Nuclear

GPU Nuclear Corporation
Post Office Box 480
Route 441 South
Middletown, Pennsylvania 17057-0191
717 944-7621
TELEX 84-2386
Writer's Direct Dial Number:

(717) 948-8400

January 17, 1990
4410-89-L-0130/0517P

US Nuclear Regulatory Commission
Washington, DC 20555

Attention: Document Control Desk

Three Mile Island Nuclear Station, Unit 2 (TMI-2)
Operating License No. DPR-73
Docket No. 50-320
Additional Information on the Defueling Completion Report

Dear Sirs:

Attached is GPU Nuclear's response to your request for additional information dated December 12, 1989. In this submittal, we are responding to those questions related to the Defueling Completion Report; responses to those questions relating to the Post-Defueling Monitored Storage Safety Analysis Report will be forthcoming.

Sincerely,

M B Roche
M. B. Roche
Director, TMI-2

EDS/emf

Attachment

cc: W. T. Russell - Regional Administrator, Region I
J. F. Stolz - Director, Plant Directorate I-4
L. H. Thonus - Project Manager, TMI Site
F. I. Young - Senior Resident Inspector, TMI

A001 1/1

RESPONSES TO USNRC REQUEST FOR ADDITIONAL INFORMATION, DATED DECEMBER 12, 1989

DEFUELING COMPLETION REPORT AND RELATED REFERENCES

Makeup Pump 1A, Engineering Calculation 4550-3211-87-027

QUESTION 1:

Elaborate on the use of the compensation factor "S" that allowed for the effect of the lead shield around the NaI crystal. Was the value verified through measurement?

RESPONSE:

The method used to determine the amount of UO_2 in tanks, pipes, or housings is indirect. Ce-144 activity formed by fission is related to the fuel quantity that produced the Ce-144. Similar chemistry ensures that fuel debris contains a commensurate amount of Ce-144, which was, in turn, measured by gamma ray spectrometers. Sodium iodide detectors were used to resolve the 2185 keV maximum energy gamma ray from Pr-144, the daughter of Ce-144.

Fuel determinations were performed as follows. First, sufficient detector shielding was used to limit dead time to 1-10%. Second, measurements were made at a number of locations designed to couple to expected fuel deposition in pipes, tanks, or other housings. Third, the energy and efficiency calibrations were performed with a standard point source (i.e., Ce-144). Finally, the conversions of data to Ce-144 activity were made as follows:

A. The unshielded sodium iodide crystal efficiency was determined by comparing the observed emission rate, corrected for the detector shield, to the known source emission rate. The correction for shielding was the "S" factor:

$S = \exp(x\mu)$ where:
x = counter shield thickness
μ = linear attenuation coefficient

B. Microshield™, ISOSHLD™, or QAD™ calculations were used to transport the 2185 keV gamma rays from an assumed distribution and amount of fuel through the walls of the pipes, tanks, or housings, across the air gap, and through the detector shield to the crystal. The calculated results were compared to the measured response. The ratios of measured to calculated were used to correct the assumed amount of fuel for the actual measurements.

The technique of determining the unshielded detector efficiency simplifies transport of the gamma rays from the actual geometry to the detector crystal. Further, this allows the calibrations to be made under conditions of the measurements which require the shield.

Makeup Pump 1A, Engineering Calculation 4550-3211-87-027

QUESTION 2:

(Page 7 of 97, paragraph 4.12.3) Provide the basis for using only half of the available count to determine the count in the photopeak of Ce-144. Indicate if a similar method of analysis was used for measurements made with the HPGe detector.

RESPONSE:

Figure 1 is a graphical depiction of data representing the last calibration measurement made in makeup pump room 'A'. The data was accumulated over more than 60 hours and clearly shows that the 2185 keV gamma ray peak from Pr-144 is the highest energy peak observed. Referring to Figure 1, the upper and lower shoulders of the peak are not equal. This is normal for sodium iodide detectors since the lower shoulder includes the Compton continuum. Clearly, the signal to background ratio of the upper energy shoulder is superior and, therefore, a more sensitive means of determining activities that approach background.

Employing the upper half peak for the highest energy transition is a standard technique for simple spectra that do not require computer unfolding. This is certainly the case for makeup pump room 'A'. Efficiency calibrations were treated the same way with the region of interest set for the upper half peak. HPGe detectors have much better energy resolution than sodium iodide detectors. Therefore, the upper half peak technique would not be used with high resolution spectrometry.

Makeup Pump 1A, Engineering Calculation 4550-3211-87-027

QUESTION 3:

(Page 64 of 97) Explain the basis for using a non-standard technique for calculation of the background correction rather than using the method described in Knoll (1979) p. 347 (Figure 10-24).

