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**NUCLEAR EXCURSION ANALYSIS
ON THE IBM 650
(EARLY CODE)**

**ALCO PRODUCTS, INC.
POST OFFICE BOX 414
SCHENECTADY, N. Y.**

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NUCLEAR EXCURSION ANALYSIS

ON THE IBM 650

(EARLY CODE)

CONTRACT NO. AT(30-3)-326

BY

EARL M. REIBACK

CLIFFORD J. STUECK

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NUCLEAR EXCURSION ANALYSIS

ON THE IBM 650

(Early Code)

INTRODUCTION:

The Early program based on (1) is designed to compute the peak power and total energy release which will occur in a reactor due to a step increase of reactivity. These excursions may be terminated by one of several automatic shutoff mechanisms caused by the power excursion itself. These are 1) shutdown due to steam void formation, 2) shutdown due to melting of the center of the fuel plate, or 3) shutdown due to the entire fuel plate melting. The second condition is shown by data from the Borax Experiment to be sufficient to cause the fuel plate to disintegrate.

The calculation assumes no thermodynamic delays and assumes void formation is due to heat conduction from the cladding to the moderator. The first of these assumptions reduces the validity of the technique for periods shorter than 0.5 milliseconds inasmuch as thermodynamic delays become increasingly important for the shorter periods. The second assumption reduces the validity for periods longer than 20 milliseconds since effects such as radiolytic gas production, fuel plate expansion, and neutron impact heating are not considered. For periods in the range 1 to 10 milliseconds, the calculation yields results which are in excellent agreement with SPERT experimental results.

NOMENCLATURE

a	fuel half thickness	cm
$b-a$	cladding thickness	cm
$c-b$	coolant channel half thickness	cm
k_{ex}	excess reactivity	fraction
$V_f(-1\%)$	water void fraction % required to introduce -1% of reactivity	%
T	period of reactor	seconds
$\$$	excess reactivity	
h_{fg}	latent heat of vaporization	cal/gm
f_{vol}	total active fuel region volume	cm ³
ℓ^*	mean neutron life	sec
$\Theta_3(b,0)$	initial temperature of coolant	°C
$\Theta_1(0,0)$	initial temperature of fuel at center line	°C
$\Theta_3(b,t_B)$	boiling temperature of coolant	°C
$\Theta_1(0,t')$	temperature of center line at end of excursion (may be melting point)	°C
$\Theta_3(b,t')$	clad coolant interface temperature	°C

NOMENCLATURE

(Cont'd)

K ₁	coefficient of thermal	
K ₂	conductivity for fuel	$\frac{\text{cal}}{\text{sec-cm}^2\text{-}^\circ\text{C}}$
K _{3W}	region, cladding, coolant	
K _{3S}	(water and steam) respectively	$\frac{\text{cm}}{\text{cm}}$
ρ_1	density of fuel region, clad-	
ρ_2	ding, coolant (water and steam)	gm/cm^3
ρ_{3W}	respectively	
ρ_{3S}		
C ₁	thermal capacity of fuel region,	$\text{cal/gm-}^\circ\text{C}$
C ₂	cladding, coolant (water and	
C _{3W}	steam) respectively	
C _{3S}		
R ₀	ratio of centerline to clad coolant interface temp.	
P(t,)	peak power	MW and BTU/sec
TP(t,)	energy expended to steam	MW-sec and BTU
	shutoff	
E	total energy expended	MW-sec and BTU

USE OF CODE:

There are three methods of calculating temperature, peak power, and energy release.

For method 1, the boiling temperature of the coolant is entered as input, and $\Theta_1(0, t')$ and $\Theta_3(b, t')$ are entered as input zeros. Using this method, calculations are made using void formation as a basis for shutdown.

For method 2, the temperature of the center line at the end of the excursion is entered as input (the melting temperature of the fuel), and $\Theta_3(b, t_B)$ and $\Theta_3(b, t')$ are entered as input zeros. Using this method, calculations are made using center line melting as a basis for shutdown.

For method 3, the temperature of the clad coolant interface (melting temperature) is entered as input, and $\Theta_3(b, t_B)$ and $\Theta_1(0, t')$ are entered as input zeros. Using this method, calculations are made using clad-coolant interface melting as a basis for shutdown.

Either T , k_{ex} , or $\$$ may be specified in the input. Only one of the three may be specified and the two unspecified must be set equal to zero.

The machine uses only T and if k_{ex} or $\$$ are given, calculates T from the k_{ex} or $\$$ by the expressions:

$$k_{ex} \text{ given} \quad T = \ell^* / (k_{ex} - .0073)$$

$$\$ \text{ given} \quad T = \ell^* / .0073(\$ - 1.0)$$

Thus in order to prevent negative periods where k_{ex} or $\$$ is given, the following limits are imposed.

$$k_{ex} > .0073$$

$$\$ > 1.0$$

Violations of these limits will result in a machine stop. If values outside these ranges are desired, the value of T must be used. Note that the quantity k_{ex} must be expressed as a fraction, not as a percent.

