

Ax-1 : a computing program for coupled neutronics-hydrodynamics calculations  
on the IBM-704 / by D. Okrent [and others].  
Lemont, Ill. : Argonne National Laboratory, 1959.

Find this Book Online: <https://hdl.handle.net/2027/mdp.39015078509448>

Digitized by Google

Original from  
TECHNICAL REPORT ARCHIVE & IMAGE  
LIBRARY



**[Public Domain, Google-digitized](#)**

We have determined this work to be in the public domain, meaning that it is not subject to copyright. Users are free to copy, use, and redistribute the work in part or in whole. It is possible that current copyright holders, heirs or the estate of the authors of individual portions of the work, such as illustrations or photographs, assert copyrights over these portions. Depending on the nature of subsequent use that is made, additional rights may need to be obtained independently of anything we can address. The digital images and OCR of this work were produced by Google, Inc. (indicated by a watermark on each page in the PageTurner). Google requests that the images and OCR not be re-hosted, redistributed or used commercially. The images are provided for educational, scholarly, non-commercial purposes.

Generated at New York University through HathiTrust on 2025-11-22 04:22 GMT  
<https://hdl.handle.net/2027/mdp.39015078509448>

Y3. At7

AEC

221 ANL-

RESEARCH REPORTS

5977

ANL-5977

# Argonne National Laboratory

## AX-1, A COMPUTING PROGRAM FOR COUPLED NEUTRONICS-HYDRODYNAMICS CALCULATIONS ON THE IBM-704

by

D.Okrent, J.M.Cook, D.Satkus,  
R.B.Lazarus, and M.B.Wells

UNIVERSITY OF  
ARIZONA LIBRARY  
Seydelants Collection  
JUN 80 1959

#### *LEGAL NOTICE*

*This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:*

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or*
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.*

*As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.*

*Price \$ 2.50 . Available from the Office of Technical Services,  
Department of Commerce, Washington 25, D.C.*

ANL-5977  
Physics and Mathematics  
(TID-4500, 14th Ed.)  
AEC Research and  
Development Report

ARGONNE NATIONAL LABORATORY  
P. O. Box 299  
Lemont, Illinois

Ax-1, A COMPUTING PROGRAM FOR COUPLED  
NEUTRONICS-HYDRODYNAMICS CALCULATIONS  
ON THE IBM-704

by

D. Okrent, J. M. Cook and D. Satkus  
of Argonne National Laboratory

and

R. B. Lazarus and M. B. Wells  
of Los Alamos Scientific Laboratory

May, 1959

Operated by The University of Chicago  
under  
Contract W-31-109-eng-38



## TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION . . . . .	3
II. GENERAL DESCRIPTION OF THE PROGRAM . . . . .	5
III. LIST OF SYMBOLS AND DEFINITION OF TERMS . . . . .	8
IV. DISCUSSION OF CONTROLS OF THE PROGRAM . . . . .	22
V. DETAILED FLOW DIAGRAM AND EXPLANATORY NOTES . . . . .	28
VI. FORTRAN LISTING OF PROGRAM . . . . .	48
VII. ROLE OF SENSE SWITCHES, SENSE LIGHTS AND FLAGS . . . . .	65
VIII. LIST OF PAUSES AND STOPS . . . . .	67
IX. OPERATING INSTRUCTIONS . . . . .	69
X. SAMPLE PROBLEM . . . . .	71
A. Input Data . . . . .	81
B. Results . . . . .	85
APPENDIX A: Details of the VJ-OK1 Test . . . . .	101
APPENDIX B: The Time Scale . . . . .	103
APPENDIX C: Discussion of Hydrodynamic Stability Criteria and Shock Wave Treatment . . . . .	105
APPENDIX D: Thermodynamic Considerations . . . . .	106
APPENDIX E: Possible Variations in Program.....Ax-1' . . . . .	108
APPENDIX F: The Ax-1 Tape Dump and Recall Routine . . . . .	110
REFERENCES . . . . .	114
ACKNOWLEDGEMENTS . . . . .	115