RESPONSE:

The general background correction method described in KNOLL (1979) p. 347 (see Figure 2) is standard and a form is built into most modern multichannel analyzer operating systems. This method works well if peaks are present but can produce rapidly changing and even negative values for spectra near background. The reason is relatively large counting uncertainty for the 'A' and 'B' values needed to define background according to KNOLL. Other methods average three channel results around the 'A' and 'B' points to improve results. The technique defined on page 64 of Calculation 4550-3211-87-027 improves on KNOLL's method as follows: A second region of interest (ROI) is taken above the 2185 keV peak. This second ROI is adjusted for the same energy width as the 2185 keV ROI. All data points in the region are used to produce the best linear fit by regression. The equation is used to calculate the 'A' and 'B' values to determine the "best" background value. The technique is outlined in Figure 3.

The two important properties of this technique are:

A. The regressed slope and intercept are much less uncertain than the single raw 'A' and 'B' values.

B. Extending the equation to the 2185 keV ROI will tend toward slightly lower slope which will tend to produce slightly higher net events. KNOLL's defines this as the peak area.

The first property improves the precision and the second property increases the reported fuel quantity over simpler, more uncertain methods.

Makeup Tank, Engineering Calculation 4550-3211-87-036

QUESTION 4:

Elaborate on the selection of geometries used to determine the maximum amount of fuel present when no signal was detected.

RESPONSE:

As shown in Table 1, all ten spectral determinations made in the makeup tank room were positive. The analysis method employed here and in general transports gamma rays to measurement locations from all pipes, tanks, and housings in the room, hereafter termed deposit regions. The measurement locations match places where uncollimated spectra determinations were made.

As discussed in the response to Question #1, an assumed value of fuel for each deposit region was adjusted to correspond to the entire measured gamma fluence rate. This provides independent fuel estimates for the nine pipe and one tank deposit regions for the first measurement location. This is repeated for all measurement locations; the results for the makeup tank calculation are shown in Table 2.

Selection of the minimum value for each of the ten deposit regions will overstate the amount of fuel present. This is because the measured gamma fluence from each location is assumed to be due to deposits in only that region, whereas it is actually from all deposit regions. The lowest value is always produced by a close measurement location or a place where shielding is minimum between assumed deposit point and measurement location. This conservative method was adopted because, frequently, fewer measurement locations were used than obvious deposit locations. Simultaneous solution of an underspecified set of equations is possible but not performed here.

PLANNING STUDY INSTRUMENT SELECTION FOR RESIDUAL FUEL MEASUREMENTS

QUESTION 5:

(Appendix C, paragraph C.1, #4) When alpha counting the bare RCS surfaces, was the film diluent factor applied to both the maximum and minimum calculations and how was this factor derived?

RESPONSE:

The film diluent factor was used to account for possible absorption of alpha particles by corrosion film material that is not related to UO_2. The factor was derived by comparing results of the alpha probe measurements to radiochemical analysis of scraping from the same area. Since then, an independent series of measurements were made which supercede the use of the film diluent factor. An average fuel density thickness of approximately 0.7 $\mu g/cm^2$ (Reference 1) was measured for inconel surfaces. The measurement on inconel covered approximately 100 times more surface area than the determination on stainless steel referenced in the planning study.

QUESTION 6:

(Appendix C) What is the area of the alpha counter. Was the effect of dead time considered in the calculations?

RESPONSE:

An Eberline PAC-6 was used to make the measurements referenced in the planning study. The sensitive area of the detector was approximately 60 cm^2.

Counting systems used for film assays were adjusted to be totally insensitive to Sr/Y-90 beta fields of approximately 1000 Rad/hr while maintaining alpha efficiencies of approximately 30% determined with a point Am-241 test source.

Dead time was never a significant concern and was less than 1% for nearly all measurements. This can be verified by a process of estimation. The ORIGEN computer analysis (Reference 2) predicts 7 alpha particles per second per square centimeter for a fuel film density thickness of one microgram per square centimeter. Assuming an efficiency of 33%, the calculated count rate at 1.0 $\mu g/cm^2$ film is:

$$\text{Count Rate} = \frac{7\,\alpha}{cm^2 s} \times 60\ cm^2 \times \frac{c}{3\,\alpha} = 140\ \text{CPS}$$

One microsecond is a reasonable pulse width produced by the proportional counter detector assembly. Therefore, approximately 10,000 CPS would be required for 1% dead time; a counting rate seldom if ever equaled . The largest film thickness measured on a steam generator access plate was approximately 50 $\mu g/cm^2$ for a count rate of 7000 CPS.

