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A COMPUTER PROGRAM FOR MATHEMATICAL
EVALUATION OF THE ROCKY FLATS NUCLEAR
ACCIDENT DOSIMETRY SYSTEM

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ACCIDENT DOSIMETRY SYSTEM**

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SUBJECT DESCRIPTORS

Personnel Dosimetry
Radiation Detection

**ROCKWELL INTERNATIONAL
ATOMICS INTERNATIONAL DIVISION
ROCKY FLATS PLANT
P. O. BOX 464
GOLDEN, COLORADO 80401**

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D. E. Hankins. *A Study of Selected Criticality Dosimetry Systems*. LA-3910, UC-41 Health and Safety. Los Alamos Scientific Laboratory, Los Alamos, New Mexico. June 14, 1968. John Mann, Roger Falk, and E. A. Putzier. "Rocky Flats Nuclear Emergency Procedure Manual." Rockwell International, Golden, Colorado. (Sixth revision) April 1973. M. R. Boss, Environmental Control, Rockwell International, Golden, Colorado.

A COMPUTER PROGRAM FOR MATHEMATICAL EVALUATION OF THE ROCKY FLATS NUCLEAR ACCIDENT DOSIMETRY SYSTEM

Charles B. Wood

Abstract. A computer program has been developed to facilitate the evaluation of the Rocky Flats Emergency Dosimetry System. This program evaluates data to determine the neutron fluence associated with a criticality accident. It is necessary to obtain information about the critical system for personnel dose estimates. Information pertaining to the geometry and position of the critical material and orientation of personnel, with respect to the material, is essential to supplement the calculations contained in this program.

DISCUSSION

The Rocky Flats Emergency Dosimetry System presently in use is contained in the personnel identification badge and consists of the following detection devices:

- a. A sulfur tablet to measure neutron fluence with energy greater than 2.9 MeV.
- b. A copper foil to measure neutron fluence to 1 MeV.
- c. A single indium foil and a cadmium (Cd) shielded indium foil to measure neutron fluence in the thermal and epithermal energy range, as well as to determine the 1 to 2.9-MeV range.

In addition to the badge system, emergency procedures require that a blood and hair sample be taken from suspected radiation cases. This measurement serves as a check on total neutron dose. A data sheet, entitled "Personnel Dosimeter Data," see Appendix, is used to record instrument readings. These forms are available at the emergency equipment station.

The program is written in Data General "basic" language and will run on any NOVA computer with sufficient memory to accept the Data General Basic compiler. It is available as a paper tape input; a cartridge disc copy was prepared for the Rocky Flats body counter disc operating system.

The program is designed to request input data from the operator in an ordered sequence. The operator responds to the first part of the program by choosing the foil type he wishes to evaluate, then entering data via the keyboard. The data entry is accomplished by a carriage return after each data value. This action results in another data request or a printout of the results obtained from the calculation.

The following equations are used by the program to calculate neutron flux for each foil:

Bare Indium:

$$t = 1.25 \times \frac{N_r}{MG \gamma (e^{-\Delta T_1} - e^{-\Delta T_2})}$$

Cd Shielded Indium:

$$t = .091 \times \frac{N_r}{MG \gamma (e^{-\Delta T_1} - e^{-\Delta T_2})}$$

Copper:

$$t = 555 \times \frac{N_r}{MG \gamma (e^{-\Delta T_1} - e^{-\Delta T_2})}$$

Scin. Indium:

$$t = 102 \times \frac{N_r}{MG \gamma (e^{-\Delta T_1} - e^{-\Delta T_2})}$$

Sulfur:

$$t = 353 \times \frac{N_r}{MG \gamma (e^{-\Delta T_1} - e^{-\Delta T_2})}$$

Where: t = Neutron Flux
 N_r = Total Counts Observed
 M = Foil Weight (grams)
 G = Detector Geometry
 Λ = Decay Constant of the Product Isotope
 T_1 = Elapsed Time from Exposure to Counting Time
 T_2 = Elapsed Time from Exposure to Completion of Counting
 γ = Foil Size Correction Factor

Upon completion of the neutron flux calculations, the operator records the results on the Personnel Dosimeter Data sheet.