**Ax-1, A COMPUTING PROGRAM FOR COUPLED  
NEUTRONICS-HYDRODYNAMICS CALCULATIONS  
ON THE IBM-704**

D. Okrent, J. M. Cook and D. Satkus  
of Argonne National Laboratory

and

R. B. Lazarus and M. B. Wells  
of Los Alamos Scientific Laboratory

**I. INTRODUCTION**

In connection with studies in the safety of fast reactors, it is necessary to calculate the energy yield and explosive force of a variety of hypothetical nuclear accidents.<sup>(1,2)</sup> A valuable analytical technique for calculating such incidents was developed by Bethe and Tait,<sup>(3)</sup> and since modified by Jankus.<sup>(1,2)</sup> To achieve an analytic solution, however, various simplifications and approximations were required, with consequent reduction of accuracy and applicability. A numerical solution, employing high speed digital computers, was needed to improve upon the accuracy available from the analytic solution and to provide a more flexible computational method. To gain this end most efficiently, the Argonne National Laboratory asked for and was granted the full cooperation of the Los Alamos Scientific Laboratory. R. B. Lazarus, assisted by M. B. Wells, drew upon Los Alamos experience in the field of coupled neutronics-hydrodynamics calculations to devise a program reasonably well suited to Argonne's needs. They collaborated closely with J. M. Cook, D. Okrent, and D. Satkus of ANL in the debugging of the original program. As operating experience was gained at ANL, some refinements in the sensitive control apparatus of the program were introduced at ANL, to provide improved accuracy and more efficient use of the computing machine. The program has not been fully optimized in every sense, however, and a reworking should make possible further increases in efficiency. The utilization and a very rough outline of a similar computing program have been given by Stratton, Colvin, and Lazarus,<sup>(4)</sup> but no details of the code were presented.

Modification of Ax-1 to permit the use of other equations of state is under study. A special version designed to permit a study of the errors introduced by certain assumptions in the analytic technique is described in Appendix E, as Ax-1'.

The presentation to follow includes a very general outline of the program, a semi-detailed flow diagram which emphasizes the physics and control aspects of the calculation, and then a detailed flow diagram and listing of the program (which is written in Fortran). Explanatory notes accompany the diagrams.

Following the notes on the program, master lists detailing the roles of the sense switches, sense lights, pauses, and stops are presented. The operating instructions are then given, followed by a sample problem, including detailed information on input data.

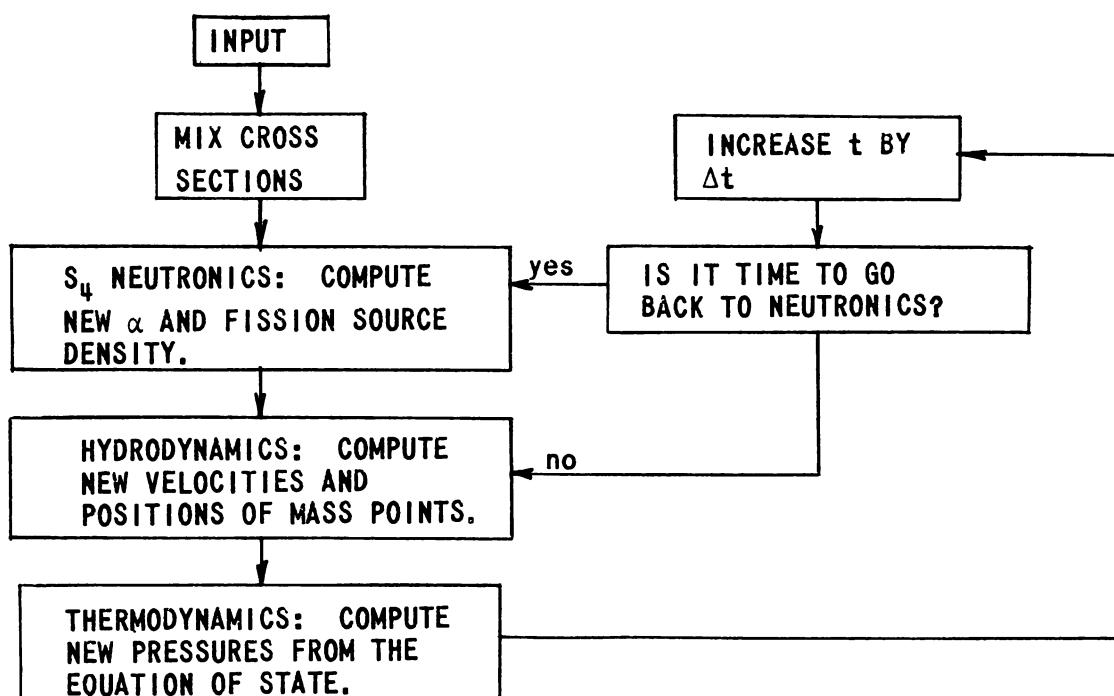
The theoretical discussion has been kept primarily in the appendices, and is generally in outline form with references, rather than in full exposition.