It should be particularly noted that if the value "a" is varied, the value "f_{vol}" will also vary.

The quantity V_f must be expressed as a percent.

All other input must be entered as specified on the input format.

All input and output follows the for transit floating point format. Floating point numbers consist of an eight digit abscissa and a two digit exponent and are written as

$\pm \text{xxxxxxxxYY}$

where xxxxxxxx is a number less than 1 but greater than or equal to 0.1 (except zero), i.e.

$$0.1 \leq |\text{xxxxxxxx}| < 1.0$$

and YY is the exponent plus 50. As examples

+123.456 = +.123456 x 10 ³	12345600 53 +
.0012345 = +.12345 x 10 ⁻²	12345000 48 +
-98.7654 = -.987654 x 10 ²	98765400 52 -
-.00098765 = -.98765 x 10 ⁻³	98765000 47 -

Input forms are available for making out input sheets. Zero is expressed as ten zeros.

INPUT

	<u>Word 1</u>	<u>Word 2</u>	<u>Word 3</u>	<u>Word 4</u>	<u>Word 5</u>	<u>Word 6</u>	<u>Word 7</u>	<u>Word 8</u>
Card 1	a	b-a	c-b	k_{ex}	$V_f(-1\%)$	T	\$	xxxxxxxx01
Card 2	hfg	fvo1	l^*	$\Theta_3(b, 0)$	$\Theta_1(0, 0)$	K1	K2	xxxxxxxx02
Card 3	K3W	K3S	$\Theta_3(b, t_B)$	$\Theta_1(0, t')$	p_1	p_2	p_{3W}	xxxxxxxx03
Card 4	p_{3S}	$\Theta_3(b, t')$	(zeros)	C_1	C_2	C_{3W}	C_{3S}	xxxxxxxx04

All input cards require an x or 12 in col 73. xxxxxxxx may be anything or blank.

OUTPUT

	<u>Word 1</u>	<u>Word 2</u>	<u>Word 3</u>	<u>Word 4</u>	<u>Word 5</u>	<u>Word 6</u>	<u>Word 7</u>	<u>Word 8</u>
Card 1	a	b-a	c-b	k _{ex}	V _f (-1%)	T	\$	00 00nn 0022
Card 2	hfg	f _{vol}	ℓ^*	$\Theta_3(b, 0)$	$\Theta_1(0, 0)$	K ₁	K ₂	00 00nn+1 0022
Card 3	K _{3W}	K _{3S}	$\Theta_3(b, t_B)$	$\Theta_1(0, t')$	ρ_1	ρ_2	ρ_{3W}	00 00nn+2 0022
Card 4	ρ_{3S}	$\Theta_3(b, t')$	(zeros)	C ₁	C ₂	C _{3W}	C _{3S}	00 00nn+3 0022
Card 5	T	K _{ex}	1/T	R ₀	-	-	-	00 00nn+4 0023
Card 6	$\Theta_3(b, t')$	$\Theta_1(0, t')$	P(t') (MW)	P(t') (BTU/sec) -	-	-	-	00 00nn+5 0024
Card 7	TR(t') (MWsec)	TP(t') (BTU)	E (MWsec)	E (BTU)	-	-	-	00 00nn+6 0025

The first four output cards are the same as the input card. nn begin with 01 for any one run or loading of the deck and increases by 1 for each card punched.

PROGRAMMED EQUATIONS

Given as input either T , k_{ex} , or $\$$

$$k_{ex} = .0073 \$$$

or,

$$k_{ex_prompt} = \frac{l^*}{T}$$

$$k_{ex} = k_{ex_prompt} + .0073$$

Given $V_{f(-1\%)}$

$$\text{slope } m = \frac{1}{V_{f(-1\%)}}$$

$$\text{and } V_f = \frac{k_{ex}}{m}$$

To calculate R_o

$$R_o = \frac{F_{11}(0) + F_{12}(0)}{F_3(b)}$$

$$F_{11}(0) = -\frac{2T}{\Delta} \alpha_1^2 \begin{bmatrix} \left(\frac{h_2}{\sqrt{T}}\right) & \left(\frac{-h_1}{\sqrt{T}}\right) \\ Ce & -Be \end{bmatrix}$$

$$F_{12}(0) = T \alpha_1^2$$

(A 2.14)

See Ref. (1)

(A 2.3)

