OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

ORNL-TM-203

COPY NO. - 118

DATE - April 6, 1962

MURGATROYD - AN IBM 7090 PROGRAM FOR THE ANALYSIS OF THE KINETICS OF THE MSRE

C. W. Nestor, Jr.

ABSTRACT

The IBM 7090 program MURGATROYD is a revised and extended version of the IBM 704 program PET-I, which solves (by a fifth-order Runge-Kutta procedure) the coupled first-order differential equations for power, delayed neutron concentration and temperature in a one-region reactor as a function of time, given an input reactivity variation represented by a series of linear ramps. The basic extensions were those which were necessary to include the effects of the separate heat capacities and temperature coefficients of the fuel salt and graphite in the MSRE, and of heat transfer between the fuel and graphite. In addition, the input and output sections of the previous program were modified to facilitate the use of the program in extensive parameter studies, and a calculation of the pressure rise in the core was included. Typical running times are of the order of 12 milliseconds per time step; a calculation of a 30-second power history using a 10 millisecond time step requires about 36 seconds of machine time.

MURGATROYD - AN IBM 7090 PROGRAM FOR THE ANALYSIS OF THE KINETICS OF THE MSRE

I. Introduction

This report is a description of an IBM 7090 program based on a particular model of the Molten Salt Reactor Experiment. The differential equations of motion are discussed in Section II; since much of the derivation has appeared elsewhere,[1] only the additional derivations necessary in the present problem are included. The fifth-order Runge-Kutta procedure is a standard one which can be found in many numerical analysis textbooks.[2] Its previous successful use in the 704 program PET[3] indicated applicability to the present problem and no revision has as yet been found either desirable or necessary. The use of the program is discussed in Section III, with instructions for the preparation of input data; sample input forms and output sheets are included.

II. Differential Equations of Motion

A. Power, Fuel and Graphite Temperatures

The reactor model used as the basis of the program is a one-point, one-energy group representation, with up to seven delayed neutron precursors, which is described by the following set of differential equations: (all symbols are defined in the Nomenclature; a dot over a symbol denotes time derivative)

$$\dot{P} = \frac{k_e(1-\beta)-1}{\ell} P + \sum_{i-1}^{N} \lambda_i \Gamma_i \qquad (1)$$

$$\dot{\Gamma}_i = \frac{\beta_i P}{\ell} - \lambda_i \Gamma_i \qquad , i = 1, N \qquad (2)$$

The effective multiplication constant k_e is assumed to be of the form

$$k_e = 1 + \Delta + bt - \left|\frac{\partial k_e}{\partial T_f}\right| (T_f - T_{fo}) - \left|\frac{\partial k_e}{\partial T_g}\right| (T_g - T_{go}) \ . \qquad (3)$$

(The subscript zero denotes the steady state value.)

$$S_f \dot{T}_f = fP - WC_p(T_2 - T_1) + h(T_g - T_f) \tag{4}$$

$$S_g \dot{T}_g = (1-f)\,P - h(T_g - T_f) \tag{5}$$

It is now necessary to specify some connection between the mean fuel temperature T_f, the inlet temperature T_1 and the outlet temperature T_2. The assumption is made that the mean fuel temperature is a weighted mean of the inlet and outlet; i.e., that

$$T_f = aT_1 + (1-a)\,T_2 \quad ; \tag{6}$$

the weight $a(0 < a < 1)$ is an input number in the 7090 program. Further it is assumed that the inlet temperature T_1 is a constant. With the definitions

$$y_f \equiv \frac{S_f(T_f - T_{fo})}{fP_o} \tag{7}$$

$$y_g \equiv \frac{S_g(T_g - T_{go})}{(1-f)\,P_o} \tag{8}$$

and the initial condition

$$h(T_{go} - T_{fo}) = (1-f)\,P_o \tag{9}$$

the following equations may be obtained

$$fP_o\dot{y}_f = f(P - P_o) - \frac{fP_o}{S_f}\,y_f\left(\frac{WC_p}{1-a} + h\right) + \frac{h(1-f)P_o}{S_g}\,y_g \tag{10}$$

$$(1-f)P_o\dot{y}_g = (1-f)(P-P_o) - \frac{h(1-f)P_o}{S_g}\,y_g + \frac{hfP_o}{S_f}\,y_f \tag{11}$$

which, with the definition

$$x \equiv P/P_o \tag{12}$$

may be further transformed to obtain the equations used in Murgatroyd:

$$\dot{y}_f = x-1 - \left[\frac{1}{(1-a)t_c} + \frac{h}{S_f}\right] y_f + \frac{h}{S_g}\,\frac{1-f}{f}\, y_g \tag{13}$$

$$\dot{y}_g = x-1 - \frac{h}{S_g} y_g + \frac{h}{S_f}\,\frac{f}{1-f}\, y_f . \tag{14}$$

Similarly equations 1 thru 6 may be transformed with the definitions

$$C_i \equiv \Gamma_i/P_o$$

and $\gamma_i \equiv \beta_i/\ell$

to

$$\dot{x} = \frac{k_e(1-\beta) - 1}{\ell}\, x + \sum_{i=1}^{N} \lambda_i\, C_i \tag{15}$$

$$\dot{C}_i = \gamma_i\, x - \lambda_i C_i \qquad , \; i = 1, N . \tag{16}$$

If the definitions of y_f and y_g, equations (7) and (8), are introduced into equation (3) the effective multiplication constant becomes

$$k_e = 1 + \Delta + bt - \left|\frac{\partial k_e}{\partial T_f}\right| \frac{fP_o}{S_f}\, y_f - \left|\frac{\partial k_e}{\partial T_g}\right| \frac{(1-f)P_o}{S_g}\, y_g \; ; \tag{17}$$

with the definitions

$$W_f^{\,2} \equiv \left|\frac{\partial k_e}{\partial T_f}\right| \frac{fP_o}{S_f \ell} \tag{18}$$

$$W_g^{\,2} \equiv \left|\frac{\partial k_e}{\partial T_g}\right| \frac{(1-f)P_o}{S_g \ell} \tag{19}$$

[These are similar to the parameter $W_N^{\,2}$ in reference 1.]

the equation for the normalized power becomes

$$\dot{x} = \left[\frac{(1 + \delta + bt)(1 - \beta) - 1}{\ell} - (1 - \beta)(W_f^{\,2} y_f + W_g^{\,2} y_g)\right] x + \sum_{i=1}^{N} \lambda_i\, C_i \tag{20}$$

The differential equations actually used in the program are the set 20, 16, 13, and 14.

