMENTS OF ATTENUATION OF
THE CONCRETE PRIMORDIAL RADIOACTIVITY
BY LEAD ATTENUATORS

LEAD ATTENUATOR THICKNESS (gms/cm2)	METER READING (uR/hr)	METER ZERO OFFSET (uR/hr)	METER NET READING (uR/hr)	NORMALIZED READING ($M_p(x)$)
0.000	5.83	0.20	5.63	1.000
0.432	3.20	0.20	3.00	0.800
2.191	1.15	0.10	1.05	0.281
3.748	1.10	0.10	1.00	0.267
5.247	1.05	0.10	0.95	0.254
6.717	0.90	0.10	0.80	0.213
8.130	0.85	0.10	0.75	0.200
15.625	0.70	0.10	0.60	0.161
23.265	0.65	0.10	0.55	0.147
26.840	0.65	0.10	0.55	0.147
58.090	0.20	0.10	0.10	0.027

Note: The source was the primordial radioactivity in the concrete floor of the Reactor Facility. The micro-R-meter was at one meter above the floor surface, surrounded on four sides and the top by 2 inches of lead. The rectangular aperture between the detector and the floor was(4 x 8) square inches. The detector recessed 1.375 inches from the aperture. Lead attenuators were added below the aperture.

TABLE IV

GAMMA FIELD
FOR
NEUTRON ACTIVATED CONCRETE

ISOTOPE SOURCE	ISO FRACT (S_j)	GAMMA ENERGY	GAM. FRACT (N_i)	RAD. LENGTH (x_i)	GAMMA FIELD ($S_jN_ix_i$)	NORMALIZED FRACTION OF GAMMA FIELD
Average Energy of Group = 50 keV						
EU152	0.73	40	0.730	3.16	1.68396	0.08939
EU154	0.06	45	0.260	3.35	0.05226	0.00277
EU152	0.73	50	0.002	3.54	0.00517	0.00027
Energy Group e_1 Subtotals					ϕ_o =1.74139	ϕ=0.09243
Average Energy of Group = 150 keV						
EU152	0.73	122	0.280	5.52	1.12829	0.05989
EU154	0.06	123	0.405	5.55	0.13486	0.00716
EU154	0.06	188	0.003	6.86	0.00123	0.00007
Energy Group e_2 Subtotals					ϕ_o =1.26438	ϕ=0.06712
Average Energy of Group = 300 keV						
EU152	0.73	245	0.075	7.83	0.42869	0.02276
EU154	0.06	248	0.066	7.87	0.03117	0.00165
EU152	0.73	296	0.004	8.60	0.02511	0.00133
EU152	0.73	329	0.001	9.07	0.00662	0.00035
EU152	0.73	344	0.265	9.27	1.79328	0.09519
EU152	0.73	368	0.009	9.59	0.06301	0.00334
Energy Group e_3 Subtotals					ϕ_o =2.34788	ϕ=0.12462
Average Energy of Group = 600 keV						
EU154	0.06	401	0.002	10.01	0.00120	0.00006
EU152	0.73	411	0.022	10.14	0.16285	0.00864
EU152	0.73	416	0.001	10.20	0.00745	0.00040
EU152	0.73	444	0.028	10.54	0.21544	0.01144
EU152	0.73	444	0.003	10.54	0.02308	0.00123
EU154	0.06	445	0.005	10.55	0.00316	0.00017
EU154	0.06	478	0.002	10.93	0.00131	0.00007
EU152	0.73	489	0.004	11.06	0.03230	0.00171
EU152	0.73	503	0.002	11.21	0.01637	0.00087
EU154	0.06	558	0.003	11.81	0.00213	0.00011
EU152	0.73	564	0.005	11.87	0.04333	0.00230
EU152	0.73	566	0.001	11.90	0.00869	0.00046
EU154	0.06	582	0.008	12.06	0.00579	0.00031
EU152	0.73	586	0.005	12.10	0.04416	0.00234
EU154	0.06	592	0.048	12.17	0.03505	0.00186

TABLE IV (CONTINUED)

GAMMA FIELD
FOR
NEUTRON ACTIVATED CONCRETE

ISOTOPE SOURCE	ISO FRACT (S_j)	GAMMA ENERGY	GAM. FRACT (N_i)	RAD. LENGTH (x_i)	GAMMA FIELD $(S_j N_i x_i)$	NORMALIZED FRACTION OF GAMMA FIELD
Average Energy of Group = 600 keV (continued)						
EU154	0.06	625	0.003	12.50	0.00225	0.00012
EU152	0.73	656	0.001	12.81	0.00935	0.00050
EU152	0.73	674	0.001	12.98	0.00948	0.00050
EU154	0.06	677	0.001	13.01	0.00078	0.00004
EU152	0.73	679	0.005	13.03	0.04756	0.00252
EU152	0.73	689	0.008	13.12	0.07662	0.00407
EU154	0.06	692	0.017	13.15	0.01341	0.00071
EU154	0.06	716	0.002	13.38	0.00161	0.00009
EU152	0.73	719	0.003	13.41	0.02937	0.00156
EU154	0.06	723	0.197	13.44	0.15886	0.00843
EU154	0.06	757	0.043	13.76	0.03550	0.00188
EU152	0.73	765	0.002	13.83	0.02019	0.00107
EU152	0.73	779	0.127	13.96	1.29423	0.06870
Energy Group e_4 Subtotals					ϕ_0 =2.30152	ϕ=0.12216
Average Energy of Group = 1200 keV						
EU152	0.73	810	0.003	14.23	0.03116	0.00165
EU154	0.06	816	0.005	14.28	0.00428	0.00023
EU152	0.73	842	0.002	14.51	0.02118	0.00112
EU154	0.06	845	0.006	14.53	0.00523	0.00028
EU154	0.06	851	0.002	14.59	0.00175	0.00009
EU152	0.73	867	0.042	14.72	0.45132	0.02396
EU154	0.06	873	0.115	14.77	0.10191	0.00541
EU154	0.06	893	0.005	14.94	0.00448	0.00024
EU154	0.06	904	0.008	15.03	0.00721	0.00038
EU152	0.73	919	0.004	15.16	0.04427	0.00235
EU152	0.73	926	0.003	15.22	0.03333	0.00177
EU152	0.73	963	0.001	15.52	0.01133	0.00060
EU152	0.73	964	0.144	15.52	1.63146	0.08660
EU154	0.06	996	0.103	15.78	0.09752	0.00518
EU152	0.73	1005	0.007	15.85	0.08099	0.00430
EU154	0.06	1005	0.179	15.85	0.17023	0.00904
EU154	0.06	1047	0.001	16.18	0.00097	0.00005
EU152	0.73	1085	0.002	16.47	0.02405	0.00128
EU152	0.73	1086	0.100	16.48	1.20304	0.06386
EU152	0.73	1090	0.017	16.51	0.20489	0.01088
EU152	0.73	1109	0.002	16.65	0.02431	0.00129
EU152	0.73	1112	0.133	16.67	1.61849	0.08591
EU154	0.06	1118	0.001	16.72	0.00100	0.00005
EU154	0.06	1128	0.003	16.79	0.00302	0.00016

TABLE IV (CONTINUED)

GAMMA FIELD
FOR
NEUTRON ACTIVATED CONCRETE

ISOTOPE SOURCE	ISO FRACT (S_j)	GAMMA ENERGY	GAM. FRACT (N_i)	RAD. LENGTH (x_i)	GAMMA FIELD ($S_j N_i x_i$)	NORMALIZED FRACTION OF GAMMA FIELD
Averge Energy of Group = 1200 keV (continued)						
EU154	0.06	1141	0.002	16.89	0.00203	0.00011
CO60	0.21	1173	0.210	17.12	0.75499	0.04008
EU152	0.73	1213	0.014	17.41	0.17793	0.00944
EU154	0.06	1242	0.001	17.62	0.00106	0.00006
EU154	0.06	1246	0.009	17.65	0.00953	0.00051
EU152	0.73	1250	0.002	17.68	0.02581	0.00137
EU154	0.06	1274	0.355	17.85	0.38021	0.02018
EU152	0.73	1293	0.001	17.98	0.01313	0.00070
EU152	0.73	1299	0.016	18.02	0.21047	0.01117
CO60	0.21	1332	0.220	18.25	0.84315	0.04476
EU152	0.73	1408	0.207	18.76	2.83482	0.15048
EU152	0.73	1458	0.005	19.09	0.06968	0.00370
EU154	0.06	1494	0.006	19.33	0.00696	0.00037
EU152	0.73	1528	0.003	19.54	0.04279	0.00227
EU154	0.06	1593	0.010	19.96	0.01198	0.00064
EU154	0.06	1597	0.018	19.98	0.02158	0.00115
Energy Group e_5 Subtotals					ϕ_0 = 11.18354	ϕ = 0.59367
Totals for All Groups					ϕ_0 = 18.83871	ϕ = 1.00000

TABLE V

PHOTON FLUX DISTRIBUTION AND EXPOSURE BASED ON THE NEUTRON ACTIVATION SOURCE DISTRIBUTION IN CONCRETE

AVERAGE PHOTON ENERGY	PHOTON FLUX FRACTION: NO BUILDUP	PHOTON FLUX FRACTION: BUILDUP FRACTION	PHOTON FLUX FRACTION: WITH BUILDUP	METER RESP. FACTOR	FLUX EXPOSURE FACTOR	EXPOSURE	METER READING
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
e_i	$\phi_0(e_i)$		$\phi(e_i)$	$f(e_i)$	$r(e_i)$	E_i	M_i
50	0.092	0.091	0.140	10.00	10.00	0.015	0.150
150	0.067	0.084	0.116	10.00	5.33	0.023	0.230
300	0.125	0.072	0.151	3.20	2.40	0.067	0.214
600	0.122	0.059	0.139	1.20	1.13	0.130	0.157
1200	0.594	0.000	0.454	0.50	0.63	0.764	0.382
Totals:	1.000		1.000			1.000	1.133

Note:

1] Photon energy of group, e_i, from table IV.