## II. GENERAL DESCRIPTION OF THE PROGRAM

Given a spherically symmetric, super-prompt critical system, the program computes the variation in time and space of the specific energy, temperature, pressure, density, and velocity. As a function of time it computes the reactivity (in the form of alpha, the inverse period), the power, the total energy, and the position of the boundaries of the various shells into which the system has been subdivided. All delayed neutron effects are ignored, and no allowance is made for transfer of heat by conduction or radiation. The input information includes the initial reactivity or geometry, the initial velocities and temperatures of the mass points, the composition and disposition of materials, the appropriate equation of state constants, and the microscopic neutron cross sections.

For calculational purposes the spherical assembly is divided into a number of hypothetical spherical shells or mass points. The neutronics of this system is calculated in conventional fashion, using the  $S_n$  method,(5,6,7) thereby providing a power distribution across the radial network, as well as the alpha of the system.

From the neutronics calculation one goes to the thermodynamics and hydrodynamics portion to calculate the variation of power, temperature, pressure, density, and velocity with time. One may characterize the overall arrangement by means of the following block diagram.



The calculation proceeds initially like the usual  $S_n$  calculation. After computing average cross sections for each of the spherical shells, in the mixture code, the program proceeds either to a calculation of alpha ( $= \frac{k_{ex}}{l}$ ) for the specified configuration, or to a scaling of the reactor radii to provide the alpha originally specified. Before proceeding to the hydrodynamics the code also computes  $k_{eff}$  for the initially converged configuration, if so requested.

The neutronics portion of the program is always done in the  $S_4$  approximation. It supplies to the succeeding portions of the program the alpha corresponding to that specific configuration. It also supplies a relative power distribution, to be used in assigning the increase in energy within each spherical shell or mass point, while this configuration remains a reasonable approximation.

The program proceeds into the hydrodynamic and thermodynamic portions. For one or more short time intervals,  $\Delta t$ , alpha is considered to remain constant while the power varies as  $e^{\alpha \Delta t}$ . From the pressure gradients in the system the average accelerations of the mass points are computed and, hence, the new velocities at the end of a time interval. These, in turn, lead to the new radial positions of each shell boundary at the end of a time interval. The solution is performed in a Lagrangian coordinate system, i.e., the mesh is embedded in the material, and follows it along throughout its motion.

During the time interval energy is added to the system (the average power times  $\Delta t$ ) and this is distributed among the shells in accord with the previously calculated fission distribution. By allowing for the work done by or on a shell in expansion or compression, the net change in internal energy is computed, and from the internal energy a new pressure and temperature are obtained. In the Ax-1 program, the relation between pressure and temperature has been taken to be linear, namely

$$P_H = \alpha \rho + \beta \theta + \tau$$

while the specific heat at constant volume is given by

$$\left( \frac{\partial E}{\partial \theta} \right)_V = A_{cv} + B_{cv}\theta$$

where

$P_H$  = pressure  
 $\rho$  = density  
 $\theta$  = temperature  
 $E$  = internal energy

The various coefficients are allowed to vary from shell to shell, but no provision is made for mixing several substances within a shell to generate average values of these coefficients, as with cross sections.

The thermodynamic equations are solved using an iterative procedure, guessing the new pressure at each mass point to be the old pressure for the first iteration. The so-called viscous pressure, a mathematical procedure devised by von Neumann and Richtmyer (see Reference 8 and Appendix C) is included to permit thermodynamic and hydrodynamic calculations in the presence of a steep shock front. Hence, the total pressure is the sum of the hydrodynamic pressure,  $P_H$ , and the synthetic viscous pressure,  $P_v$ .