B. Pressure

The simplified model of the primary fuel salt system is shown in Fig. III. It is assumed that compression of the gas in the pump bowl is adiabatic, and that the behavior of the molten salt is adequately described by the linear equation of state

$$\rho(T_f) = \rho_o + \frac{\partial\rho}{\partial T_f}(T_f - T_{fo}) \; . \tag{21}$$

A force balance on the liquid in the outlet pipe yields the equation

$$\frac{M_r}{144\, g_c}\, \dot{U} = A(p_c - p_p - a_f U^2) \quad ; \tag{22}$$

in steady state

$$p_c(o) = p_p(o) + a_f U_o^2 \; . \tag{23}$$

The assumption that compression of the gas in the pump bowl is adiabatic can be stated as

$$p_p V_p^n = p_p(o)\left[V_p(o)\right]^n \quad ; \tag{24}$$

if we assume that $V_p - V_p(o) << V_p(o)$ and neglect second order terms, we obtain

$$p_p = p_p(o)\left[1 - \frac{n\Delta V_p}{V_p(o)}\right] . \tag{25}$$

The change ΔV_p in the pump bowl gas space volume is now assumed to be equal to the change in volume of the core fuel salt due to the change in temperature of the core fuel salt during a transient; i.e., compression of the molten salt is neglected, as is heating of the external loop. The change in volume ΔV_c is expressed as

$$-\Delta V_p = \Delta V_c = - V_c \frac{\Delta\rho}{\rho_o}$$

$$\simeq - V_c \frac{1}{\rho_o} \frac{\partial\rho}{\partial T_f}(T_f - T_{fo})$$

and substituting in (25) we obtain

$$p_p = p_p(o)\left[1 + \frac{nV_c}{V_p(o)}\left|\frac{1}{\rho_o}\ \frac{\partial\rho}{\partial T_f}\right|(T_f - T_{fo})\right] . \tag{26}$$

Solving equation (22) for the core pressure we obtain

$$p_c = p_p + a_f\, U^2 + \frac{M_r}{144\ g_c A}\ \dot{U}\ ;$$

subtracting equation (23), we obtain

$$\Delta p = p_c - p_c(o) = p_p - p_p(o) + a_f\ (U^2 - U_o^{\ 2}) + \frac{M_r}{144\ g_c A}\ \dot{U}\ ; \tag{27}$$

the term $p_p - p_p(o)$ is due to the compression of gas in the pump bowl, the term $a_f(U^2 - U_o^{\ 2})$ is due to the increase in friction losses, and the last term is the contribution from the inertia of the fluid in the outlet pipe.

In order to proceed, a relation between outlet velocity and fluid density change is needed. The equation of continuity for the fuel salt in the core is approximately

$$\dot{\rho} = -\ \frac{A}{V_c}\ \rho_o\ (U - U_o)\ ; \tag{28}$$

solving for the velocity U we obtain

$$U = U_o - \frac{V_c}{A}\ \frac{\dot{\rho}}{\rho_o}$$

and substituting the equation of state (21) we obtain

$$U = U_o - \frac{V_c}{A}\ \frac{1}{\rho_o}\ \frac{\partial\rho}{\partial T_f}\ \dot{T}_f\ ; \tag{29}$$

and taking time derivatives

$$\dot{U} = -\ \frac{V_c}{A}\ \frac{1}{\rho_o}\frac{\partial\rho}{\partial T_f}\ \ddot{T}_f\ . \tag{30}$$

We now substitute equations (29) and (30) into (27); after some re-arrangement we obtain

$$\Delta p = - \frac{V_c}{A} \frac{1}{\rho_o} \frac{\partial\rho}{\partial T_f} \left[\frac{M_r}{144\ g_c A} \ddot{T}_f + p_p(o) \frac{nA}{V_p(o)} (T_f - T_{fo}) \right.$$

$$\left. + 2\ U_o\ a_f\ \dot{T}_f \left(1 - \frac{V_c}{2AU_o} \frac{1}{\rho_o} \frac{\partial\rho}{\partial T_f} \dot{T}_f \right) \right] \quad (31)$$

With the definitions of y_f and x (equations 11 and 16) equation (31) is transformed into*

$$\Delta p = - \frac{V_c}{A} \frac{1}{\rho_o} \frac{\partial\rho}{\partial T_f} \frac{fP_o}{S_f} \left[\frac{M_r}{144\ g_c A} \dot{x} + p_p(o) \frac{nA}{V_p(o)} y_f \right.$$

$$\left. + 2U_o\ a_f\ \dot{y}_f \left(1 - \frac{V_c}{2AU_o} \frac{1}{\rho_o} \frac{\partial\rho}{\partial T_f} \frac{fP_o}{S_f} \dot{y}_f \right) \right] \quad (32)$$

With the definitions

$$d_1 \equiv - \frac{V_c}{A} \frac{1}{\rho_o} \frac{\partial\rho}{\partial T_f} \frac{M_r}{144\ g_c A} \frac{fP_o}{S_f}$$

$$d_2 \equiv - p_p(o) \frac{nA}{V_p(o)} \frac{144\ g_c A}{M_r}$$

$$\alpha_1 \equiv 2U_o a_f \frac{144\ g_c A}{M_r}$$

amd

$$d_3 \equiv - \frac{V_c}{2AU_o} \frac{1}{\rho_o} \frac{\partial\rho}{\partial T_f} \frac{fP_o}{S_f}$$

we obtain the equation used in the program:

$$sp = d_1 \left[\dot{x} + d_2\ y_f + \alpha_1\ \dot{y}_f\ (1 + d_3\ \dot{y}_f) \right] \quad (33)$$

In terms of the dimensional groups of reference 1 and the parameter W_f^2 defined in equation (18), the constants, d_1, d_2, and d_3 may be written

---

*It is assumed that $\ddot{T}_f = f\dot{P}/S_f$.

$$\left.\begin{aligned} d_1 &= \frac{fW_f^{\,2}}{\gamma_2 W_H^{\,2}} \\ d_2 &= W_H^{\,2}\, C_2 \\ d_3 &= W_f^{\,2}/2\gamma_3 \end{aligned}\right\} \tag{34}$$

C. Effective Delayed Neutron Yields

In order to account for the reduction in delayed neutron production in the core due to fluid flow, an effective yield is calculated for each precursor, assuming constant flux and slug flow. The fraction ν_i of delayed neutrons of the ith group which are released in the core is given by[4]

$$\nu_i = 1 - \frac{1 - e^{-\lambda_i t_c}}{\lambda_i t_c} \; \frac{1 - e^{-\lambda_i t_L}}{1 - e^{-\lambda_i (t_c + t_L)}} \tag{35}$$

where t_c is the core residence time, λ_i is the decay constant of the ith precursor and t_L is the external loop transit time.

III. Organization and Use of the Machine Program

The program is designed for use in parameter studies; therefore the calculation is separated into two parts, the first of which deals with the characteristics of the reactor which remain constant for a series of cases, and the second of which deals with the characteristics which change from case to case. Input forms are shown in Figures Ia and Ib; in the usual procedure the first form would be filled out once to describe the characteristics of the reactor, and a second form would be filled out to describe each set of initial conditions and ramp insertions. The input data symbols appearing on the input forms are listed in Tables 3 and 4, with their definitions, the names given them in the program, and the format with which they are read from the input tape.

The standard CDPF Monitor input (logical 10) and output (logical 9) tapes are used; no other tapes are required.

Output for a typical case is displayed in Figures IIa and IIb. Figure IIa is an edit of the input describing the reactor system, with the calculated effective delayed neutron yields; Figure IIb is the input for a particular case, and the continuations of Figure IIb show the time behavior of the reactor. The two columns headed

PCT DK REMOVED BY

FUEL GRAPHITE

show the percent reactivity removed from the system by the temperature rise of the fuel salt and graphite, respectively. The quantity labeled "(1/P)(DP/DT)" is calculated from the expression

$$\alpha = \frac{P(t) - P(t - \Delta t)}{\Delta t} \cdot \frac{2}{P(t) + P(t - \Delta t)}$$

and is therefore approximately the inverse period at $t - \Delta t/2$, where Δt is the input time step.