QUESTION 7:

(Appendix C, paragraph C.4.1, assumption 3) Elaborate on Assumption number 3 for the Germanium Detector (C.4.1) that the collimated detector is insensitive to distance from the line source (Flux = approx 2 π RL).

RESPONSE:

Assumption 3 of Paragraph C.4.1 is incomplete. The expression for uncollided gamma fluence in air is:

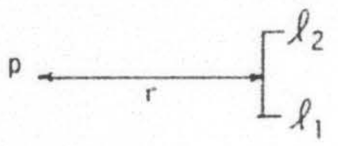
$$\phi\gamma(p) = \frac{S}{4\pi\, r\, \ell}\left[\tan^{-1}\frac{\ell_2}{r} + \tan^{-1}\frac{\ell_1}{r}\right] \quad \text{(Reference 3)}$$

where:

$\phi\gamma(p)$ = gamma fluence of point p

$S = \gamma/s$

$\ell = \ell_1 + \ell_2$



If $\ell_1 = \ell_2$, then:

$$\phi\gamma(p) = \frac{S}{2\pi\, r\, \ell}\left[\tan^{-1}\frac{\ell}{2r}\right]$$

The planning study was primarily a statement of intention prior to the practice of measurement. The actual determinations of fuel content always accounted for absorption thereby requiring a correct and more complete statement of gamma fluence transport. In any event, the assumption and incorrectly stated approximation was never used.

POST-DEFUELING SURVEY REPORT - REACTOR BUILDING BASEMENT

QUESTION 8:

(Pages 4 and 5) Provide additional details regarding the geometry and the detector calibration for the gamma spectrometry measurements used to estimate 1.2 kg of fuel in the reactor coolant drain tank (RCDT) discharge area.

RESPONSE:

Additional information regarding measurement geometry and detector calibration are included in Appendix A.

QUESTION 9:

(Page 6) Indicate the location of the drain system that runs from the tool decontamination facility on the 347-ft elevation to the reactor building basement. Indicate the basis for the assumption that the fuel particles from the tool decontamination facility would have been washed into the reactor building basement sump. Provide the basis for the unstated assumption that additional fuel has not been added since the completion of the PDSR and is currently not being added to the inventory of the reactor building basement, as a result of the continued decontamination of tools on the 347-ft elevation.

RESPONSE:

The Reactor Building basement boundary was taken to include all space below the 305' elevation with one partial exception. The exception is the Reactor Building drain line that was used to transfer defueling tool decontamination wash water to the basement. As stated in the Post-Defueling Survey Report (PDSR) for the Reactor Building basement, a separate PDSR will be issued for this drain line when the decontamination effort is concluded and final drain measurements can be made. Interim measurements will be used to define the fuel content of this special drain line for the purposes of the Defueling Completion Report.

The discharge path from the tool decontamination enclosure located on the 347' elevation of the RV is from the decon sink to a floor drain located within the decon enclosure. The discharge piping, from the floor drain, passes through the 347' elevation floor, turns nearly horizontal for about ten feet and then is essentially vertical for about 55 feet to a long horizontal run under the 282' elevation basement floor. The pipe traverses from south to the north RB sump under the floor. More than a dozen basement floor drains empty into the line.

To suppress airborne contamination, the basement floor has been maintained under a few inches of water. Discharges from the decon sink, typically about 200 gallons, effectively flush clean the upper short horizontal section below the 347' elevation floor. However, the flooded lower section, assisted by pressure relief from the basement floor drains, acts as a hydraulic buffer to reduce the linear velocity of the discharge. Settlement of dense fuel particles is expected a few feet downstream of the start of the horizontal run.

Since the deposit location is not accessible for direct fuel assay, special means were employed. Small gamma detectors, strapped to a drain snake, were used to determine the intensity of a significant part of the horizontal pipe run under the basement floor. Results show an intensity increase that corresponded to the expected region of debris deposit.

The measurements were modeled for three reasonable orientations of the detector, snake, and debris. The first placed the detector directly "on" a thin layer of debris. The second is similar to the first except that the layer of debris is thicker. The last model considered the detector to be displaced to one side with the steel snake shielding the detector. These models provide total UO_2 deposits of 0.27, 0.48, and 5.1 kg, respectively. Therefore, the UO_2 deposit of record is 5.1 kg $\pm$ 100%.

The last paragraph on page 6 of the Reactor Building Basement PDSR states that the basement fuel content is expected to remain static. As discussed above, the basement fuel content does not include the RB drain line which serves as a hydraulic buffer between the decon enclosure and the RB basement. This effectively precludes the addition of residual fuel to the basement as a result of tool decontamination. Therefore, an insignificant amount of fuel has been added to the RB basement since the completion of the PDSR.