2] Normalized photon flux, without buildup, from table IV.

3] Buildup factor for each group.

4] Normalized photon flux, with buildup: $\phi = \frac{\phi_0(1+Bu)}{\Sigma\phi_0(1+Bu)}$

5] Meter-exposure factor, $r(e_i)$, from Figure 1.

6] Flux-exposure factor, $f(e_i)$, from Figure 1.

7] Normalized Exposure: $E_i = (\phi/f)/\Sigma\ (\phi/f)$

8] Meter reading: $M_i = r(e_i)E_i$

TABLE VI - a

EXPOSURE ROOM EAST WALL

Survey Block	1 meter Reading µR/HR	1 centimeter Reading µR/HR	Background µR/HR
A-2	22.0	22.6	12.0
A-3	22.0	29.0	
A-4	20.0	23.4	
B-1	21.0	21.0	
B-4	20.0	20.6	
C-1	23.0	25.0	
D-1	22.0	22.4	
D-2	22.0	22.6	
D-3	23.0	23.6	

TABLE VI - b

EXPOSURE ROOM   SOUTH WALL

Survey Block	1 meter Reading µR/HR	1 Centimeter Reading µR/HR	Background µR/HR
F-2	16.0	16.0	12.0
F-3	16.0	16.0	
F-5	15.0	15.3	
G-2	20.0	22.4	
G-3	20.0	22.8	
G-4	20.0	21.2	
H-3	21.0	19.6	
H-4	20.0	21.2	
H-5	22.0	21.0	
I-2	22.0	24.0	
I-3	22.0	20.2	
I-4	21.0	20.6	
I-5	21.0	20.4	
J-1	23.0	19.8	
J-2	21.0	21.0	
J-4	20.0	18.2	
J-5	20.0	17.8	

TABLE VI - c

EXPOSURE ROOM NORTH WALL

Survey Block	1 meter Reading μR/HR	1 centimeter Reading μR/HR	Background μR/HR
F-1	21.0	17.0	12.0
F-2	22.0	26.8	
F-3	20.0	20.0	
F-4	18.0	19.2	
F-5	15.0	13.2	
G-1	22.0	27.2	
G-2	24.0	28.0	
G-3	23.0	20.4	
G-4	22.0	19.6	
G-5	18.0	19.6	
H-1	21.0	26.0	
H-2	20.0	20.2	
H-3	20.0	17.4	
H-4	18.0	18.8	
H-5	16.0	15.0	
I-2	17.0	17.6	
I-3	16.0	13.6	
I-4	15.0	14.0	
I-5	14.0	13.6	
J-1	22.0	20.4	
J-2	19.0	19.4	
J-3	16.0	15.2	
J-5	15.0	14.0	

TABLE VI - d

EXPOSURE ROOM FLOOR

Survey Block	1 meter Reading µR/HR	1 centimeter Reading µR/HR	Background µR/HR
AA-1	22.0	26.0	12.0
AA-2	23.0	26.6	
AA-3	23.0	22.6	
AA-4	22.0	22.2	
BB-1	22.0	22.6	
BB-2	23.0	25.4	
BB-5	21.0	13.0	
CC-1	20.0	20.4	
CC-2	21.0	22.6	
CC-3	23.0	22.6	
CC-4	24.0	22.4	
CC-5	22.0	20.0	

TABLE VI - e

EXPOSURE ROOM CEILING

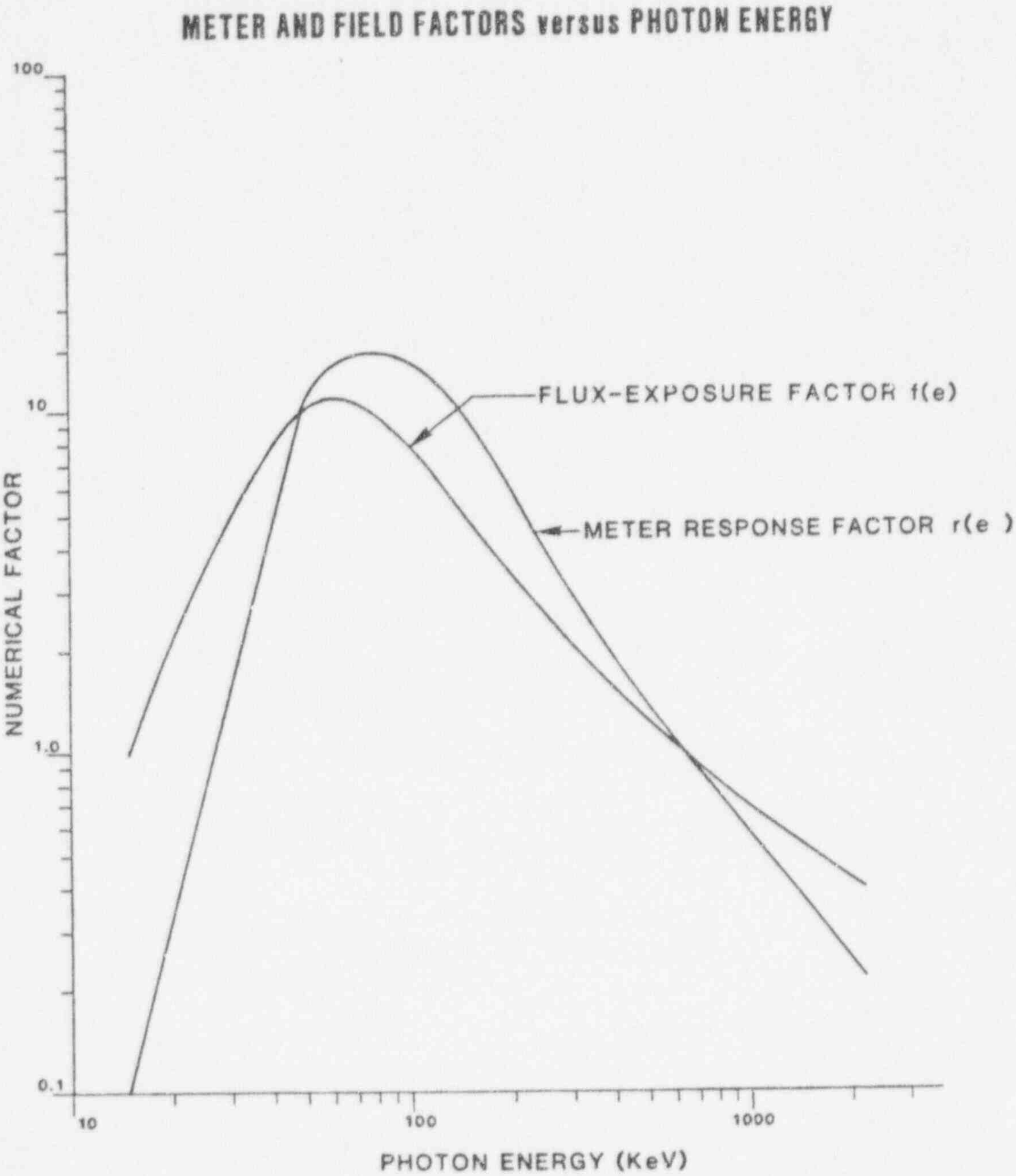
Survey Block	1 meter Reading µR/HR	1 centimeter Reading µR/HR	Background µR/HR
AA-1	17.0	16.8	12.0
AA-2	21.0	18.8	
AA-3	18.0	20.6	
AA-4	20.0	20.4	
AA-5	18.0	21.2	
BB-2	22.0	20.4	
BB-3	20.0	20.6	
BB-4	20.0	20.4	
BB-5	18.0	16.4	
CC-1	18.0	16.4	
CC-2	20.0	17.4	
CC-5	20.0	20.2	