Since the frequency of printing is an input number, special provision has been made for indicating the first power maximum, the first pressure maximum and the subsequent pressure minimum. ("Maximum" and "minimum" are to be taken here in the mathematical sense of points of zero first derivative and negative or positive second derivative, respectively.) The values labeled "VALUES AT POWER MAXIMUM" are the values at the time t_3 when the power has first decreased, and the values at the two previous times, t_1 and t_2, as shown in Table 1.

Table 1. Power Maximum Indication

Time	Power	(1/P)(DP/DT)
t_1	$P(t_1)$	
		$\alpha_{1,2}$
t_2	$P(t_2)$	
		$\alpha_{2,3}$
t_3	$P(t_3)$	

The criterion for printing is

$$P(t_1) < P(t_2) \geq P(t_3)$$

and the quantities $\alpha_{i,j}$ are

$$\alpha_{i,j} = \frac{P(t_j) - P(t_i)}{\Delta t} \cdot \frac{2}{P(t_j) + P(t_i)} .$$

Similar remarks apply, mutatis mutandis, to the values labeled "VALUES AT PRESSURE MAXIMUM" and "VALUES AT PRESSURE MINIMUM."

Acknowledgment

Thanks are due P. N. Haubenreich and J. R. Engel, for assistance in the derivation of the equations and other helpful comments and suggestions; to M. P. Lietzke, for considerable programming assistance; and to H. A. MacColl, for preparation of the input forms.

References

1. P. R. Kasten, Operational Safety of the Homogeneous Reactor Test, ORNL-2088, July 3, 1956.

2. R. G. Stanton, Numerical Methods for Science and Engineering, Prentice-Hall, Inc., 1961.

3. S. Jaye and M. P. Lietzke, Power Response Following Reactivity Additions to the HRT, ORNL CF-58-12-106, Dec. 30, 1958.

4. P. R. Kasten, Dynamics of the Homogeneous Reactor Test, ORNL-2072, June 7, 1956.

Table 2. Nomenclature

Symbol	Definition	Equation
A	area of outlet pipe, ft^2	22
a_f	friction factor, $psi/(ft/sec)^2$	22
b	initial ramp reactivity input	3
C_P	specific heat of fuel salt	4
f	fraction of power generated in fuel salt	4
g_c	conversion factor	22
h	product of heat transfer coefficient times wetted area of graphite	4
k_e	effective multiplication constant	1
ℓ	prompt neutron lifetime	1
M_r	mass of fluid in outlet pipe, lb	22
n	ratio of specific heats (C_P/C_V) for pump bowl gas	24
P	power	1
p_c	core pressure, psi	22
p_p	pump bowl pressure, psi	22
$p_c(o)$	initial core pressure, psi	23
$p_p(o)$	initial pump bowl pressure, psi	23
S_f	fuel salt heat capacity	4
S_g	graphite heat capacity	5
T_f	fuel temperature	4
T_g	graphite temperature	4
t	time	3
t_c	core residence time	13
T_1	fuel salt inlet temperature	4
T_2	fuel salt outlet temperature	4

Table 2. - Cont'd

Symbol	Definition	Equation
U	outlet speed in pipe, ft/sec	22
$V_p(o)$	initial gas space volume in pump bowl, ft^3	24
W	mass flow rate of fuel through core	4
β	total delayed neutron yield	1
β_i	yield of ith delayed neutron precursor	2
Γ_i	latent power due to ith precursor	1
Δ	initial step reactivity input	3
ρ	fuel salt density	21

Table 3. Input for Description of Reactor System

Title		Fortran Name
1. Core characteristics		HØLM
V_c	salt volume, ft^3	VC
t_c	residence time, sec (if fuel is not circulating, enter zero)	TCØRE
a	weighting factor for mean temperature	ATMX
h	heat transferred from graphite to sale per unit temperature difference, Mw sec/^oF	HTRAN
f	fraction of power generated in salt	FRACT
S_f	fuel heat capacity, Mw sec/^oF	HCAPF
S_g	graphite heat capacity, Mw sec/^oF	HCAPG
$\left\|\partial k_e/\partial T_f\right\|$	fuel temperature coefficient of reactivity, $(^oF)^{-1}$	TCØF
$\left\|\partial k_e/\partial T_g\right\|$	graphite temperature coefficient of reactivity, $(^oF)^{-1}$	TCØG
ℓ	prompt neutron lifetime, sec	FLT
ρ_o	fuel density, lb/ft^3	DENSE
$\left\|(1/\rho)(\partial\rho/\partial T_f)\right\|$	fuel expansion coefficient, $(^oF)^{-1}$	EXPCØ
λ_i	delayed neutron precursor decay constants, sec^{-1}	FLAM(I)
β_i	delayed neutron precursor yields	BETAS(I)
2. External loop characteristics		
t_L	residence time, sec (if fuel is not circulating, enter zero)	TLØØP
A	outlet pipe area, ft^2	AREA
L	outlet pipe length, ft	PLGTH
U_o	steady state outlet velocity, ft/sec	VELØX
a_f	friction factor, psi/(ft/sec^2)	AFR

Table 3. Cont'd

Title		Fortran Name
3. Pump bowl characteristics		
$V_p(o)$	initial gas volume, ft^3	VPRS
$p_p(o)$	initial pressure, psi	PPRS
N	ratio of specific heat at constant pressure to specific heat at constant volume for gas in pump bowl	CPØCV

Title card is read with format 12AG; others with 7E10.0.

Table 4. Input for Individual Cases

Symbol	Definition	Fortran name	Format
Case number		ICASE	16, 11AC
Title		HØLC	
P_o	initial power, watts	PZERØ	6E10.0, 2I5
T_{fo}	initial fuel mean temperature, °F	TFO	
T_{go}	initial graphite mean temperature, °F	TGO	
$\Delta k(o)$	initial step insertion, %	STEP	
b(o)	initial ramp rate, %/sec	RATE	
δt	time step, sec	HH	
NPØ	printout frequency	NPØ	
KSTØP	number of time steps to be run after power peak	KSTØP	
STØP TIME	total time to run	YEND	E10.0, I5
NTC	number of ramp rate changes	NTC	
	time to change ramp rate, sec	TC	6E10.0
	new ramp rate, %/sec	BNEW	3 pairs to a card)

MURGATROYD INPUT I

1 TITLE FOR SERIES OF CASES	73–80

CORE DATA

V_c (1)	t_c (11)	a (21)	h (31)	f (41)	S_f (51)	S_g (61)	(71)	(73–80)

$\lvert\partial ke/\partial T_f\rvert$ (1)	$\lvert\partial ke/\partial T_g\rvert$ (11)	l (21)	ρ (31)	$\left\lvert \frac{1}{\rho}\ \frac{\partial \rho}{\partial T_f}\right\rvert$ (41)	(51)		(73–80)

DELAYED NEUTRON DATA

λ_1 (1)	λ_2 (11)	λ_3 (21)	λ_4 (31)	λ_5 (41)	λ_6 (51)	λ_7 (61)	(71)	(73–80)