The second part of the foil calculations requires operator input of the recorded neutron flux. The operator chooses the neutron energy range he wishes to evaluate, and the program requests a flux-reading for the foils used to evaluate that range of energies. The computer output is recorded by the operator, in units of RAD dose, on the Personnel Dosimeter Data sheet. The following equations are used for neutron dose calculations:

- $(\phi T \text{ Bare Indium} - \phi T \text{ Cd-Indium}) \times .32 \times 10^{-9}$
= Thermal Neutron Dose
- $(\phi T \text{ Cd - Indium}) \times .45 \times 10^{-9}$ = Epithermal Neutron Dose
- $(\phi T \text{ Copper Foil}) \times 1.37 \times 10^{-9}$ = 2 ev-1 MeV Neutron Dose
- $(\phi T \text{ Scin. Indium - Sulfur}) \times 4.2 \times 10^{-9}$
= 1 MeV - 2.9 MeV Neutron Dose
- $(\phi T \text{ Sulfur}) \times 5.8 \times 10^{-9}$ = >2.9 MeV Neutron Dose

After completing the Neutron Dose calculations, the operator records the results on the Personnel Dosimeter Data sheet.

The blood sodium calculation may be selected by the operator at the beginning of the program. This may be the only evaluation available if the individual was not wearing a badge. Selecting this part of the program results in a program request for data input. The first part of the program requires a count of a 5-cc blood sample using a well-scintillation counter.

Assuming a typical neutron activation factor for an unmoderated spectrum, the program uses the following calculations:

$$\text{Rad Dose} = .55 \times 10^{-4} \frac{N_r}{GV (e^{-\Lambda T_1} - e^{-\Lambda T_2})}$$

Where: N_r = Total Counts
 G = Geometry Factor
 V = Volume of Sample (5cc)
 T_1 = Elapsed Time from Exposure to Counting (Min)
 T_2 = Counting Time (Min)
 Λ = Decay Constant of the Product Isotope

The second half of the program evaluates the blood sodium count and utilizes a hair sample to obtain a high energy neutron ratio. The program requires an evaluation of a 1-gram hair sample which has been reduced by chemical procedures.

The calculations used for this evaluation are:

- Blood Sodium Activity = pci $^{24}\text{Na}/\text{Mg } ^{23}\text{Na}$

$$= 1.09 \times 10^{-4} \frac{N_r}{GV (e^{-\Lambda T_1} - e^{-\Lambda T_2})}$$
- Hair Sulfur Fluence = $224 \frac{N_r}{RG (e^{-\Lambda T_1} - e^{-\Lambda T_2})}$

where: R = Chemical Recovery Factor

The above calculations are combined by the program to produce a ratio of hair-sulfur fluence to blood sodium activity. This ratio is applied to the graph in Figure 1 to obtain an activation factor.

The activation factor is fed into the computer which, in turn, uses this number to obtain a corrected neutron dose by the following calculation:

$$\text{Rad Dose} = \text{pci } ^{24}\text{Na}/\text{Mg } ^{23}\text{Na} \times \frac{1}{\text{Activation Factor}}$$

This evaluation completes the program utility; however, the program will be expanded to include future additions. An appendix to this report includes reproductions of the Personnel Dosimeter Data Form, flow chart of the program, and line printout of the program.

FIGURE 1. Blood Sodium Activation Factor (By permission of D. E. Hankins, Los Alamos Scientific Laboratory, Los Alamos, New Mexico)

A P P E N D I X
(Pages IA through VIIA)

```

0010 PRINT "DO YOU WISH TO CALCULATE T VALUES FOR (1) FOIL & SULFUR OR (
2) BLOOD"
0020 INPUT Q2
0030 IF Q2=2 THEN GOTO 1020
0040 LET T=0
0050 PRINT "INPUT THE MASS OF THE FOIL"
0060 INPUT M
0070 PRINT "INPUT DECAY TIME IN MIN,T1"
0080 INPUT T1
0090 PRINT "IS THE COUNTING TIME 1000 SEC?,YES(1),NO(0)"
0100 INPUT Q3
0110 IF Q3=0 THEN GOTO 0140
0120 LET T2=1000/60
0130 GOTO 0160
0140 PRINT "INPUT COUNTING TIME IN MIN,(T2)"
0150 INPUT T2
0160 LET T2=T1+T2
0170 PRINT "INPUT THE COUNTER BACKGROUND"
0180 INPUT B
0190 PRINT "INPUT THE NUMBER OF COUNTS"
0200 INPUT N
0210 LET N=N-B
0220 PRINT "INPUT THE GEOM FACTOR"
0230 INPUT G
0240 PRINT "INPUT THE FOIL TYPE; (1) BARE IND,(2) CAD SHIELD IND,(3) COP
PER"
0250 PRINT "(4) SCIN IND,(5) SULFUR"
0260 INPUT F
0270 IF F=1 THEN GOTO 0320
0280 IF F=2 THEN GOTO 0360
0290 IF F=3 THEN GOTO 0400
0300 IF F=4 THEN GOTO 0440
0310 IF F=5 THEN GOTO 0480
0320 LET K=1.25