REFERENCES:

1. B. H. Brosey. Uranium Film Quantity and Alpha Probe Efficiency. Engineering Calculation 4530-3224-89-009, Rev. 0. Middletown, PA: GPU Nuclear Corporation.

2. R. E. Lancaster. LCSA Grid Rib Section C-1 Analysis. Engineering Calculation 4530-3227-88-025, Rev. 0. Middletown, PA: GPU Nuclear Corporation.

3. J. R. Lamarsh. Introduction to Nuclear Engineering. Reading, PA: Addison-Wesley Publications. 1975.

TABLE 1

TABLE 5.13
MEASURED PHOTON FLUX

MEASURED PHOTON FLUX(GAMMAS/CM^2-S)=(GROSS -BACKGROUND COUNTS)/
/(COUNT TIME(S) X DETECTOR EFFICIENCY(COUNTS-CM^2/GAMMA))

	GROSS COUNTS	BACKGROUND COUNTS	COUNT TIME	DETECTOR EFFICIENCY	MEASURED FLUX
LOCATION 1	17540	5651.9615	231000	0.00440	11.7038
LOCATION 2	3309	1095.9231	80400	0.00440	6.2599
LOCATION 3	1889	495.0769	86400	0.00440	3.6691
LOCATION 4	1747	578.7115	136800	0.00440	1.9422
LOCATION 5	441	145.7308	86400	0.00440	0.7772
LOCATION 6	1480	522.6538	257100	0.00440	0.8468
LOCATION 7	695	204.2692	86400	0.00440	1.2917
LOCATION 8	12000	4087.0385	228600	0.00440	7.8721
LOCATION 9	309	90.4231	86400	0.00440	0.5753
LOCATION 10	588	239.0769	80400	0.00440	0.9870

TABLE 2
Sheet 1 of 2

TABLE 5.15
AX116 FUEL CALCULATION SUMMARY
(ALL VALUES IN GRAMS)

	LOCATION 1	LOCATION 2	LOCATION 3	LOCATION 4	LOCATION 5
LINE 1	47.17	25.2316	625.92	99.72	95.49
LINE 2	709.01	14.3066	270.88	48.93	118.65
LINE 3	979.08	172.9010	570.46	7.16	53.20
LINE 4	159.12	42.8543	12.27	60.39	70.86
LINE 5	528.87	152.4519	25.88	19.21	70.79
LINE 6	971.35	602.4739	753.43	13.37	47.18
LINE 7	25844.71	3536.8118	25166.39	1007.47	434.31
LINE 8	22473.09	14173.0039	86479.69	2885.09	1447.22
LINE 9	1081.19	936.5731	203.45	47.01	15.97
TANK	494.63	618.8577	360.12	312.25	190.33
TOTAL	232.09	66.6814	87.63	25.54	81.62

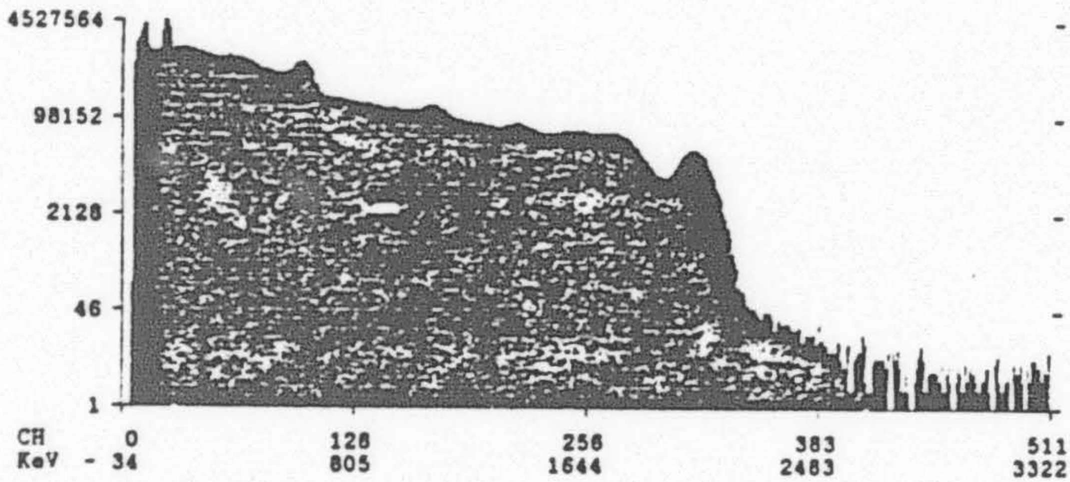
TABLE 2 (Continued)
Sheet 2 of 2

TABLE 5.15 (CONT)
AX116 FUEL CALCULATION SUMMARY
(ALL VALUES IN GRAMS)