β_1 (1)	β_2 (11)	β_3 (21)	β_4 (31)	β_5 (41)	β_6 (51)	β_7 (61)	(71)	(73–80)

EXTERNAL LOOP DATA

t_L (1)	A (11)	L (21)	U_0 (31)	a_f (41)	(51)	(73–80)

PUMP BOWL DATA

$V_p(0)$ (1)	$P_p(0)$ (11)	n (21)	(31)	(73–80)

FIG. Ia. INPUT DESCRIBING REACTOR SYSTEM

MURGATROYD INPUT-2

CASE NO. (1)	CASE TITLE (7)	(73–80)

P_o (1)	T_{fo} (11)	T_{go} (21)	ΔK (0) (31)	b_o (41)	δt (51)	NPO (61)	K STOP (66)		(73–80)

STOP TIME, sec (1)	NTC (11)	(16)	(73–80)

TIME, sec. (1)	NEW RAMP, %/sec. (11)	TIME, sec. (21)	NEW RAMP, %/sec. (31)	TIME, sec. (41)	NEW RAMP, %/sec (51)		(73–80)
1	11	21	31	41	51		73–80
1	11	21	31	41	51		73–80
1	11	21	31	41	51		73–80
1	11	21	31	41	51		73–80
1	11	21	31	41	51		73–80
1	11	21	31	41	51		73–80

FIG Ib. INPUT FOR ONE CASE

Fig. IIa. Sample Output

PROGRAM MURGATROYD-II

MSRE NORMAL FLOW NO SOAK-UP 3/27/62

INPUT EDIT

HEAT TRANSFER RATE (GRAPHITE TO FUEL) 0.020 MW/DEG F

FRACTION OF POWER GENERATED IN FUEL 0.940

RESIDENCE TIMES

CORE	7.318 SEC
LOOP	17.334 SEC

HEAT CAPACITY,	GRAPHITE	FUEL
MW*SEC/DEG F	3.530E 00	1.470E 00
DK/DT,/DEG F	6.000E-05	2.800E-05

DELAYED NEUTRON DATA

DELAY GROUP	LAMBDA, SEC**-1	STATIC BETA	EFFECTIVE BETA	GAMMA(I), SEC**-1	INITIAL C(I)
1	0.0124	2.112E-04	5.294E-05	2.170E-01	1.750E 01
2	0.0305	1.402E-03	4.258E-04	1.468E 00	4.813E 01
3	0.1114	1.254E-03	4.706E-04	1.623E 00	1.457E 01
4	0.3013	2.528E-03	1.513E-03	5.216E 00	1.731E 01
5	1.1400	7.400E-04	6.513E-04	2.246E 00	1.970E 00
6	3.0100	2.700E-04	2.577E-04	8.888E-01	2.953E-01
TOTAL		6.405E-03	3.381E-03		

***GAMMA#BETA/LIFETIME
C # GAMMA/LAMBDA

NEUTRON LIFETIME 2.900E-04 SEC

FUEL TEMPERATURE # 0.50*INLET + 0.50*OUTLET

DATA FOR PRESSURE CALCULATION

OUTLET PIPE DATA				PUMP BOWL DATA			CORE SALT DATA		
AREA, SQ FT	LENGTH, FT	FLOW SPEED, FT/SEC	FRICTION TERM, PSI/(FT/SEC)**2	GAS VOLUME, CUBIC FT	PRESSURE, PSI	CP/CV	VOLUME, CU FT	DENSITY, LB/CU FT	-(1/V)(DV/DT), PER DEG F
0.139	16.0	19.3	0.0203	2.5	5.0	1.67	19.6	154.5	1.26E-04

Fig. II b.

CASE 1

PROMPT CRITICAL STEP AT 10 MW

INITIAL VALUES

POWER	1.000E 07	WATTS
FUEL TEMP	1200.000	DEGREES F
GRAPHITE TEMP	1230.000	DEGREES F
STEP DELTA K	0.338	PERCENT
RAMP RATE	-0.	PERCENT PER SECOND
TIME STEP	5.000E-03	SECONDS

PRINT EVERY 20 STEPS

Fig. II b. (Cont.)

MURGATROYD II CASE 1

TIME, SEC	POWER, WATTS	FUEL TEMP, DEG F	GRAPHITE TEMP, DEG F	PRESSURE RISE, PSI	DELTA K INPUT, PCT	PCT DK REMOVED BY FUEL	PCT DK REMOVED BY GRAPHITE	(1/P)(DP/DT), PER SECOND
0.100	2.170E 07	1200.369	1230.010	7.677E-01	0.3381	0.0010	0.0001	5.468E 00
0.200	3.388E 07	1201.479	1230.041	9.016E-01	0.3381	0.0041	0.0002	3.687E 00
0.300	4.673E 07	1203.346	1230.093	1.040E 00	0.3381	0.0094	0.0006	2.811E 00
0.400	6.006E 07	1205.988	1230.170	1.159E 00	0.3381	0.0168	0.0010	2.233E 00
0.500	7.331E 07	1209.396	1230.270	1.235E 00	0.3381	0.0263	0.0016	1.769E 00

VALUES AT PRESSURE MAXIMUM

TIME, SEC	PRESSURE RISE, PSI
0.560	1.2503E 00
0.565	1.2504E 00
0.570	1.2503E 00

TIME, SEC	POWER, WATTS	FUEL TEMP, DEG F	GRAPHITE TEMP, DEG F	PRESSURE RISE, PSI	DELTA K INPUT, PCT	PCT DK REMOVED BY FUEL	PCT DK REMOVED BY GRAPHITE	(1/P)(DP/DT), PER SECOND
0.600	8.562E 07	1213.519	1230.395	1.246E 00	0.3381	0.0379	0.0024	1.350E 00
0.700	9.601E 07	1218.245	1230.541	1.184E 00	0.3381	0.0511	0.0032	9.576E-01
0.800	1.036E 08	1223.410	1230.706	1.058E 00	0.3381	0.0655	0.0042	5.926E-01
0.900	1.081E 08	1228.809	1230.883	8.922E-01	0.3381	0.0807	0.0053	2.677E-01

VALUES AT POWER MAXIMUM

TIME, SEC	POWER, WATTS	D(LN P)/DT
0.990	1.0938E 08	
		4.6791E-05
0.995	1.0938E 08	
		-1.3430E-05
1.000	1.0938E 08	

TIME, SEC	POWER, WATTS	FUEL TEMP, DEG F	GRAPHITE TEMP, DEG F	PRESSURE RISE, PSI	DELTA K INPUT, PCT	PCT DK REMOVED BY FUEL	PCT DK REMOVED BY GRAPHITE	(1/P)(DP/DT), PER SECOND
1.000	1.094E 08	1234.234	1231.069	7.172E-01	0.3381	0.0959	0.0064	-2.685E-03
1.100	1.081E 08	1239.503	1231.257	5.594E-01	0.3381	0.1106	0.0075	-2.090E-01
1.200	1.050E 08	1244.483	1231.445	4.335E-01	0.3381	0.1246	0.0087	-3.492E-01
1.300	1.010E 08	1249.093	1231.629	3.420E-01	0.3381	0.1375	0.0098	-4.300E-01
1.400	9.653E 07	1253.301	1231.807	2.797E-01	0.3381	0.1492	0.0108	-4.634E-01
1.500	9.214E 07	1257.110	1231.981	2.384E-01	0.3381	0.1599	0.0119	-4.637E-01
1.600	8.805E 07	1260.544	1232.149	2.105E-01	0.3381	0.1695	0.0129	-4.440E-01
1.700	8.436E 07	1263.635	1232.313	1.903E-01	0.3381	0.1782	0.0139	-4.143E-01
1.800	8.108E 07	1266.420	1232.472	1.744E-01	0.3381	0.1860	0.0148	-3.812E-01
1.900	7.818E 07	1268.932	1232.627	1.607E-01	0.3381	0.1930	0.0158	-3.487E-01

Fig. IIb (cont.)