```

```
0330 LET B1=1.1
0340 LET L=.0128
0350 GOTO 0520
0360 LET K=.091
0370 LET B1=.83
0380 LET L=.0128
0390 GOTO 0520
0400 LET K=555
0410 LET B1=1
0420 LET L=.0009
0430 GOTO 0520
0440 LET K=102
0450 LET B1=1
0460 LET L=.00256
0470 GOTO 0520
0480 LET K=353
0490 LET B1=1
0500 LET L=3.36E-05
0510 GOTO 0520
0520 LET C=(EXP(-L*T1))-(EXP(-L*T2))
0530 PRINT "C=";C
0540 PRINT "N";N
0550 PRINT "M";M
0560 PRINT "G";G
0570 PRINT "K";K
0580 LET Z=M*G*C*B1
0590 LET T=K*N/Z
0600 PRINT "THE FLUX FOR THIS FOIL=";T
0610 PRINT "DO YOU DESIRE THE DATA FOR (1).025-.4EU,(2).4-1.4EU,(3)2EU-1
MEU"
0620 PRINT ",(4) 1MEU-2.9MEU,(5) >2.9MEU ?"
0630 INPUT P
0640 IF P=1 THEN GOTO 0690
0650 IF P=2 THEN GOTO 0780
0660 IF P=3 THEN GOTO 0830
```

```

0670 IF P=4 THEN GOTO 0880
0680 IF P=5 THEN GOTO 0950
0690 PRINT "INPUT T FOR BARE IND"
0700 LET T1=0
0710 INPUT T1
0720 PRINT "INPUT T FOR CD-IND"
0730 LET T2=0
0740 INPUT T2
0750 LET D=3.2E-10*(T1-T2)
0760 PRINT "RANGE (1)=";D
0770 GOTO 0990
0780 PRINT " INPUT T FOR CD-IND"
0790 INPUT T3
0800 LET D=4.5E-10*(T3)
0810 PRINT "RANGE (2)=";D
0820 GOTO 0990
0830 PRINT "INPUT T FOR COPPER "
0840 INPUT T4
0850 LET D=1.37E-09*(T4)
0860 PRINT "RANGE (3)=";D
0870 GOTO 0990
0880 PRINT "INPUT T FOR SCIN-IND"
0890 INPUT T5
0900 PRINT "INPUT T FOR SULFUR"
0910 INPUT T6
0920 LET D=4.2E-09*(T5-T6)
0930 PRINT "RANGE(4)=";D
0940 GOTO 0990
0950 PRINT "INPUT T FOR SULFUR"
0960 INPUT T7
0970 LET D=5.8E-09*(T7)
0980 PRINT "RANGE 5 =" ;D
0990 PRINT "DO YOU WISH TO CALCULATE A BLOOD SODIUM COUNT,(1)YES,(0)NO"
1000 INPUT Y9
1010 IF Y9=0 THEN GOTO 1640