	LOCATION 6	LOCATION 7	LOCATION 8	LOCATION 9	LOCATION 10	MINIMUM FUEL
LINE 1	67.45	151.23	1303.58	1284.09	124.77	25.23
LINE 2	302.79	505.36	6563.07	331.72	13.33	13.33
LINE 3	260.51	424.62	9461.81	311.18	70.10	7.16
LINE 4	184.29	193.79	1777.60	827.25	64.12	12.27
LINE 5	205.82	298.83	5004.01	277.42	93.47	19.21
LINE 6	315.31	460.23	14044.08	235.28	61.88	13.37
LINE 7	2245.17	3148.00	214932.19	5.24	608.01	5.24
LINE 8	4745.08	7230.04	190858.10	6.83	1574.66	6.83
LINE 9	293.49	317.08	10496.90	198.64	143.38	15.07
TANK	207.38	316.33	644.47	309.09	271.44	100.33
TOTAL	213.26	355.45	2704.76	23.39	74.20	

FIGURE 1

FILE 16 NOW IN MEMORY



AX007 CALOUT 4000M 7-20-87

ROI# 1 314 338 I= 2722420522
ROI# 2 339 363 I= 1422038

10:55 08/04/87 ID=3 -73 ACQ AT 15:09:59 07/16/87
LIVE TIME=4000 M REAL TIME=4028 M MEMORY= 5 OF 8 B

ROI#	BEG	END	MAX	ENERGY(KEV)	INTEGRAL	AREA	UNCERTAINTY
1	314	338	314	2028.08	272242	*****	*****

CH 314	27349	26873	26258	25160	23391	21863	19740	17789
CH 322	15541	13422	11507	9352	7896	6343	4983	3911
CH 330	3079	2245	1682	1262	890	660	460	336
CH 338	250							

ROI#	BEG	END	MAX	ENERGY(KEV)	INTEGRAL	AREA	UNCERTAINTY
2	339	363	339	2192.27	1422	*****	*****

CH 339	160	150	117	106	80	57	58	49
CH 347	50	57	42	40	35	44	33	51
CH 355	44	42	34	30	22	33	29	33
CH 363	26							

hotofraction relative to a sodium iodide crystal of the
de exhibits both a higher efficiency and a greater
mewhat lower light output (see Chapter 8) leads to a
. Gamma ray detection efficiency for NE-213 organic
iven in Refs. 33 and 34, and for lead-doped plastic

MINATION

k efficiency data for any detector, the area under the
pear in its spectrum must be determined. Even after
l background, nearly all such peaks will be superim-
aused by many of the complicating effects described
is therefore not always a simple task to determine the
ntribute to a given full-energy peak.
ple isolated one without any superimposed continuum,
, its area could be determined by simple integration
n. When the spectrum is recorded in a multichannel
process is a simple addition of the content of each
icated limits. If a continuum is also present, as in Fig.
unwanted counts are included in this process, and must
e must therefore be assumed for the continuum within
, and a number of fitting procedures of varying degrees
pplied. A linear interpolation between the continuum
he peak is the easiest approach and will give sufficient
ses.
d or overlapping peaks do not allow the straightforward
applied. More complex methods must then be used to
contributions of each of the closely lying peaks. These
e fitting an analytic shape to that portion of the peak
olved, and assuming that the remainder of the peak is
function. It has been demonstrated[36] that a Gaussian
that lie within one standard deviation on either side of
ly represents the shape of the measured photopeak from
ver an assortment of source geometry and counting
ex shapes are sometimes necessary for spectra recorded
nideal circumstances. Because a good deal of complex-
fitting routines, nearly all are carried out by computer
cribed in further detail in Chapter 18.

ROSCOPY WITH SCINTILLATORS

applied to the measurement of fast electrons (such as
incident on one surface of the crystal. Although it has
to use lithium-drifted silicon detectors for this purpose