MURGATROYD II CASE 1

TIME, SEC	POWER, WATTS	FUEL TEMP, DEG F	GRAPHITE TEMP, DEG F	PRESSURE RISE, PSI	DELTA K INPUT, PCT	PCT DK REMOVED BY FUEL	GRAPHITE	(1/P)(DP/DT), PER SECOND
2.000	7.562E 07	1271.201	1232.779	1.483E-01	0.3381	0.1994	0.0167	-3.184E-01
2.100	7.336E 07	1273.255	1232.928	1.356E-01	0.3381	0.2051	0.0176	-2.911E-01
2.200	7.135E 07	1275.116	1233.074	1.256E-01	0.3381	0.2103	0.0184	-2.668E-01
2.300	6.955E 07	1276.805	1233.218	1.152E-01	0.3381	0.2151	0.0193	-2.452E-01
2.400	6.794E 07	1278.349	1233.360	1.053E-01	0.3381	0.2194	0.0202	-2.260E-01
2.500	6.648E 07	1279.734	1233.500	9.606E-02	0.3381	0.2233	0.0210	-2.088E-01
2.600	6.516E 07	1281.002	1233.638	8.737E-02	0.3381	0.2268	0.0218	-1.934E-01
2.700	6.396E 07	1282.155	1233.775	7.924E-02	0.3381	0.2300	0.0227	-1.795E-01
2.800	6.287E 07	1283.203	1233.911	7.164E-02	0.3381	0.2330	0.0235	-1.670E-01
2.900	6.187E 07	1284.156	1234.045	6.456E-02	0.3381	0.2356	0.0243	-1.555E-01
3.000	6.095E 07	1285.021	1234.178	5.798E-02	0.3381	0.2381	0.0251	-1.451E-01
3.100	6.010E 07	1285.806	1234.310	5.186E-02	0.3381	0.2403	0.0259	-1.356E-01
3.200	5.932E 07	1286.518	1234.440	4.616E-02	0.3381	0.2423	0.0266	-1.268E-01
3.300	5.859E 07	1287.163	1234.570	4.087E-02	0.3381	0.2441	0.0274	-1.188E-01
3.400	5.793E 07	1287.745	1234.699	3.597E-02	0.3381	0.2457	0.0282	-1.114E-01
3.500	5.730E 07	1288.271	1234.827	3.141E-02	0.3381	0.2472	0.0290	-1.045E-01
3.600	5.673E 07	1288.745	1234.955	2.718E-02	0.3381	0.2485	0.0297	-9.822E-02
3.700	5.619E 07	1289.170	1235.081	2.327E-02	0.3381	0.2497	0.0305	-9.236E-02
3.800	5.569E 07	1289.551	1235.207	1.964E-02	0.3381	0.2507	0.0312	-8.694E-02
3.900	5.522E 07	1289.890	1235.332	1.627E-02	0.3381	0.2517	0.0320	-8.189E-02
4.000	5.479E 07	1290.192	1235.456	1.316E-02	0.3381	0.2525	0.0327	-7.722E-02
4.100	5.438E 07	1290.458	1235.580	1.028E-02	0.3381	0.2533	0.0335	-7.284E-02
4.200	5.399E 07	1290.693	1235.703	7.608E-03	0.3381	0.2539	0.0342	-6.881E-02
4.300	5.364E 07	1290.897	1235.826	5.133E-03	0.3381	0.2545	0.0350	-6.507E-02
4.400	5.330E 07	1291.074	1235.948	2.853E-03	0.3381	0.2550	0.0357	-6.151E-02

Fig II b. (cont)

MURGATROYD II CASE 1

TIME, SEC	POWER, WATTS	FUEL TEMP, DEG F	GRAPHITE TEMP, DEG F	PRESSURE RISE, PSI	DELTA K INPUT, PCT	PCT DK REMOVED BY FUEL	GRAPHITE	(1/P)(DP/DT), PER SECOND
4.500	5,298E 07	1291,225	1236,070	7,413E-04	0,3381	0,2554	0,0364	-5,827E-02
4.600	5,268E 07	1291,353	1236,191	-1,213E-03	0,3381	0,2558	0,0371	-5,523E-02
4.700	5,240E 07	1291,459	1236,311	-3,018E-03	0,3381	0,2561	0,0379	-5,239E-02
4.800	5,213E 07	1291,545	1236,431	-4,676E-03	0,3381	0,2563	0,0386	-4,972E-02
4.900	5,188E 07	1291,613	1236,551	-6,219E-03	0,3381	0,2565	0,0393	-4,726E-02
5,000	5,164E 07	1291,663	1236,670	-7,641E-03	0,3381	0,2567	0,0400	-4,496E-02
5,100	5,142E 07	1291,697	1236,789	-8,956E-03	0,3381	0,2568	0,0407	-4,283E-02
5,200	5,120E 07	1291,717	1236,907	-1,017E-02	0,3381	0,2568	0,0414	-4,083E-02
5,300	5,100E 07	1291,723	1237,025	-1,128E-02	0,3381	0,2568	0,0422	-3,894E-02
5,400	5,080E 07	1291,717	1237,143	-1,231E-02	0,3381	0,2568	0,0429	-3,722E-02
5,500	5,062E 07	1291,699	1237,260	-1,325E-02	0,3381	0,2568	0,0436	-3,559E-02
5,600	5,044E 07	1291,670	1237,376	-1,413E-02	0,3381	0,2567	0,0443	-3,408E-02
5,700	5,028E 07	1291,631	1237,493	-1,494E-02	0,3381	0,2566	0,0450	-3,269E-02
5,800	5,012E 07	1291,584	1237,609	-1,567E-02	0,3381	0,2564	0,0457	-3,135E-02
5,900	4,996E 07	1291,528	1237,724	-1,634E-02	0,3381	0,2563	0,0463	-3,013E-02
6,000	4,982E 07	1291,464	1237,839	-1,697E-02	0,3381	0,2561	0,0470	-2,898E-02
6,100	4,967E 07	1291,393	1237,954	-1,755E-02	0,3381	0,2559	0,0477	-2,794E-02
6,200	4,954E 07	1291,315	1238,069	-1,806E-02	0,3381	0,2557	0,0484	-2,693E-02
6,300	4,941E 07	1291,232	1238,183	-1,854E-02	0,3381	0,2554	0,0491	-2,601E-02
6,400	4,928E 07	1291,143	1238,297	-1,898E-02	0,3381	0,2552	0,0498	-2,515E-02
6,500	4,916E 07	1291,048	1238,410	-1,939E-02	0,3381	0,2549	0,0505	-2,437E-02
6,600	4,904E 07	1290,949	1238,524	-1,975E-02	0,3381	0,2547	0,0511	-2,359E-02
6,700	4,893E 07	1290,846	1238,637	-2,009E-02	0,3381	0,2544	0,0518	-2,292E-02
6,800	4,882E 07	1290,739	1238,749	-2,039E-02	0,3381	0,2541	0,0525	-2,225E-02
6,900	4,871E 07	1290,628	1238,861	-2,067E-02	0,3381	0,2538	0,0532	-2,165E-02