TABLE VII

BACKGROUND SURVEY DATA

	LOCATION	GAMMAS uR/hr at 1 meter
1.	Gate 15 Area	12
		12
	747 Building	
2.	Southwest side	12
3.	West side	11
4.	Center	9
5.	North-center	11
6.	North-east	12
7.	Quonset Hut	12
8.	Quonset Hut	12
9.	Quonset Hut	11
10.	Building 3-61	12
11.	Building 3-61	11
12.	Building 3-61	12
13.	Building 2-7	9
14.	Building 2-7	11
15.	Building 2-7	11
16.	Parking Lot 747/NE Side	12
17.	Parking Lot 747/NE Side	12
18.	Parking Lot 747/NE Side	12
19.	Utility Building 1-85	12
20.	Utility Building 1-85	12
21.	Wind Tunnel Parking Lot	12
22.	Wind Tunnel Parking Lot	12
23.	Trans-Wharehouse	12
24.	Trans-Wharehouse	12
	Trans-Wharehouse	12
	Paved City Streets	
25.	Northrop & Prairie	12
26.	Prairie & El Segundo	12
27	Northrop & Crenshaw	12
		12
	Average (30 readings)	11.6
	STD Deviation	0.8

FIGURES



METER AND FIELD FACTORS versus PHOTON ENERGY
100
10
1.0
0.1
NUMERICAL FACTOR
FLUX-EXPOSURE FACTOR f(e)
METER RESPONSE FACTOR r(e)
10
100
1000
PHOTON ENERGY (KeV)

Figure 1

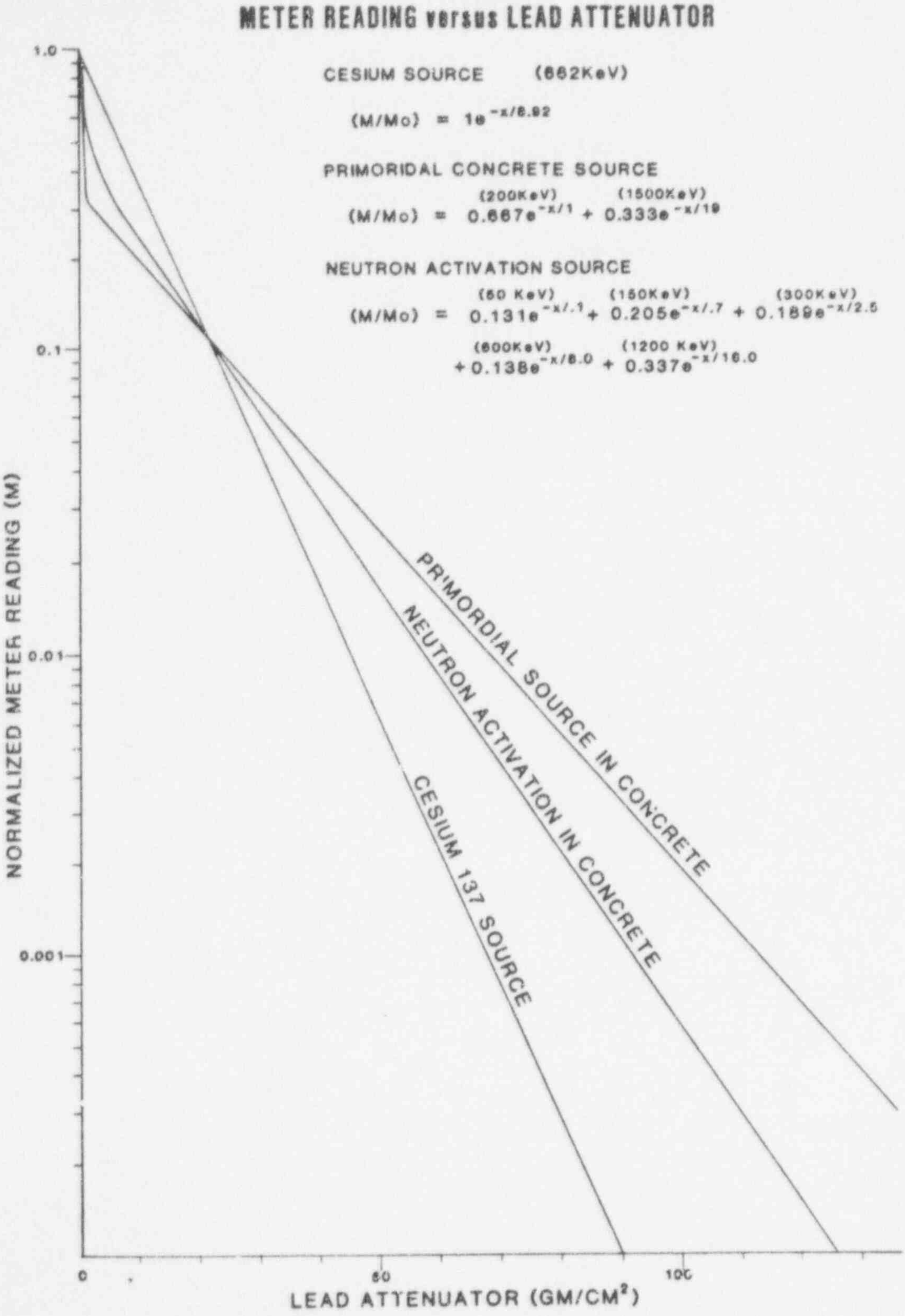

METER READING versus LEAD ATTENUATOR
CESIUM SOURCE (662KeV)
(M/Mo) = 1e^{-x/8.92}
PRIMORIDAL CONCRETE SOURCE
(200KeV) (1500KeV)
(M/Mo) = 0.667e^{-x/1} + 0.333e^{-x/19}
NEUTRON ACTIVATION SOURCE
(50 KeV) (150KeV) (300KeV)
(M/Mo) = 0.131e^{-x/.1} + 0.205e^{-x/.7} + 0.189e^{-x/2.5}
(600KeV) (1200 KeV)
+ 0.138e^{-x/8.0} + 0.337e^{-x/16.0}
PR'MORDIAL SOURCE IN CONCRETE
NEUTRON ACTIVATION IN CONCRETE
CESIUM 137 SOURCE
1.0
0.1
0.01
0.001
NORMALIZED METER READING (M)
0
50
100
LEAD ATTENUATOR (GM/CM²)