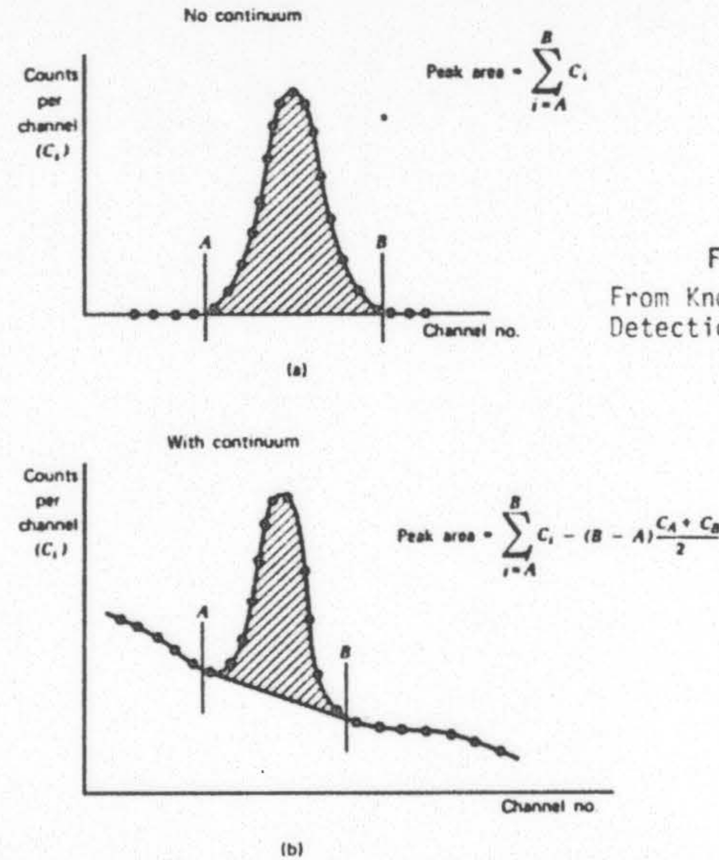


FIGURE 10-24. Methods of obtaining peak areas from multichannel spectra.

FIGURE 2

From Knoll,G.F., Radiation Detection and Measurement,1979.

(see Chapter 13), applications sometimes arise in which the size limitation of silicon detectors or other considerations dictate the use of scintillators.

The nature of the electron response function depends on the scintillation material, its physical thickness, and the angle of incidence of the electrons. Electrons from an external source normally must pass through some protective covering and/or light reflector before reaching the surface of the scintillator itself. In the discussion that follows, the energy loss that may occur in these intervening materials is not explicitly considered, but may be important if the electron energy is small. We will also assume that the scintillators under consideration are thicker than the maximum range of the incident electrons. Even so, the detector may not be totally opaque to the secondary bremsstrahlung photons which will be generated along the path of the electron.

FIGURE 3 - HP-10C OWNERS HANDBOOK REV. B 1982 HEWLETT-PACKARD CO.

Linear Regression

Linear regression is a statistical method for finding a straight line that best fits a set of two or more data pairs, thus providing a relationship between two variables. After the statistics of a group of data pairs have been accumulated in registers R_0 through R_5, you can calculate the coefficients in the linear equation $y = Ax + B$ using the least squares method by pressing [f][L.R.].

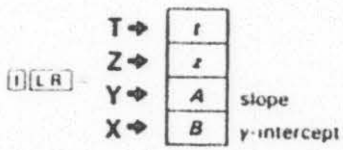
To use the linear regression function on your HP-10C, use the [Σ+] key to accumulate the statistics of a series of two or more data pairs. Then execute [L.R.]. When you press [f][L.R.]:

1. The contents of the stack registers are lifted as they are when you press [f][x̄], as described on page 47.

2. The slope (A) and the y-intercept (B) of the least squares line of the data are calculated using the equations:

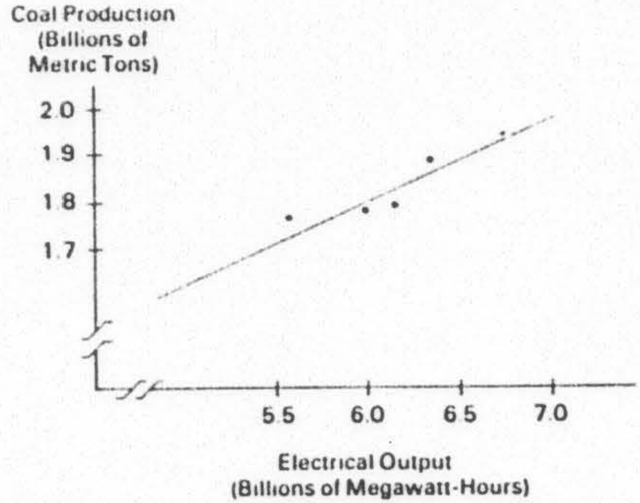
$$A = \frac{n\Sigma xy - \Sigma x \Sigma y}{n\Sigma x^2 - (\Sigma x)^2} \qquad B = \frac{\Sigma y \Sigma x^2 - \Sigma x \Sigma xy}{n\Sigma x^2 - (\Sigma x)^2}$$

The slope A is placed in the Y-register; the y-intercept, B, is placed in display (X-register).