Fig. 2b (cont)

MURGATROYD II CASE 1

TIME, SEC	POWER, WATTS	FUEL TEMP, DEG F	GRAPHITE TEMP, DEG F	PRESSURE RISE, PSI	DELTA K INPUT, PCT	PCT DK REMOVED BY FUEL	PCT DK REMOVED BY GRAPHITE	(1/P)(DP/DT), PER SECOND
7.000	4.861E 07	1290.513	1238.973	-2.093E-02	0.3381	0.2534	0.0538	-2.111E-02
7.100	4.851E 07	1290.396	1239.085	-2.115E-02	0.3381	0.2531	0.0545	-2.057E-02
7.200	4.841E 07	1290.276	1239.196	-2.136E-02	0.3381	0.2528	0.0552	-2.010E-02
7.300	4.831E 07	1290.153	1239.307	-2.155E-02	0.3381	0.2524	0.0558	-1.966E-02

VALUES AT PRESSURE MINIMUM

TIME, SEC	PRESSURE RISE, PSI
7.320	-2.1584E-02
7.325	-2.1598E-02
7.330	-2.1595E-02

TIME, SEC	POWER, WATTS	FUEL TEMP, DEG F	GRAPHITE TEMP, DEG F	PRESSURE RISE, PSI	DELTA K INPUT, PCT	PCT DK REMOVED BY FUEL	PCT DK REMOVED BY GRAPHITE	(1/P)(DP/DT), PER SECOND
7.400	4.822E 07	1290.028	1239.418	-2.172E-02	0.3381	0.2521	0.0565	-1.924E-02
7.500	4.813E 07	1289.900	1239.529	-2.186E-02	0.3381	0.2517	0.0572	-1.882E-02
7.600	4.804E 07	1289.771	1239.639	-2.201E-02	0.3381	0.2514	0.0578	-1.847E-02
7.700	4.795E 07	1289.640	1239.749	-2.213E-02	0.3381	0.2510	0.0585	-1.813E-02
7.800	4.786E 07	1289.507	1239.858	-2.223E-02	0.3381	0.2506	0.0592	-1.781E-02
7.900	4.778E 07	1289.373	1239.968	-2.233E-02	0.3381	0.2502	0.0598	-1.754E-02
8.000	4.770E 07	1289.238	1240.077	-2.241E-02	0.3381	0.2499	0.0605	-1.726E-02
8.100	4.761E 07	1289.101	1240.186	-2.250E-02	0.3381	0.2495	0.0611	-1.703E-02
8.200	4.753E 07	1288.963	1240.294	-2.256E-02	0.3381	0.2491	0.0618	-1.678E-02
8.300	4.745E 07	1288.824	1240.402	-2.261E-02	0.3381	0.2487	0.0624	-1.656E-02
8.400	4.738E 07	1288.685	1240.510	-2.266E-02	0.3381	0.2483	0.0631	-1.637E-02
8.500	4.730E 07	1288.544	1240.618	-2.270E-02	0.3381	0.2479	0.0637	-1.618E-02
8.600	4.722E 07	1288.403	1240.725	-2.273E-02	0.3381	0.2475	0.0644	-1.600E-02
8.700	4.715E 07	1288.261	1240.833	-2.276E-02	0.3381	0.2471	0.0650	-1.584E-02
8.800	4.707E 07	1288.119	1240.939	-2.278E-02	0.3381	0.2467	0.0656	-1.569E-02
8.900	4.700E 07	1287.976	1241.046	-2.279E-02	0.3381	0.2463	0.0663	-1.554E-02
9.000	4.693E 07	1287.833	1241.152	-2.281E-02	0.3381	0.2459	0.0669	-1.542E-02
9.100	4.686E 07	1287.689	1241.258	-2.281E-02	0.3381	0.2455	0.0676	-1.528E-02

Fig. 2b (cont)

MURGATROYD II CASE 1

TIME, SEC	POWER, WATTS	FUEL TEMP, DEG F	GRAPHITE TEMP, DEG F	PRESSURE RISE, PSI	DELTA K INPUT, PCT	PCT DK REMOVED BY FUEL	PCT DK REMOVED BY GRAPHITE	(1/P)(DP/DT), PER SECOND
9.200	4.678E 07	1287.545	1241.364	-2.283E-02	0.3381	0.2451	0.0682	-1.522E-02
9.300	4.671E 07	1287.401	1241.470	-2.283E-02	0.3381	0.2447	0.0688	-1.513E-02
9.400	4.664E 07	1287.257	1241.575	-2.282E-02	0.3381	0.2443	0.0695	-1.502E-02
9.500	4.657E 07	1287.112	1241.680	-2.282E-02	0.3381	0.2439	0.0701	-1.494E-02
9.600	4.650E 07	1286.967	1241.785	-2.280E-02	0.3381	0.2435	0.0707	-1.485E-02
9.700	4.643E 07	1286.822	1241.889	-2.278E-02	0.3381	0.2431	0.0713	-1.475E-02
9.800	4.637E 07	1286.677	1241.994	-2.277E-02	0.3381	0.2427	0.0720	-1.469E-02
9.900	4.630E 07	1286.532	1242.098	-2.276E-02	0.3381	0.2423	0.0726	-1.465E-02
10.000	4.623E 07	1286.387	1242.201	-2.274E-02	0.3381	0.2419	0.0732	-1.459E-02
10.100	4.616E 07	1286.242	1242.305	-2.272E-02	0.3381	0.2415	0.0738	-1.453E-02
10.200	4.610E 07	1286.097	1242.408	-2.270E-02	0.3381	0.2411	0.0744	-1.448E-02
10.300	4.603E 07	1285.952	1242.511	-2.267E-02	0.3381	0.2407	0.0751	-1.441E-02
10.400	4.596E 07	1285.807	1242.614	-2.265E-02	0.3381	0.2403	0.0757	-1.440E-02
10.500	4.590E 07	1285.662	1242.716	-2.263E-02	0.3381	0.2399	0.0763	-1.437E-02
10.600	4.583E 07	1285.517	1242.819	-2.260E-02	0.3381	0.2394	0.0769	-1.432E-02
10.700	4.577E 07	1285.372	1242.921	-2.257E-02	0.3381	0.2390	0.0775	-1.427E-02
10.800	4.570E 07	1285.228	1243.022	-2.254E-02	0.3381	0.2386	0.0781	-1.425E-02
10.900	4.564E 07	1285.083	1243.124	-2.252E-02	0.3381	0.2382	0.0787	-1.425E-02
11.000	4.557E 07	1284.939	1243.225	-2.249E-02	0.3381	0.2378	0.0793	-1.421E-02