Figure 2

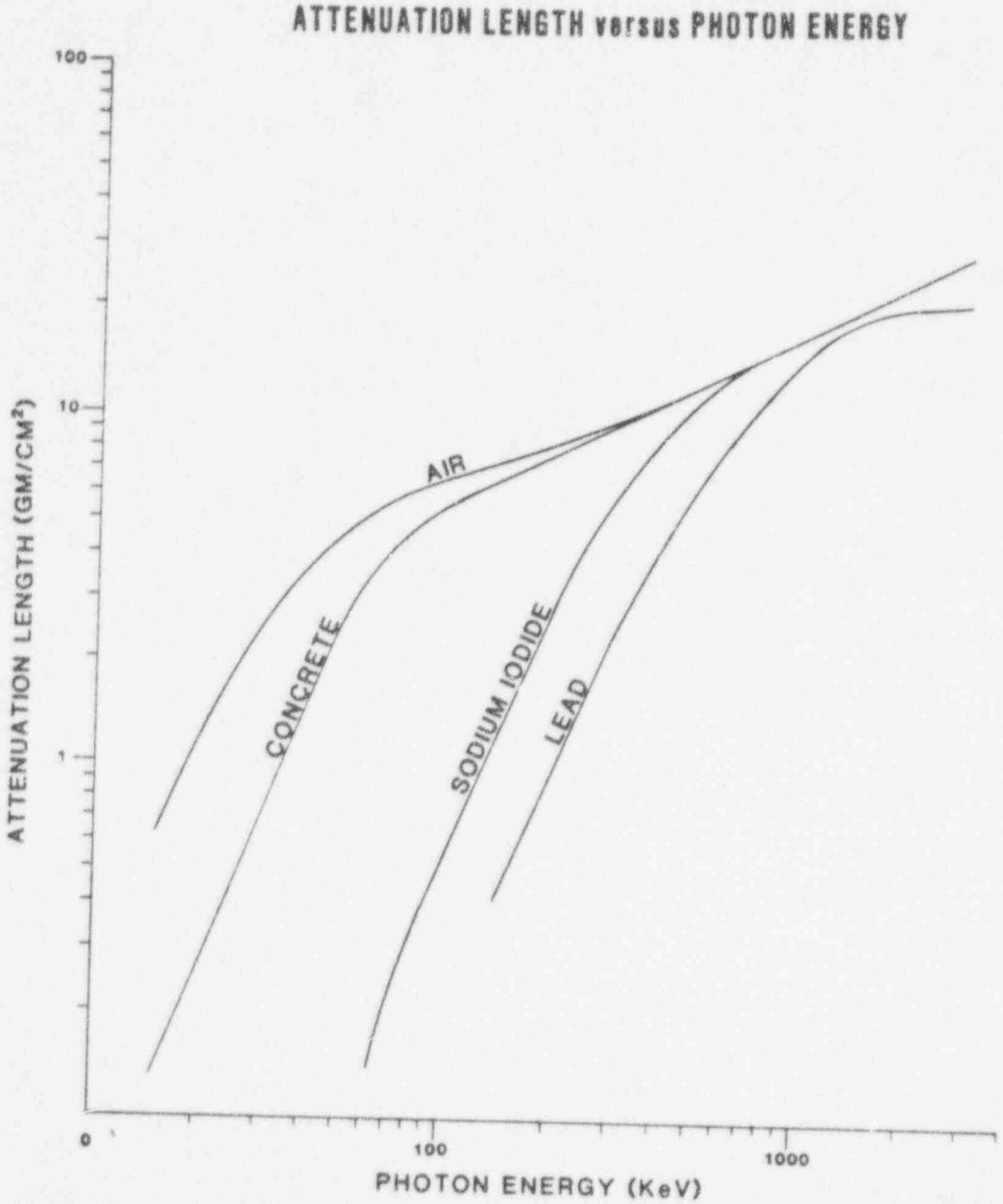
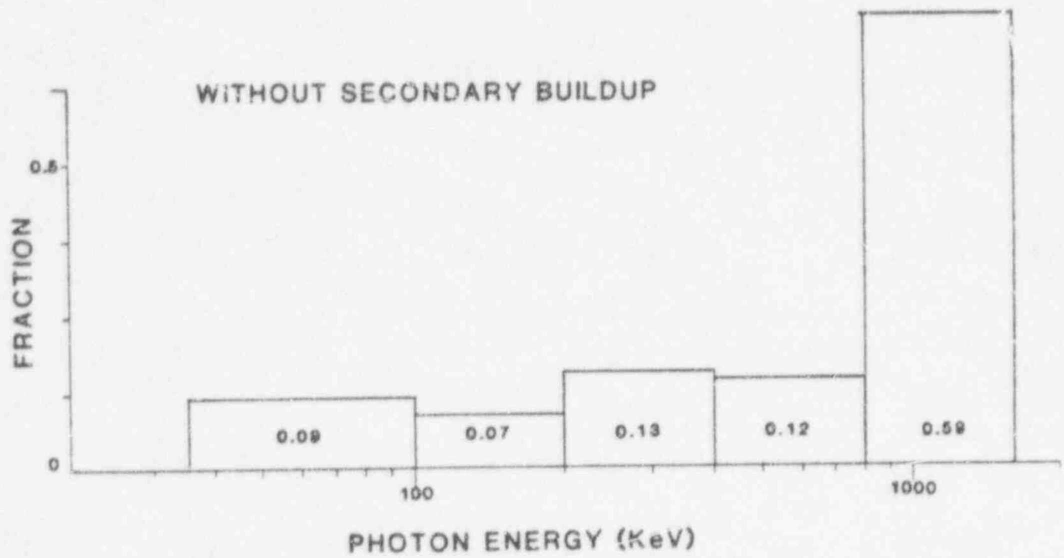

ATTENUATION LENGTH versus PHOTON ENERGY
100
10
1
0
100
1000
ATTENUATION LENGTH (GM/CM²)
PHOTON ENERGY (KeV)
AIR
CONCRETE
SODIUM IODIDE
LEAD