Example: Calculate the y-intercept and slope of Voltz's corrected data.

Solution: Voltz *could* draw a plot of coal production against electrical output like the one shown below. However, with her HP-10C, Voltz has only to accumulate the statistics (as we have already done) using the [Σ+] key, then press [f][L.R.].



Keystrokes	Display	
[f][L.R.]	0.777	y-intercept of the line.
[x⇄y]	0.172	Slope of the line.

Retain these statistics in your calculator for use in the next example.

Linear Estimation and Correlation Coefficient

When you execute the [ŷ,r] or [x̂,r] function, the *linear estimate* ($\hat{y}$ or $\hat{x}$) is placed in the X-register, and the *correlation coefficient* (r) is placed in the Y-register.

Linear Estimation. With statistics accumulated in registers R_0 through R_5, a predicted value for y (denoted $\hat{y}$) can be calculated by keying in a known value for x and pressing [f][ŷ,r]. Similarly, a predicted value for x (denoted $\hat{x}$) can be calculated by keying in a known value for y and pressing [f][x̂,r].

GPU Nuclear **Calculation Sheet**

Subject	Calc. No.	Rev No.	Sheet No
FUEL CHARACTERIZATION ON BASEMENT FLOOR IN DISCHARGE PATH OF RCDT.	4550-3572-85-016	0	1 of 4

PURPOSE: TO DETERMINE THE QUANTITY OF FUEL Deposited ON THE REACTOR BUILDING BASEMENT FLOOR.

METHOD: SCAN A FLOOR AREA OF ABOUT 500 ft^2 centered on the REACTOR COOLANT DRAIN TANK OVERFLOW DISCHARGE PATH SPLASH DOWN. EMPLOY A NaI SPECTROMETRY SYSTEM TO DISCRIMINATE AGAINST NON Ce/Pr-144 CONTAINING ACTIVITY.

SUMMARY: 1.2 ± .3 kgrams of UO_2 ARE DEPOSITED ON THE BASEMENT FLOOR WITHIN THE VIEW OF THE TUNSTEN SHIELDED SPECT.

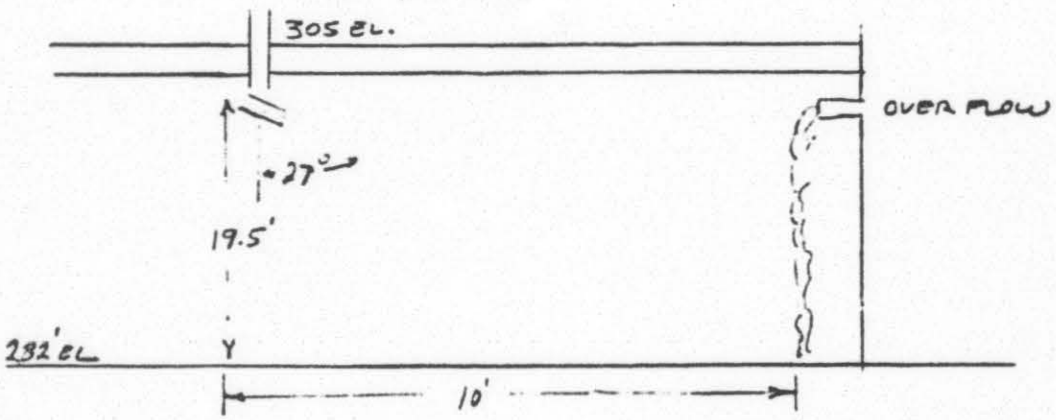
REFERENCES.

- REACTOR SHIELDING DESIGN MANUAL, 1st ED T. ROCKWELL, USAEC
- TECH PLAN. BULLETIN 85-5

Subject	Calc. No.	Rev No.	Sheet No.
	4550-3572-85-016	0	2 of 4

1

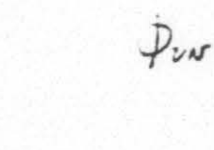
DATA: 75 EVENTS (24 BACKGROUND EVENTS) WERE MEASURED IN 2660 SECONDS AS FOLLOWS:



ASSUME:
- ACTIVITY WITHIN 10' RADIUS
- H_2O DEPTH = 0.3'
- OFF-CENTER DISC SOURCE GEOMETRY
- BAS'S 1 KG UO_2 IN FIELD OF VIEW

$$\Phi_{UN} = \frac{S_A}{2}\left[E_1(b_1) - E_1(b_1 \sec\theta)\right] k$$

where k is off center correction via Rockwell



$\theta = \tan^{-1}\frac{10}{19.5} = 27°$

b_1: Tungsten 3/4"