UNCLASSIFIED
ORNL-LR-DWG 67933

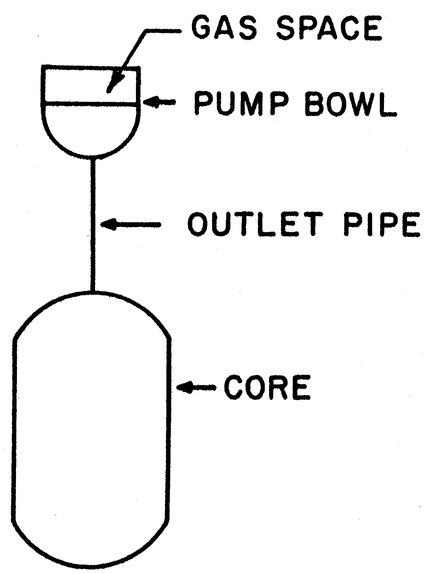


FIG. III SIMPLIFIED MODEL FOR PRESSURE CALCULATIONS

Internal Distribution

1-2. MSRP Director's Office, Rm. 219, Bldg. 9204-1
3. G. M. Adamson
4. L. G. Alexander
5. V. E. Anderson, K-25
6. S. E. Beall
7. M. Bender
8. L. L. Bennett
9. C. E. Bettis
10. E. S. Bettis
11. D. S. Billington
12. M. Blander
13. F. F. Blankenship
14. A. L. Boch
15. E. G. Bohlmann
16. S. E. Bolt
17. C. J. Borkowski
18. C. A. Brandon
19. F. R. Bruce
20. O. W. Burke
21. S. Cantor
22. R. S. Carlsmith
23. W. L. Carter
24. R. D. Cheverton
25. H. C. Claiborne
26. T. E. Cole
27. J. A. Conlin
28. W. H. Cook
29. L. T. Corbin
30. G. A. Cristy
31. F. L. Culler
32. J. G. Delene
33. J. H. DeVan
34. R. G. Donnelly
35. D. A. Douglas
36. N. E. Dunwoody
37. J. R. Engel
38. E. P. Epler
39. W. K. Ergen
40. D. E. Ferguson
41. T. B. Fowler
42. A. P. Fraas
43. J. H. Frye
44. C. H. Gabbard
45. R. B. Gallaher
46. E. H. Gift
47. D. R. Gilfillan
48. B. L. Greenstreet
49. W. R. Grimes
50. A. G. Grindell
51. R. H. Guymon
52. P. H. Harley
53. C. S. Harrill
54. P. N. Haubenreich
55. E. C. Hise
56. H. W. Hoffman
57. P. P. Holz
58. A. S. Householder
59. L. N. Howell
60. J. P. Harvis
61. W. H. Jordan
62. P. R. Kasten
63. R. J. Kedl
64. M. T. Kelley
65. M. J. Kelly
66. T. W. Kerlin
67. S. S. Kirslis
68. J. W. Krewson
69. J. A. Lane
70. W. J. Leonard
71. M. P. Lietzke
72. R. B. Lindauer
73. M. I. Lundin
74. R. N. Lyon
75. H. G. MacPherson
76. F. C. Maienschein
77. W. D. Manly
78. E. R. Mann
79. B. F. Maskewitz, K-25
80. W. B. McDonald
81. H. F. McDuffie
82. C. K. McGlothlan
83. A. J. Miller
84. E. C. Miller
85. R. L. Moore
86. J. C. Moyers
87. E. A. Nephew
88-92. C. W. Nestor
93. T. E. Northup
94. W. R. Osborn
95. L. F. Parsly
96. P. Patriarca
97. H. R. Payne
98. A. M. Perry
99. W. B. Pike
100. P. H. Pitkanen
101. C. A. Preskitt
102. M. Richardson
103. R. C. Robertson
104. T. K. Roche

Distribution - Cont'd

105. M. W. Rosenthal
106. H. W. Savage
107. A. W. Savolainen
108. J. E. Savolainen
109. D. Scott
110. C. H. Secoy
111. J. H. Shaffer
112. M. J. Skinner
113. G. M. Slaughter
114. A. N. Smith
115. O. L. Smith
116. P. G. Smith
117. I. Spiewak
118. B. Squires
119. J. A. Swartout
120. A. Taboada
121. J. R. Tallackson
122. R. E. Thoma
123. M. Tobias
124. D. B. Trauger
125. Marina Tsagaris
126. W. C. Ulrich
127. R. Van Winkle
128. D. R. Vondy
129. B. S. Weaver
130. B. H. Webster
131. A. M. Weinberg
132. J. H. Westsik
133. J. C. White
134. G. E. Whitesides
135. L. V. Wilson
136. C. H. Wodtke
137-138. Reactor Div. Library
139-140. Central Res. Library
141-143. Document Ref. Section
144-146. Laboratory Records
147. ORNL-RC
148. J. L. Crowley

External Distribution

149-150. D. F. Cope, Reactor Division, AEC, ORO
151. H. M. Roth, Division of Research and Development, AEC, ORO
152. F. P. Self, AEC, ORO
153. R. A. DuVal, AEC, Washington
154. T. W. McIntosh, AEC, Washington
155-169. Division of Technical Information Extension, AEC, ORO
170. Mrs. Margaret Butler, Argonne Code Center,
Argonne National Laboratory, Argonne, Illinois