Figure 3

NEUTRON ACTIVATION PHOTON FLUX DISTRIBUTION



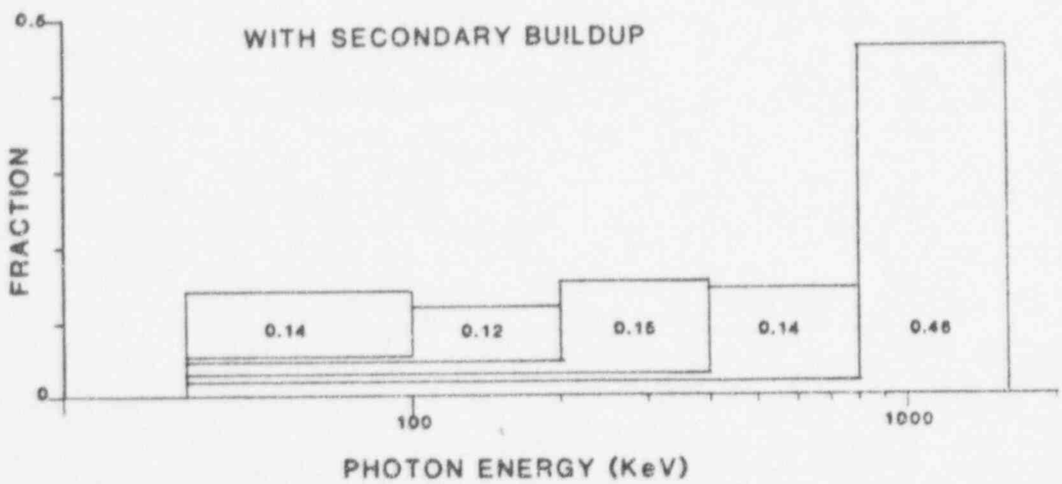


Figure 4

Figure 5a

EXPOSURE ROOM- EAST WALL

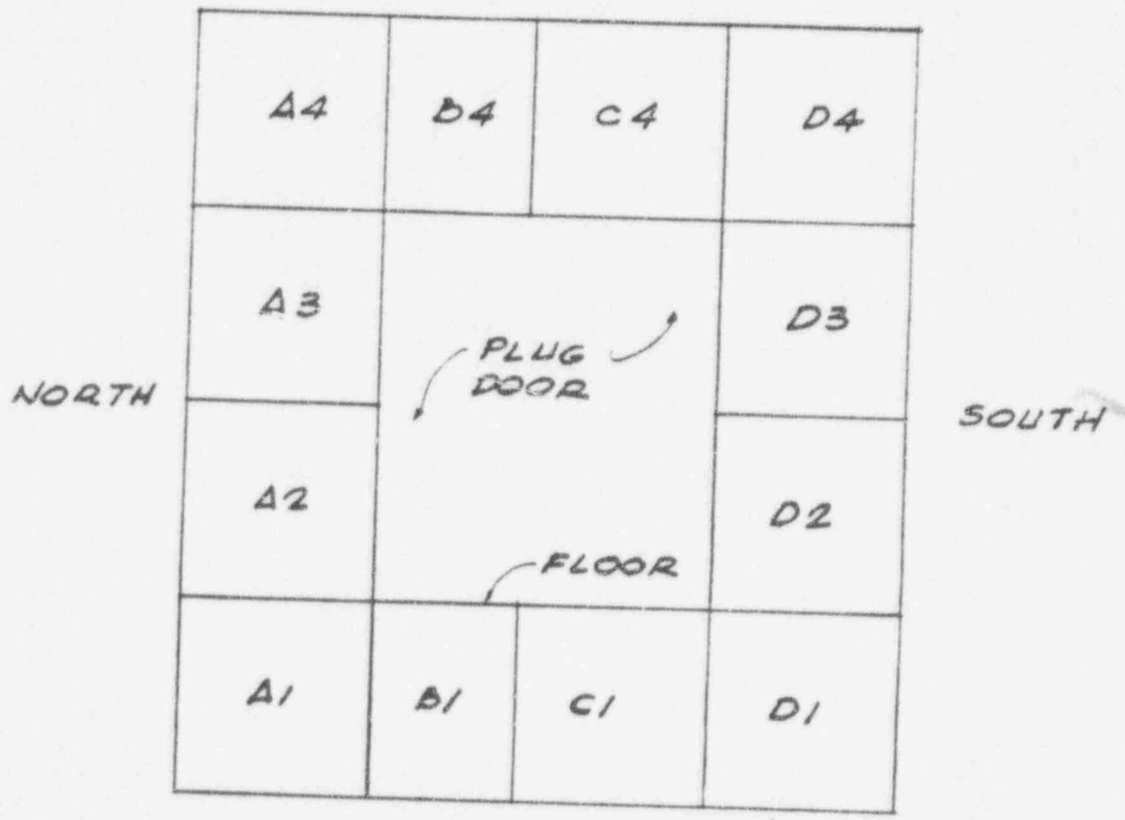


FIGURE 5b

EXPOSURE ROOM - SOUTH WALL

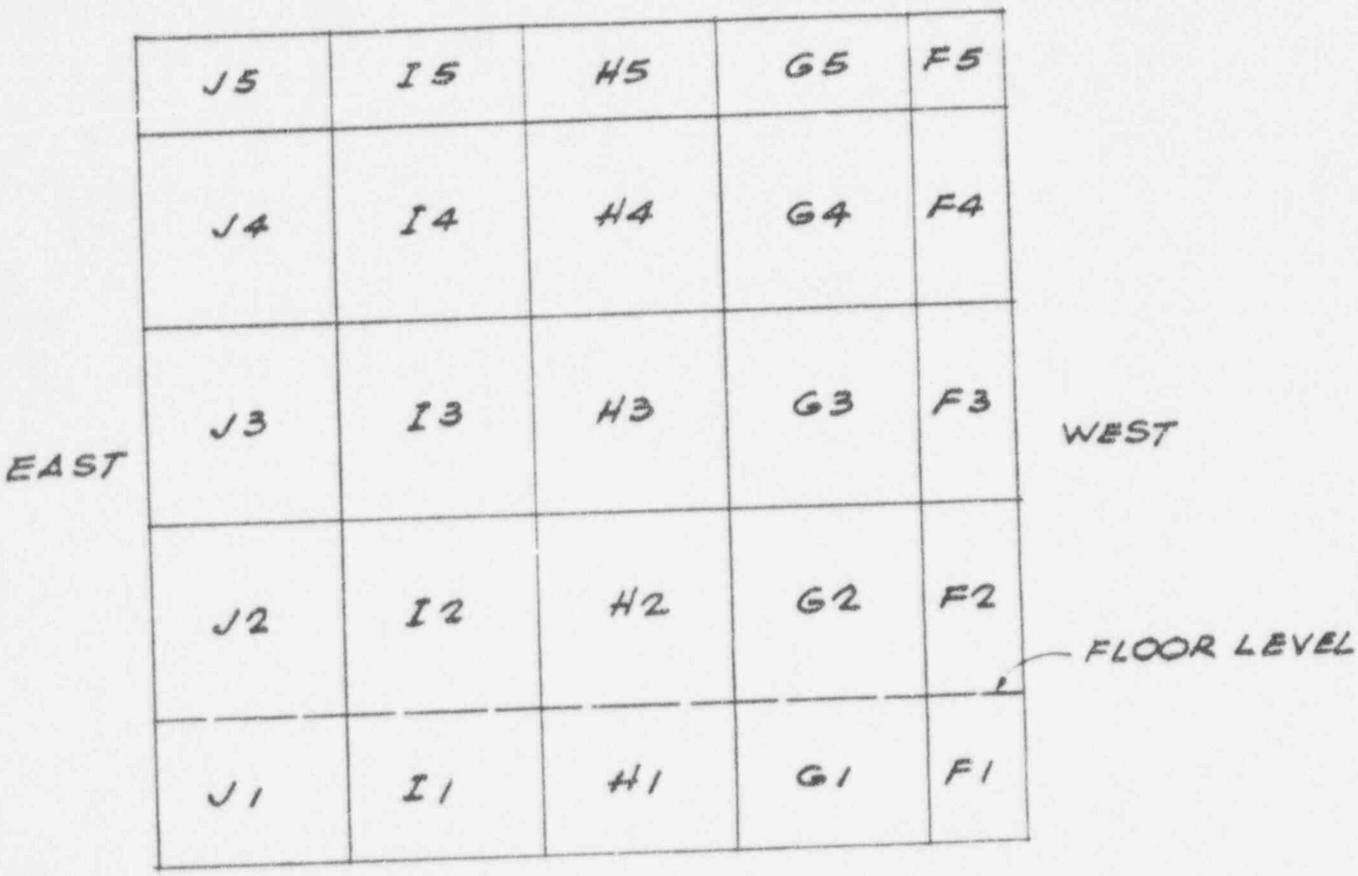


FIGURE 5c

EXPOSURE ROOM - NORTH WALL

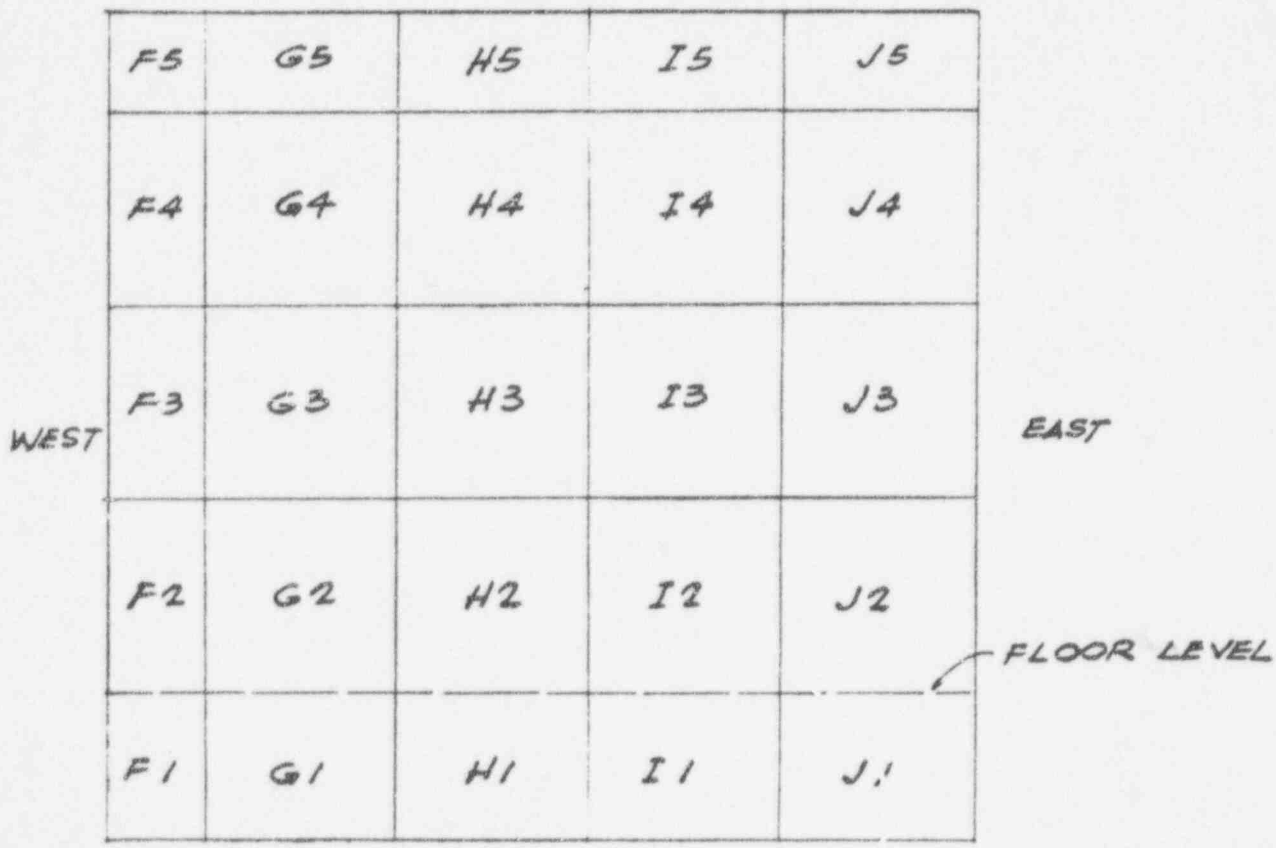


FIGURE 5d

EXPOSURE ROOM - FLOOR

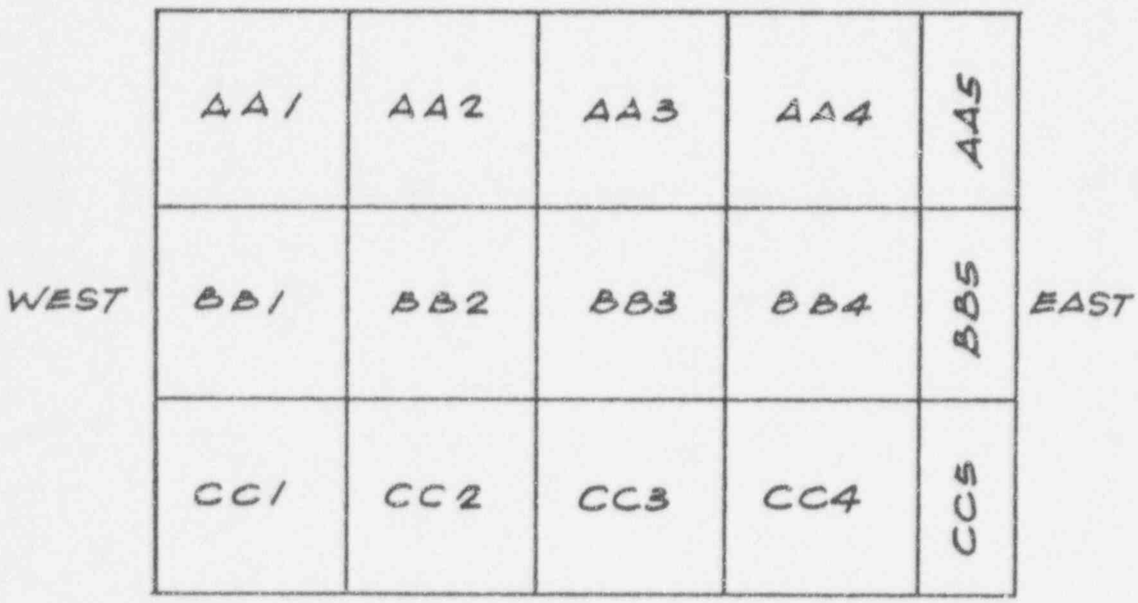


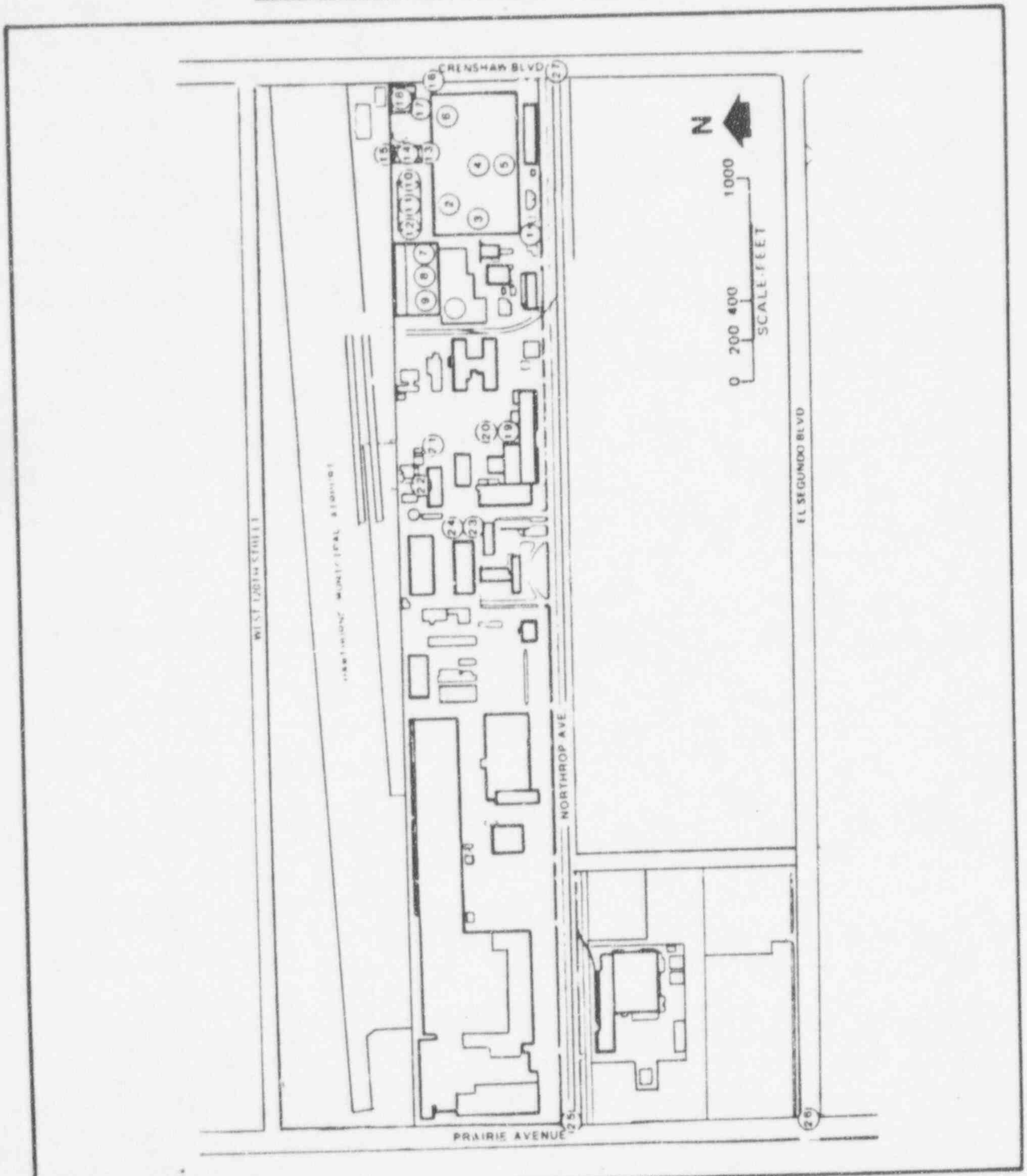
FIGURE 5e

EXPOSURE ROOM - CEILING

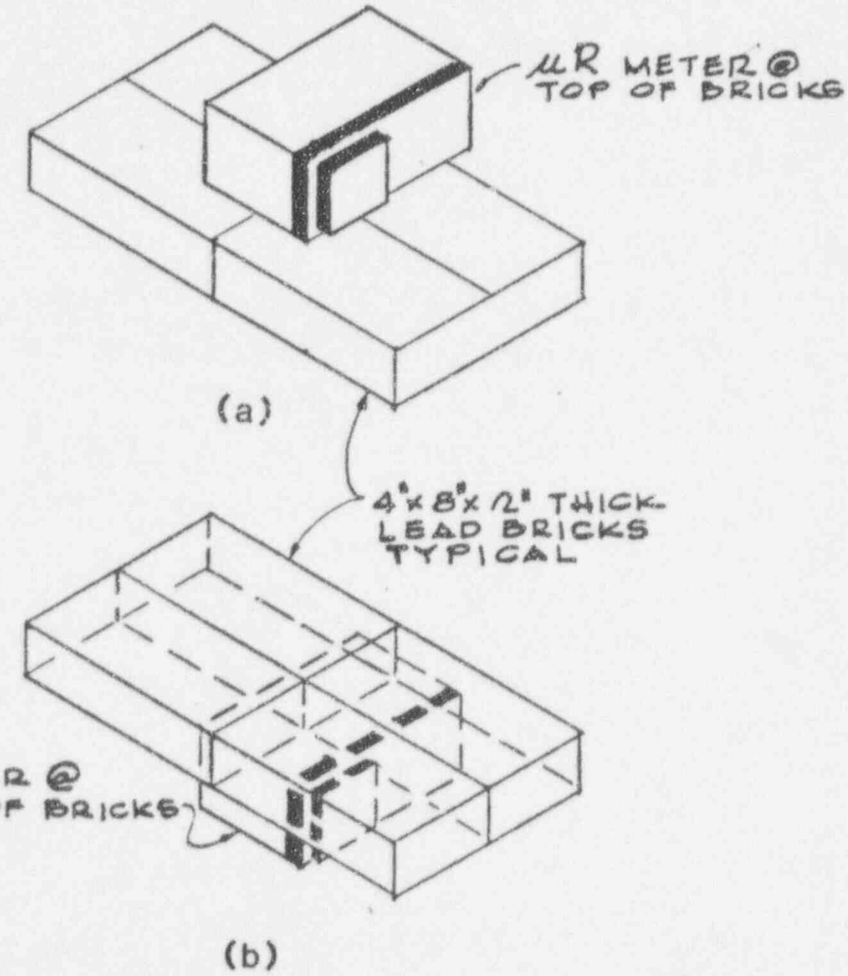
	CC1	CC2	CC3	CC4	CC5	
WEST	BB1	BB2	BB3	BB4	BB5	EAST
	AA1	AA2	AA3	AA4	AA5	

FIGURE 6

BACKGROUND SURVEY AREAS LOCATIONS



The construction in the areas surveyed was done during the same time period as the reactor facility. The measured radiation at these locations is consistent with measured natural primordial radioactivity in the concrete and soil, and with the measured radioactivity in the reactor facility.



μR METER @
TOP OF BRICKS
(a)
4"x 8"x 2" THICK
LEAD BRICKS
TYPICAL
μR METER @
BOTTOM OF BRICKS
(b)