```

```
1020 PRINT "THIS PART OF THE PROGRAM IS FOR THE BLOOD SODIUM CALCULATION"

1030 PRINT "ENTER THE DECAY TIME IN MIN,(T1)"
1040 INPUT T3
1050 PRINT "IS THE COUNTING TIME 1000 SEC?,YES(1),NO(0)"
1060 INPUT Q5
1070 IF Q5=0 THEN GOTO 1100
1080 LET T4=1000/60
1090 GOTO 1120
1100 PRINT "INPUT COUNTING TIME IN MIN,(T2)"
1110 INPUT T4
1120 LET T4=T4+T3
1130 LET M5=.016
1140 PRINT "INPUT THE COUNTER BACKGROUND"
1150 INPUT B5
1160 PRINT "INPUT THE NUMBER OF COUNTS"
1170 INPUT N5
1180 PRINT "INPUT THE GEOMETRY FACTOR"
1190 INPUT G5
1200 LET N5=N5-B5
1210 LET L5=.000777
1220 LET C5=(EXP(-L5*T3))-(EXP(-L5*T4))
1230 LET K5=.000055
1240 LET Z5=M5*G5*C5
1250 LET T5=K5*N5/Z5
1260 PRINT "RAD DOSE FOR A TYPICAL UNMODERATED SPECTRUM=";T5
1270 PRINT "DO YOU WISH TO CALCULATE USING THE FAST NEUTRON CORRECTION?"
1280 PRINT ",YES(1),NO(0)"
1290 INPUT Y5
1300 IF Y5=0 THEN GOTO 1640
1340 LET K5=.000109
1350 LET Z5=M5*G5*C5
1360 LET T5=K5*N5/Z5
1370 PRINT "PCI 24NA/MG 23NA=";T5
1372 GOTO 1420
```

```

1375 PRINT "SULFUR FLUENCE ACTIVATION FACTOR=";T6/T5
1380 PRINT "INPUT THE ACTIVATION FACTOR AS TAKEN FROM THE GRAPH"
1390 INPUT F5
1400 LET T5=T5*1/F5
1410 PRINT "RAD DOSE WITH HIGH ENERGY NEUTRON CORRECTION=";T5
1415 GOTO 1640
1420 PRINT "THIS PART OF THE PROGRAM ASSUMES A 1G MASS FOR THE HAIR"
1430 PRINT "SAMPLE AND OUTPUTS T FOR >2.9 MEV NEUTRONS"
1440 PRINT "INPUT THE DECAY TIME IN MIN(T1)"
1450 INPUT T6
1460 PRINT "INPUT THE COUNTING TIME IN MIN(T2)"
1470 INPUT T7
1480 LET T7=T7+T6
1490 PRINT "INPUT THE COUNTER BACKGROUND"
1500 INPUT B6
1510 PRINT "INPUT THE TOTAL NUMBER OF COUNTS"
1520 INPUT N6
1530 LET N6=N6-B6
1540 PRINT "INPUT FRACTION CHEMICAL RECOVERY"
1550 INPUT R6
1560 PRINT "INPUT GEOMETRY FACTOR"
1570 INPUT G6
1580 LET L=3.36E-05
1590 LET C6=(EXP(-L*T6))-(EXP(-L*T7))
1600 LET K6=224
1610 LET Z6=R6*G6*C6
1620 LET T6=K6*N6/Z6
1630 PRINT "HAIR SULFUR FLUENCE(NEUTRONS>2.9MEV)=";T6
1635 GOTO 1340
1640 END

```

*

PERSONNEL DOSIMETER DATA

DOSIMETER NO. _____ DATE _____ TIME _____

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I.	Foil	M	t ₁ (min)	t ₂ (min)	B	Foil Counts	G	φ*
	Bare In							
	Cd-In							
	Scin. In							
	Copper						0.055	
	Sulfur							
	²⁴ Na	0.016 g					0.0215	

II.	Energy Range	Detector	φ†	K	Kxφ† (rad)
	Thermal	Bare In minus Cd-In		0.32 X 10 ⁻⁹	
	Epithermal	Cd-In		0.45 X 10 ⁻⁹	
	2 ev - 1 MeV	Copper		1.37 X 10 ⁻⁹	
	1 MeV - 2.9 MeV	Scin. In minus S		4.2 X 10 ⁻⁹	
	>2.9 MeV	Sulfur		5.8 X 10 ⁻⁹	

Sum of above = _____ = Total dose (rad)

III.	Energy Range	Detector	φ†	K	Kxφ† (rad)
	All energies	²⁴ Na		5 X 10 ⁻⁹	Total dose

IV.	Type of Radiation	Detector	Rem
	Neutron dose	Film badge, Type A film	
	Thermal neutron dose	Film badge indium	
	Gamma dose	Film badge film	
	Gamma dose	Glass rods	

V. Miscellaneous Data

Range	Detector	M	t ₁ (min)	t ₂ (min)	Total Counts	φ†
>2.9 MeV neutron	Hair	1 g				

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VIIIA

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