$\mu/\rho = .043$ for 2.2 MeV

$\rho = 18$ g/cc ∴ $\mu = .043 \times 18 = .77$

$\mu l = .77 \times .75 \times 2.54 = 1.48$

Subject	Calc. No.	Rev No	Sheet No
	4550-3572-85-016	0	3 of 4

b. for H_2O

$\mu/\rho = .0475$; $\mu = .0475$

$\mu R = .0475 \times 12'' \times .3' \times 2.54 = 0.434$

$b_1 = 1.52 + .43 = 1.95$

FROM TABLES

$E_1(b) = 5.4E-2$

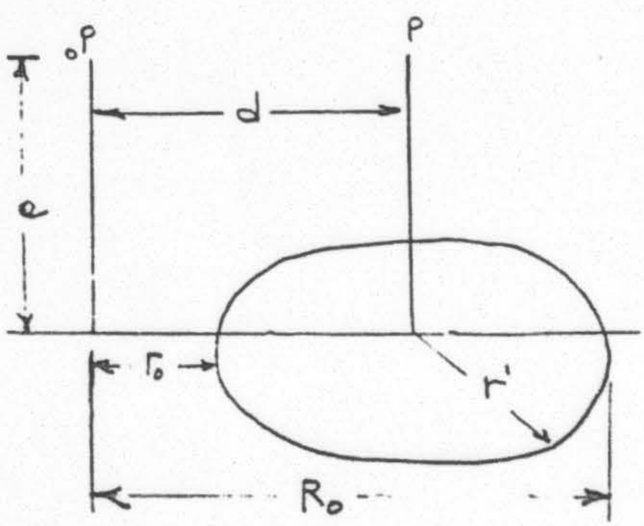
$E_1(b \cdot \sec\theta) = E(1.95 \times \sec 27°) = 3.85E-2$

$$_0\Phi_{UN} = \frac{SA}{2}\left[(5.4 - 3.85) \times 10^{-2}\right]$$

$$S_A = 1\,kg \times \frac{1.6\,Ci}{kg} \times \frac{3.7 \times 10^{10}\,d}{s\,Ci} \times \frac{.007\,\gamma}{d} \times \frac{1}{\pi(10' \times 12'' \times 2.54)^2}$$

$$S_A = \frac{1420\,\gamma}{cm^2 s}$$

$$_0\Phi_{UN} = 11.0\ \gamma/cm^2 s$$



OF = CENTER CORRECTION

$d/R_0 = \frac{12}{10} = 1.2$

$a/R_0 = \frac{19}{10} = 1.9$

$\bar{\mu} = \frac{\Sigma \mu_i t_i}{\Sigma t_i} = .0475$

$\bar{\mu} R_0 = .0475 \times 10' \times 12'' \times 2.54 cm = 14.5$

Subject	Calc. No.	Rev No.	Sheet No
	4550-3572-85-016	0	4 of 4

FOR $\frac{a}{R_0} = 1$ $k = .2$

$\frac{a}{R_0} = 3$ $k = .275$

$\therefore$ for $\frac{a}{R_0} = 2$; $k = .24$

$\phi = \phi_0 k = 11.0 \times .24 = 2.6\ \gamma/s\,cm^2$

ASSUME DETECTOR $A_{eff} = 1.27\,cm^2$

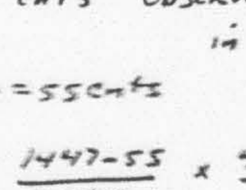
$\therefore$ Projected EVENTS $= 2.6 \times .005 \frac{cnts}{\gamma} \times 1.27 \times 2660\,s$

$= 44$ EVENTS (See CALIB.)

MEASURED EVENTS $= 75 - 24 = 51$ cnts

$\therefore$ FUEL $= \frac{51 \pm 14}{44} \times 1\,KG = 1.2 \pm .3$

CALIBRATION:



SOURCE Co-60
3.2 mCi 10/1/84
2.5 mCi 2/1/84
$t_{1/2}$ = 284.4 days

1447 cnts OBSERVED IN 4840 Sec
in upper 1/2 peak ℄ 1.2 MeV; Σch=26

BKG = 55 cnts

$$Eff = \frac{1447-55}{4840} \times \frac{4\pi(6 \times 2.54)^2}{1.27\,cm^2} \times \frac{1}{2.5 \times 3.7 \times 10^7 \times .007\,\gamma/d}$$

$$Eff = 1.03 \times 10^{-3} \times e^{1.52} = .0047 \pm .0001$$