(A 2.4)

$$F_3(b) = \frac{2T}{\Delta} \alpha_1^2 A \left[e^{\frac{-g}{\sqrt{T}}} - e^{\frac{+g}{\sqrt{T}}} \right] e^{\left(\frac{-b}{\alpha_{3W} \sqrt{T}} \right)} \quad (A 2.5)$$

$$\Delta = (C + E) e^{+\left(\frac{-g+h_2}{\sqrt{T}} \right)} + (C-E) e^{+\left(\frac{g+h_2}{\sqrt{T}} \right)} \\ + (D-B) e^{+\left(\frac{-g - h_1}{\sqrt{T}} \right)} - (D + B) e^{\left(\frac{g - h_1}{\sqrt{T}} \right)} \quad (A 1.13)$$

$$\alpha_i = \frac{K_i}{\rho_i C_i} \quad (A 1.2_h)$$

where $i = 1, 2, 3W, 3S$

$$A = \frac{K_1 K_2}{\alpha_1 \alpha_2} \quad (A 1.14)$$

$$B = \frac{K_2^2}{\alpha_2^2} + \frac{K_2 K_{3W}}{\alpha_2 \alpha_{3W}} \quad (A 1.15)$$

$$C = \frac{K_2^2}{\alpha_2^2} - \frac{K_2 K_{3W}}{\alpha_2 \alpha_2} \quad (A 1.16)$$

$$D = \frac{K_1 K_2}{\alpha_1 \alpha_2} + \frac{K_1 K_{3W}}{\alpha_1 \alpha_{3W}} \quad (A 1.17)$$

$$E = \frac{K_1 K_2}{\alpha_1 \alpha_2} - \frac{K_1 K_{3W}}{\alpha_1 \alpha_{3W}} \quad (A 1.18)$$

$$g = \frac{a}{\alpha_1} \quad (A 1.19)$$

$$h_1 = \frac{a - b}{\alpha_2} + \frac{b}{\alpha_{3W}} \quad (\text{A } 1.20)$$

$$h_2 = \frac{a - b}{\alpha_2} - \frac{b}{\alpha_{3W}} \quad (\text{A } 1.21)$$

For Method 1, boiling temperature of coolant is given as input, void causing shutdown

$$\theta_3(b, t_B) = \Theta_3(b, t_B) - \Theta_3(b, 0)$$

$$Q^* = (c-b) (\rho_{3S}) (h_{fg}) (V_f) + \theta_3(b, t_B) (c-b) (\rho_{3S}) (V_f) (C_{3W})$$

$$\theta_3(b, t') = \frac{\alpha_{3S} Q^*}{K_{3S} \sqrt{T}} + \theta_3(b, t_B)$$

$$\Theta_3(b, t') = \theta_3(b, t') + \Theta_3(b, 0)$$

$$\theta_1(0, t') = R_0 \left[\theta_3(b, t') \right]$$

$$\Theta_1(0, t') = \theta_1(0, t') + \Theta_1(0, 0)$$

Methods 1, 2 and 3; peak power and energy calculations:

Maximum Power density:

$$p(t') = \frac{K_1}{F_3(b)} \theta_3(b, t') \quad \text{cal/sec-cm}^3$$

Peak Power:

$$P(t') = p(t') (f_{vol}) \quad \text{cal/sec}$$

$$P(t') = P(t') \text{cal/sec} (4.18 \times 10^{-6}) \quad \text{MW}$$

$$P(t') = 948 P(t') \text{MW} \quad \text{BTU/sec}$$

Energy Expended to shutdown:

$$TP(t') = P(t') \text{MW}(T) \quad \text{MW-sec}$$

$$TP(t') = 948 TP(t') \text{MW-sec} \quad \text{BTU}$$

Total Energy Expended during Excursion

$$E = 2TP(t') \text{BTU} \quad \text{BTU}$$

$$E = 2TP(t') \text{MW-sec} \quad \text{MW-sec}$$

OPERATING INSTRUCTIONS

Input

Input consists of:

1. Program Deck
2. Input Sets (each set ends
with low x in col 10)

533 Read-Punch Unit

- (a) IT-SOAP II Wiring Board
- (b) Ready read-feed with input deck
- (c) Ready punch feed with blanks

650 Console

- (a) Set programmed switch to STOP
Set half-cycle switch to RUN
Set control switch to RUN
Set display switch to PROGRAM REGISTER
Set overflow switch to SENSE
Set error switch to STOP
- (b) Set 70 1952 9999 + in
storage entry switches
- (c) Press computer reset key
- (d) Press computer start key
- (e) When read hopper empties, press end
of file key.

To reload input cards

Set (00 0000 1999 +) in storage entry switches

Repeat steps (c), (d), and (e)

PROGRAMMED STOPS

If no value is given to either T, k_{ex} , or β , the computer will stop.

All other stops are as described in FOR TRANSIT manual.

CALCULATION TIME

Time = 25 sec per case

REFERENCES

- (1) NRL Report 4495 RD480 (Del) "Transient Response of Parallel Fuel Assemblies to Exponential Power Excursions", S.E. Golian, et al.