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

ORNL - TM - 203 Addendum

COPY NO. - 118

DATE - May 25, 1962

MURGATROYD - AN IBM 7090 PROGRAM FOR THE ANALYSIS OF THE KINETICS OF THE MSRE

C. W. Nestor, Jr.

Addendum to ORNL-TM-203

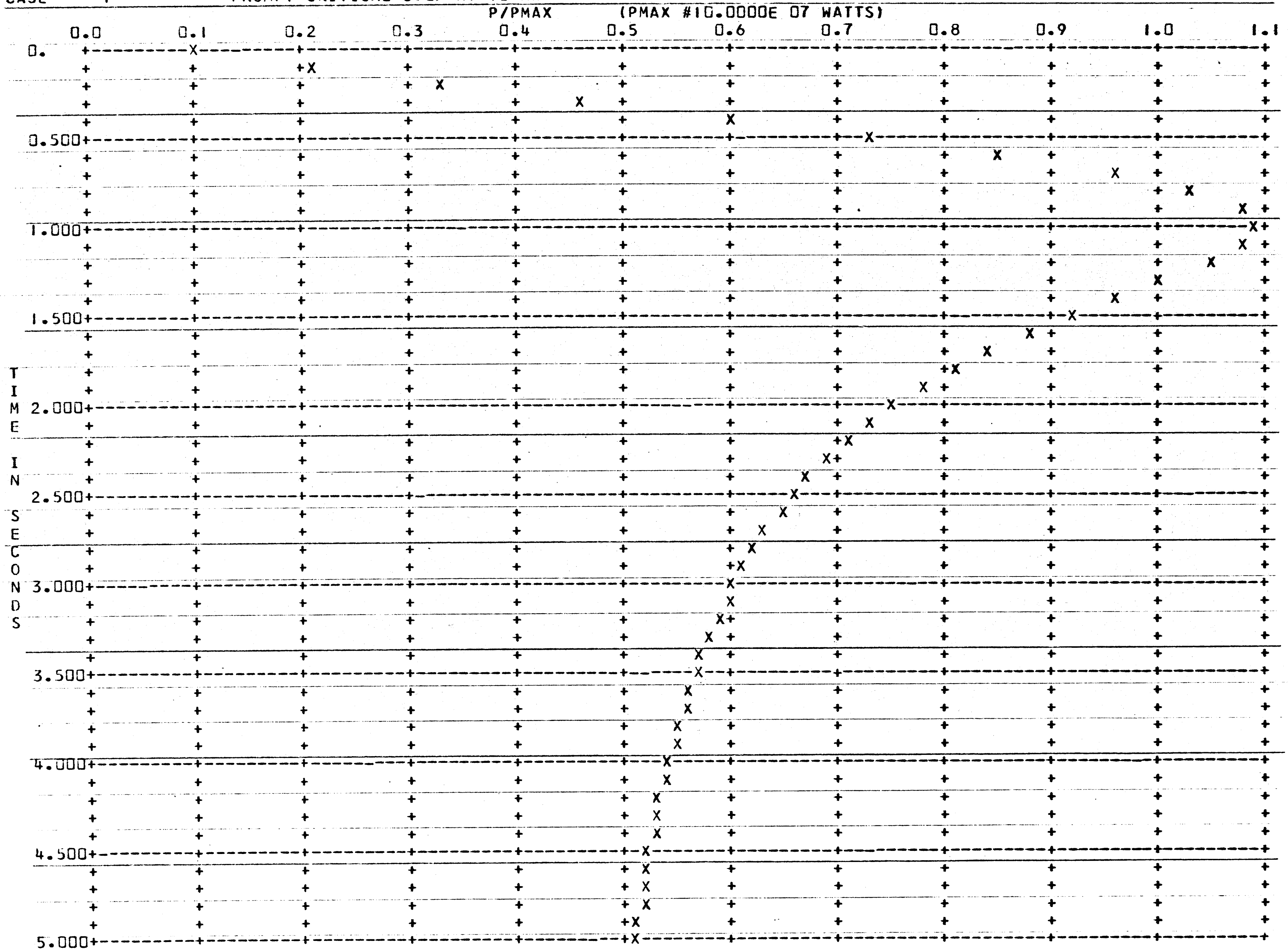
An addition has been made to the IBM-7090 program MURGATROYD to produce a rough graph of the reactor power *versus* time. A logical tape 6 is required for storage of the power *versus* time results in addition to the standard input and output tapes. The plotting frequency (analogous to the printout frequency) is specified in columns 16-21 of the card containing the stop time and the number of ramp rate changes (see p 18, ORNL-TM-203). A sample of the graphical output is attached for the case given as an example on pages 19-25. If the plotting frequency specified in the input is zero or blank, no plot is produced; however, a logical tape 6 must be specified even if no plot is desired.

Corrigendum

On page 15, in the last sentence, for "12AG" read "12A6".

MURGATROYD POWER VS. TIME

CASE 1 PROMPT CRITICAL STEP AT 10 MW



Internal Distribution

1-2. MSRP Director's Office, Rm. 219, Bldg. 9204-1
3. G. M. Adamson
4. L. G. Alexander
5. V. E. Anderson, K-25
6. S. E. Beall
7. M. Bender
8. L. L. Bennett
9. C. E. Bettis
10. E. S. Bettis
11. D. S. Billington
12. M. Blander
13. F. F. Blankenship
14. A. L. Boch
15. E. G. Bohlmann
16. S. E. Bolt
17. C. J. Borkowski
18. C. A. Brandon
19. F. R. Bruce
20. O. W. Burke
21. S. Cantor
22. R. S. Carlsmith
23. W. L. Carter
24. R. D. Cheverton
25. H. C. Claiborne
26. T. E. Cole
27. J. A. Conlin
28. W. H. Cook
29. L. T. Corbin
30. G. A. Cristy
31. F. L. Culler
32. J. G. Delene
33. J. H. DeVan
34. R. G. Donnelly
35. D. A. Douglas
36. N. E. Dunwoody
37. J. R. Engel
38. E. P. Epler
39. W. K. Ergen
40. D. E. Ferguson
41. T. B. Fowler
42. A. P. Fraas
43. J. H. Frye
44. C. H. Gabbard
45. R. B. Gallaher
46. E. H. Gift
47. D. R. Gilfillan
48. B. L. Greenstreet
49. W. R. Grimes
50. A. G. Grindell
51. R. H. Guymon
52. P. H. Harley
53. C. S. Harrill
54. P. N. Haubenreich
55. E. C. Hise
56. H. W. Hoffman
57. P. P. Holz
58. A. S. Householder
59. L. N. Howell
60. J. P. Harvis
61. W. H. Jordan
62. P. R. Kasten
63. R. J. Kedl
64. M. T. Kelley
65. M. J. Kelly
66. T. W. Kerlin
67. S. S. Kirslis
68. J. W. Krewson
69. J. A. Lane
70. W. J. Leonard
71. M. P. Lietzke
72. R. B. Lindauer
73. M. I. Lundin
74. R. N. Lyon
75. H. G. MacPherson
76. F. C. Maienschein
77. W. D. Manly
78. E. R. Mann
79. B. F. Maskewitz, K-25
80. W. B. McDonald
81. H. F. McDuffie
82. C. K. McGlothlan
83. A. J. Miller
84. E. C. Miller
85. R. L. Moore
86. J. C. Moyers
87. E. A. Nephew
88-92. C. W. Nestor
93. T. E. Northup
94. W. R. Osborn
95. L. F. Parsly
96. P. Patriarca
97. H. R. Payne
98. A. M. Perry
99. W. B. Pike
100. P. H. Pitkanen
101. C. A. Preskitt
102. M. Richardson
103. R. C. Robertson
104. T. K. Roche

Distribution - Cont'd

105. M. W. Rosenthal
106. H. W. Savage
107. A. W. Savolainen
108. J. E. Savolainen
109. D. Scott
110. C. H. Secoy
111. J. H. Shaffer
112. M. J. Skinner
113. G. M. Slaughter
114. A. N. Smith
115. O. L. Smith
116. P. G. Smith
117. I. Spiewak
118. B. Squires
119. J. A. Swartout
120. A. Taboada
121. J. R. Tallackson
122. R. E. Thoma
123. M. Tobias
124. D. B. Trauger
125. Marina Tsagaris
126. W. C. Ulrich
127. R. Van Winkle
128. D. R. Vondy
129. B. S. Weaver
130. B. H. Webster
131. A. M. Weinberg
132. J. H. Westsik
133. J. C. White
134. G. E. Whitesides
135. L. V. Wilson
136. C. H. Wodtke
137-138. Reactor Div. Library
139-140. Central Res. Library
141-143. Document Ref. Section
144-146. Laboratory Records
147. ORNL-RC
148. J. L. Crowley

External Distribution

149-150. D. F. Cope, Reactor Division, AEC, ORO
151. H. M. Roth, Division of Research and Development, AEC, ORO
152. F. P. Self, AEC, ORO
153. R. A. DuVal, AEC, Washington
154. T. W. McIntosh, AEC, Washington
155-169. Division of Technical Information Extension, AEC, ORO
170. Mrs. Margaret Butler, Argonne Code Center, Argonne National Laboratory, Argonne, Illinois