When calculation of the thermo- and hydro-dynamic changes during the time interval  $\Delta t$  is complete (a hydrocycle), a series of tests are run, and the program either proceeds with another hydrocycle or goes back to the neutronics calculation.

To control the pace of a problem, the code continually examines the magnitude or rate of change of certain crucial parameters, and varies the  $\Delta t$  of a hydrocycle or the number of hydrocycles per neutron cycle accordingly. This latter number begins at unity and is allowed to build up gradually if the forces present are not changing alpha too rapidly or modifying the density of a mass point radically. When the power variation in a hydrocycle, or the change in alpha between neutron cycles, gets so large as to damage the accuracy of the solution, the pace of the calculation is slowed automatically - or stopped in extreme cases.

### III. LIST OF SYMBOLS AND DEFINITION OF TERMS

The program is written in Fortran, forcing a symbolic notation consistent with the requirements of the Fortran system and not always identical to customary physical usage. Hence, a dual list of symbols follows, that on the left comprising the Fortran symbols in alphabetical order. There is generally an associated physical symbol next to it, together with a translation or definition of the pair. In the explanation which follows, the physical symbol will generally be used.

The system of units used in the calculation is somewhat different from that conventionally used by the reactor physicist, so a brief discussion is given.

The basic choice for mass, length, time, and temperature is as follows:

unit of mass = grams

unit of length = cm

unit of time =  $\mu$ sec

unit of temperature = kev

Then, it follows that

the unit of velocity = cm/ $\mu$ sec

the unit of acceleration = cm/ $\mu$ sec<sup>2</sup>

the unit of force = gm cm/ $\mu$ sec<sup>2</sup> (=  $10^{12}$  dynes)

the unit of energy = gm cm<sup>2</sup>/ $\mu$ sec<sup>2</sup> (=  $10^{12}$  ergs)

the unit of power = gm cm<sup>2</sup>/ $\mu$ sec<sup>3</sup> (=  $10^{12}$  ergs/ $\mu$ sec)

the unit of pressure =  $\frac{g}{\mu \text{sec}^2 \cdot \text{cm}}$  ( $= 10^{12} \frac{\text{dynes}}{\text{cm}^2} = \text{megabars}$ )

the unit of specific heat =  $\frac{\text{gm cm}^2}{\mu \text{sec}^2 \cdot \text{kev}}$

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
A(1) A(2) A(3) A(4)			Storages for previous $\alpha$ 's
ACV(M)	$A_{cv}(M)$	$\frac{\text{cm}^2}{\mu\text{sec}^2 \text{kev}}$	Constant in equation $C_V = A_{cv} + B_{cv} \theta$
AITCT			Total number of $S_n$ iterations completed
AK(I)	$K_{eff,i}$		$K_{eff}$ from previous iteration
AKEFF	$K_{eff}$		Multiplication factor
ALPH(M)	$\alpha(M)$	$\frac{\text{cm}^2}{\mu \text{ sec}^2}$	Constant in equation of state
ALPHA	$\alpha$	$\mu \text{ sec}^{-1}$	Inverse of reactor period = $\frac{K_{ex}}{\ell}$
ALPHAO	$\alpha_0$	$\mu \text{ sec}^{-1}$	Absolute value of alpha at Order No. 6820, the maximum absolute value of alpha at Order No. 9014.
ALPHA P	$\alpha'$	$\mu \text{ sec}^{-1}$	The alpha resulting from the previous converged $S_n$ calculation
AM(1)	$M(1)$		
...	...		$S_n$ constants
AM(5)	$M(5)$		
AMBAR (1)	$\bar{M}(1)$		
...	...		$S_n$ constants
AMBAR (5)	$\bar{M}(5)$		