FIGURE 7 a & b

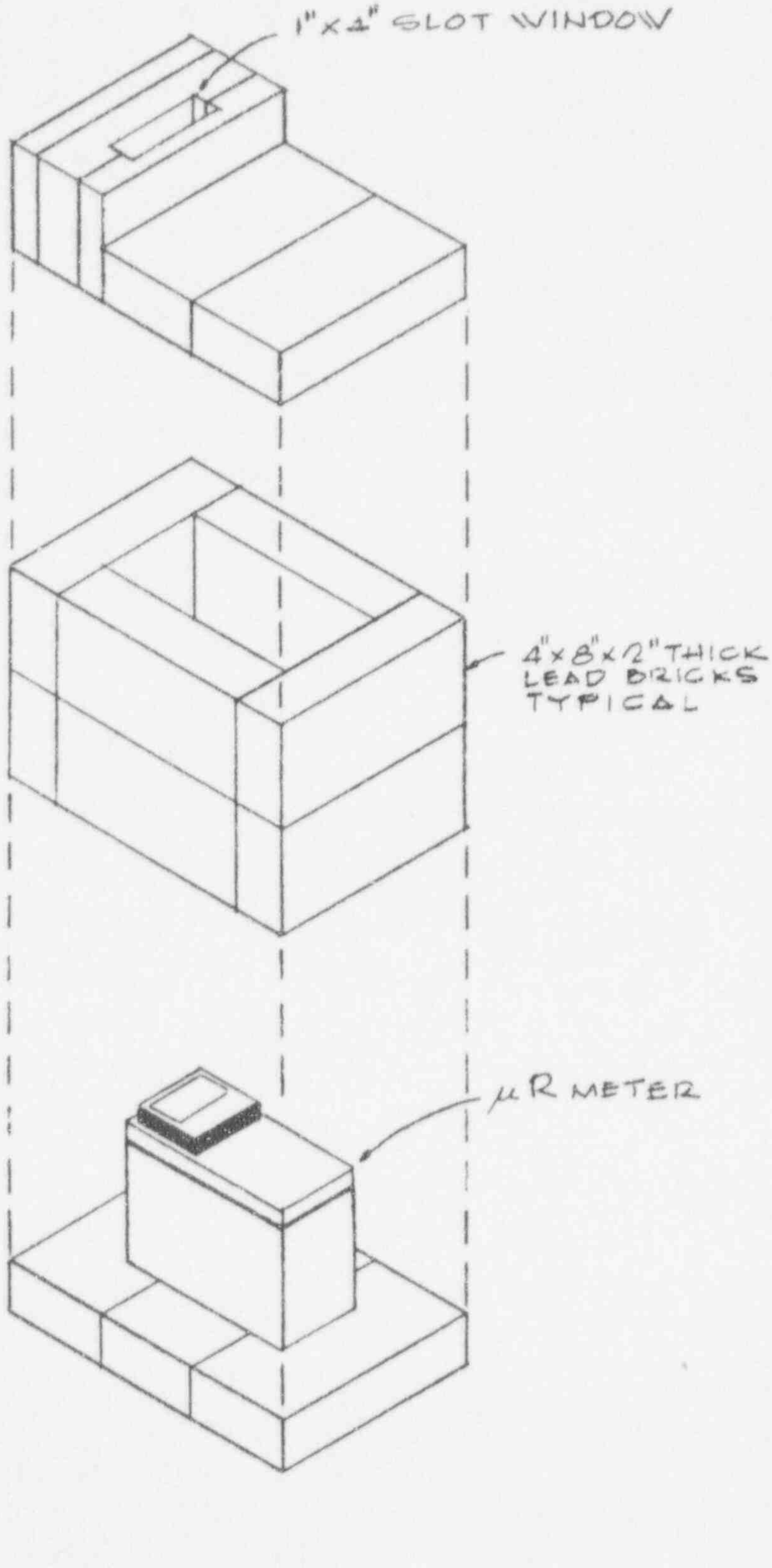


FIGURE 7c

JOHNSON PROPERTY
STORAGE YARD A-5
DATE: 30 JANUARY 1986
TIME: 15:00 - 17:50

FIGURE 8

SURVEY BY: GEORGE B. COZENS
METER USED: LUDLUM MOD 19, μR, SN. 37438
CALIBRATION DATE: 10/14/85

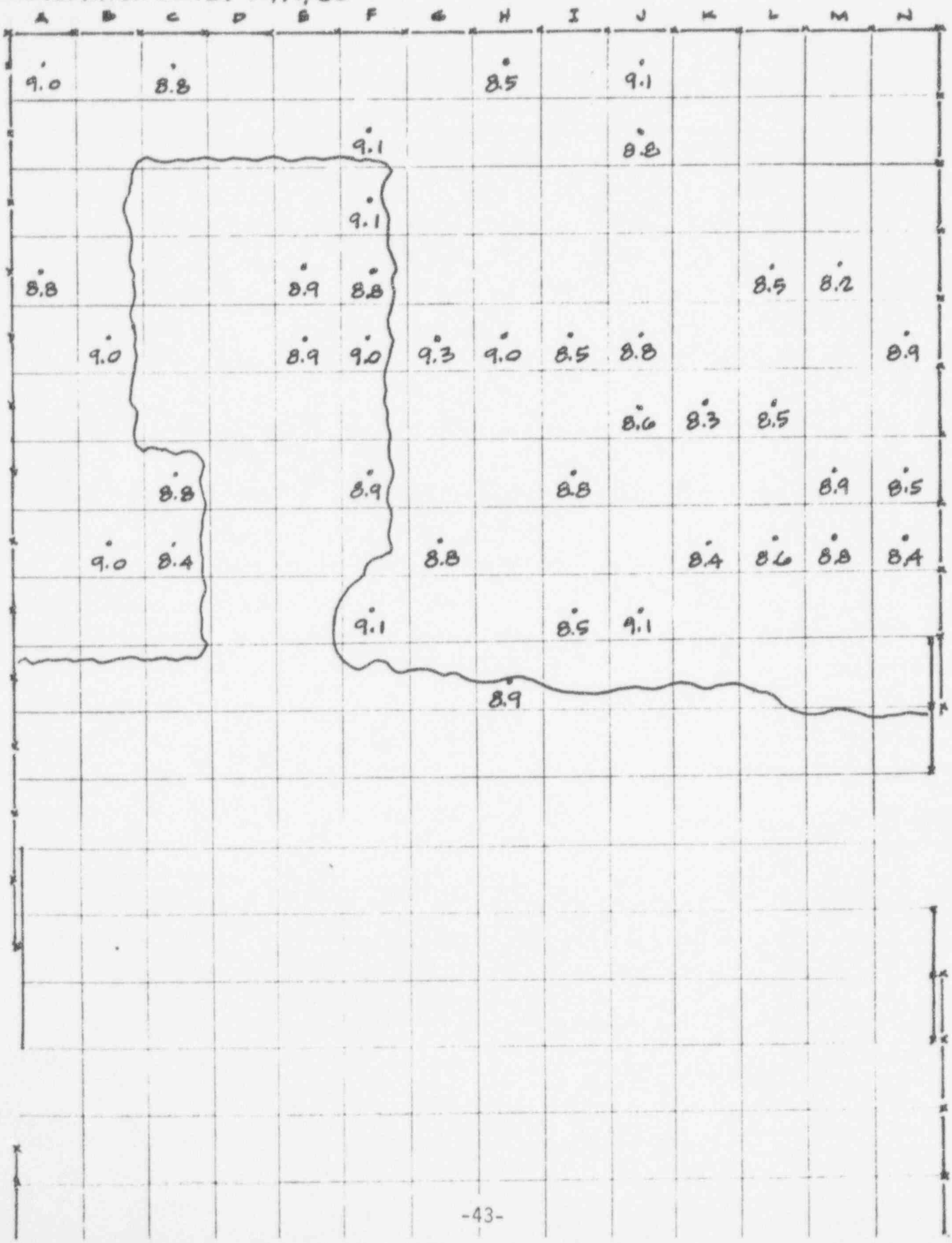


FIGURE 9a

```
ABSTAT 4.09          STATISTICAL ANALYSIS OF CONCRETE RUBBLE IN PARKING LOT
FILE:  CONCLOT      REV# 0                                                 PAGE  1

COMMAND:  DESC

MISSING VALUE TREATMENT: VARWISE

THERE ARE 1 VARIABLES AND 38 CASES IN THE DATA SET

38 CASES (100.0%) ARE VALID

                                                          STD ERROR       COEFF OF
VARIABLE               MEAN      STD.DEV.     VARIANCE      OF MEAN      VARIATION
  1 GR              8.77105      0.264991    0.0702205    0.0429873        3.02120

VARIABLE            MINIMUM       MAXIMUM        RANGE        TOTAL
  1 GR              8.20000       9.30000      1.10000      333.300

VARIABLE             MEDIAN          MODE     SKEWNESS     KURTOSIS
  1 GR              8.80000       8.80000    -0.274444      2.22932



COMMAND:  HIST

MISSING VALUE TREATMENT: VARWISE

VARIABLE:  1 GR

AT LEAST        8.00000                5         10        15        20         25         30
BUT NOT OVER:   FREQ     %    +--------+---------+---------+---------+----------+---------+
      8.00000      0   00.0   I
      8.20000      1    2.6   IXXXX
      8.40000      4   10.5   IXXXXXXXXXXXXXXXXXXX
      8.60000      8   21.1   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      8.80000      9   23.7   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      9.00000     10   26.3   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      9.20000      5   13.2   IXXXXXXXXXXXXXXXXXXXXXXX
      9.40000      1    2.6   IXXXX
      9.60000      0   00.0   I
      9.80000      0   00.0   I
      10.0000      0   00.0   I
                              +--------+---------+---------+---------+----------+---------+
        TOTAL     38  100.0            5         10        15        20         25         30
```

FIGURE 9b

COMMAND: DESC

MISSING VALUE TREATMENT: VARWISE

THERE ARE 1 VARIABLES AND 5 CASES IN THE DATA SET

5 CASES (100.0%) ARE VALID

VARIABLE	MEAN	STD.DEV.	VARIANCE	STD ERROR OF MEAN	COEFF OF VARIATION
1 GR	8.44000	0.0894427	0.00800000	0.0400000	1.05975

VARIABLE	MINIMUM	MAXIMUM	RANGE	TOTAL
1 GR	8.30000	8.50000	0.200000	42.2000

VARIABLE	MEDIAN	MODE	SKEWNESS	KURTOSIS
1 GR	8.50000	8.50000	-0.843750	2.07812

COMMAND: HIST

MISSING VALUE TREATMENT: VARWISE

VARIABLE: 1 GR

```
AT LEAST        8.00000          10        20        30        40        50        60
BUT NOT OVER:   FREQ     %    +--------+---------+---------+---------+---------+-------+
     8.00000      0    00.0   I
     8.20000      0    00.0   I
     8.40000      2    40.0   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     8.60000      3    60.0   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     8.80000      0    00.0   I
     9.00000      0    00.0   I
     9.20000      0    00.0   I
     9.40000      0    00.0   I
     9.60000      0    00.0   I
     9.80000      0    00.0   I
     10.0000      0    00.0   I
                              +--------+---------+---------+---------+---------+-------+
       TOTAL      5   100.0          10        20        30        40        50        60
```

FIGURE 10

ONE METER SURVEY

JOHNSON PROPERTY
STORAGE YARD A-5
DATE: 13 MARCH 1986
TIME: 08:50

SURVEY BY:

METER USED: LUDLUM MOD 19 µR, SN 37438

CALIBRATION DATE: 10/14/85

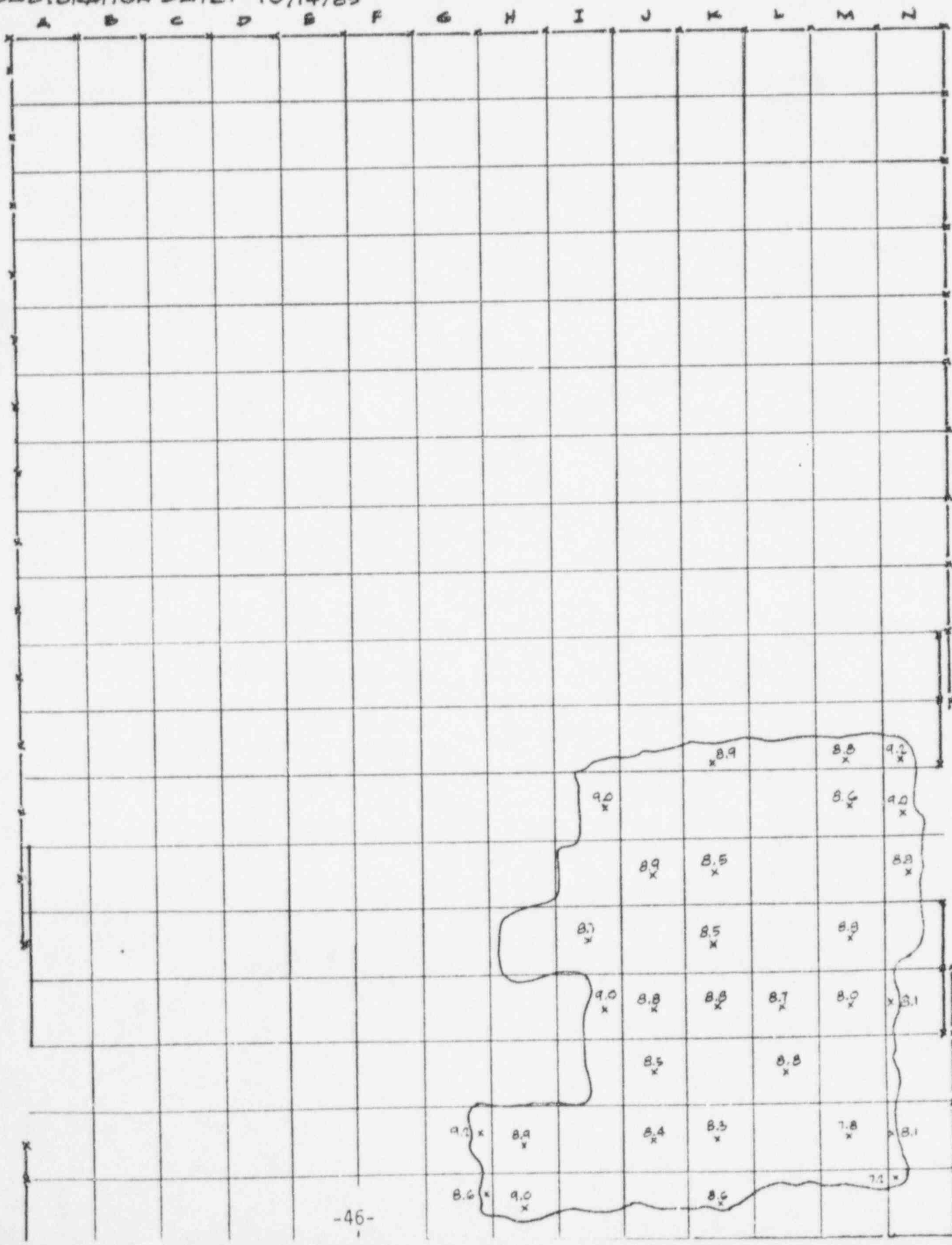
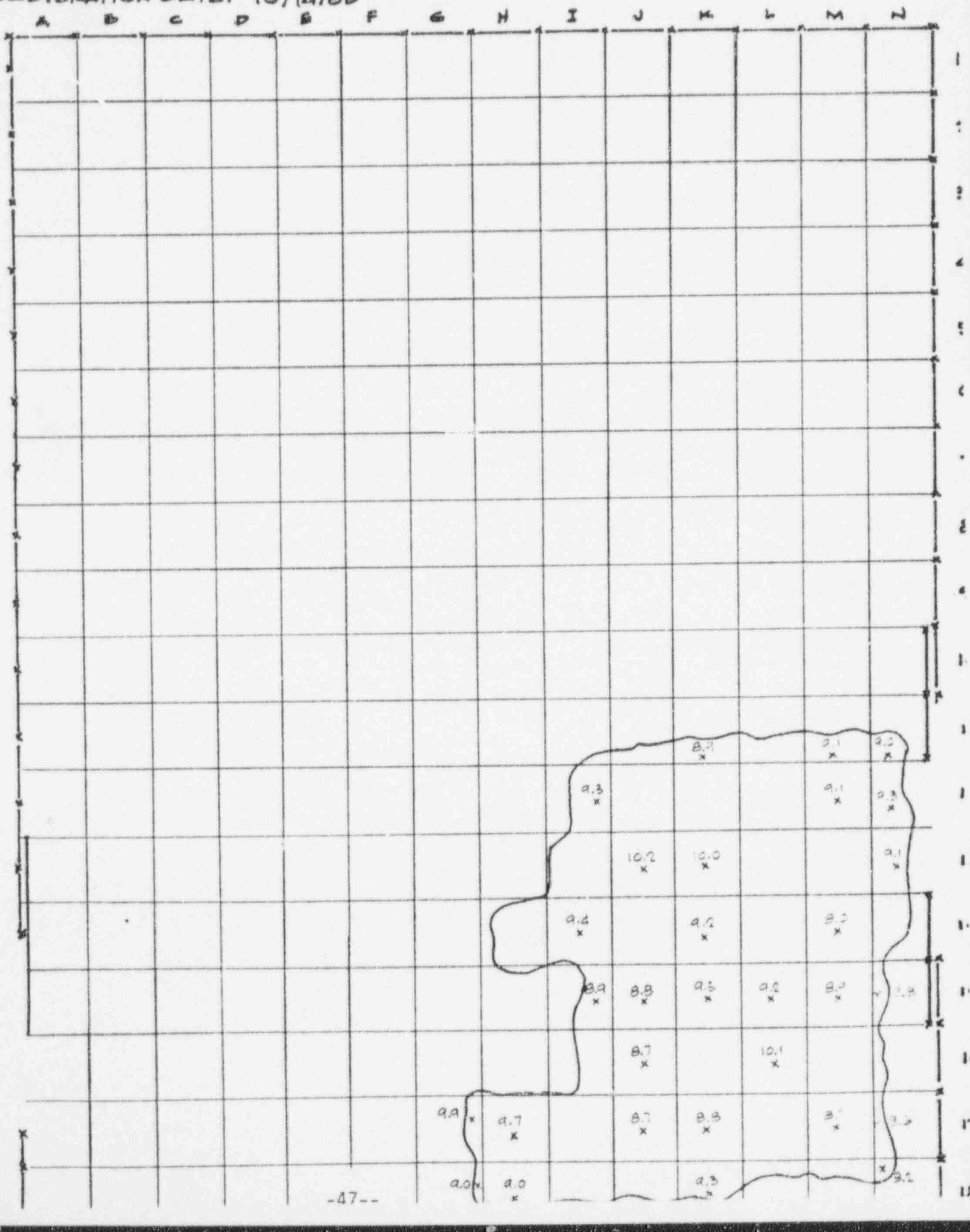


FIGURE 11

JOHNSON PROPERTY
STORAGE YARD A-5
DATE: 13 MARCH 1986
TIME: 08:50

SURFACE SURVEY

SURVEY BY:
METER USED: LUDLUM MOD 19 μR, SN 37438
CALIBRATION DATE: 10/14/85



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