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
AMBART	$\bar{M}_T$		$S_n$ constant
AMT	$M_T$		$S_n$ constant
ANU (IG)	$\nu(g)$		Fraction of fission neutrons born into g'th group
ANUSIG (IG, N)	$(\nu\sigma_f)g, N$	Barns	Microscopic fission cross section times average number of neutrons emitted per fission
B(1)	B(1)		
...	...		$S_n$ constants
B(5)	B(5)		
BCV(M)	$B_{cv}(M)$	$\frac{\text{cm}^2}{\mu\text{sec}^2 \text{kev}^2}$	Constant in equation $C_V = A_{cv} + B_{cv}\theta$
BETA(M)	$\beta(M)$	$\frac{\text{g}}{\text{cm} \mu\text{sec}^2 \text{kev}}$	Constant in equation of state $(P_H = \alpha\rho + \beta\theta + \tau)$
BS	$B_S$		Intermediate term in $S_n$
BT	$B_T$		$S_n$ constant
CHECK			Fractional difference in total energy as computed in two different ways.
CSC	$C_{sc}$		Courant stability constant. Is largest estimate for $\gamma(\gamma - 1) \approx \left(\frac{\partial p}{\partial \rho}\right)_s / E_{int} = \frac{C^2}{E_{int}}$
CVP	$C_{vp}$		Viscous pressure coefficient for shock smearing (See Appendix C)

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
DELE	$\Delta E$	$\frac{10^{12} \text{ ergs}}{\text{g}}$	Increment in specific internal energy during hydrocycle.
DELQ	$\Delta Q$	$\frac{10^{12} \text{ ergs}}{\text{g}}$	Energy per gram added to mass point I during hydrocycle.
DELR	$\Delta R$	cm	$= R(I) - R(I-1)$ , outer radius of mass point I less inner radius. Is negative in event of radii crossing.
DELT	$\Delta T$	$\mu\text{sec}$	Time increment between hydrocycles in successive stages in the calculation
DELTA(I)	$\Delta(I)$	cm	$\bar{R}(I) - R(I-1)$
DELTP	$\Delta t'$	$\mu\text{sec}$	The time interval appropriate to calculations of changes in velocity or power (See Appendix B). Equals $\Delta t$ except when $\Delta t$ is halved or doubled.
DELV	$\Delta V$	$\text{cm}^3/\text{g}$	$= \frac{1}{\rho_{\text{Hyd}}^T} - \frac{1}{\rho_{\text{Hyd}}^I}$ , the change in specific volume during hydrocycle
DTMAX	$\Delta t_{\max}$	$\mu\text{sec}$	Largest $\Delta t$ allowed
E(I)	$E(I)$		$= \rho_{\text{neut}}(I) \sum_g \sigma_{gg, K(I)} \cdot N_g(I)$ , the elastic collision density for new $S_n$ calculation
EN(IG, I)	$N_g(I)$		Total flux in group g at $\bar{R}(I)$
ENN(I, J)	$N(I, \mu_j)$		Flux in direction J at $R(I)$ for current group or last group calculated

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
ENNN(I)	N(I)		$= \sum_g \frac{N_g(I)}{V_g}$ , average inverse neutron velocity at mass point I
EPS	$\epsilon$		Internal parameter set equal to EPSA, EPSR, or EPSK in accordance with current calculations.
EPSI	$\epsilon_I$	megabars	Largest negligible pressure, needed in test for convergence of hydrodynamic pressure when pressure is small.
EPSA	$\epsilon_A$	$\mu\text{sec}^{-1}$	Convergence criterion on calculation of alpha.
EPSK	$\epsilon_K$		Convergence criterion on $K_{\text{eff}}$ calculation.
EPSR	$\epsilon_R$	cm	Convergence criterion on outer radius when radius is varied to provide specified alpha.
ERRLCL	Error Local	$\frac{10^{12} \text{ ergs}}{\text{g}}$	The maximum difference between the specific internal energy at the various mass points computed in two different ways. (See Appendix D)
ETA 1	$\eta_1$		Convergence criterion for iteration on hydrodynamic pressure in equation of state calculation.
ETA 2	$\eta_2$		1/4 the maximum value for $\alpha \Delta T$ which is tolerated without halving $\Delta T$ .

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
ETA 3	$\eta_3$		Tolerance on fractional change in alpha between successive $S_n$ calculations. If exceeded, $NS_4$ is reduced.
F (I)	F (I)		Relative fission density of zone between $R(I)$ and $R(I - 1)$ .
F BAR	$\bar{F}$		$= \sum_I T(I) F(I)$ , total fissions in system.*
FE BAR	$\bar{FE}$		$= \sum_I WN(I) \cdot E(I)$ , the elastic collisions for new $S_n$ calculation, weighted with the new flux.*
FE BAR P	$\bar{FE}'$		The elastic collisions for the previous $S_n$ calculation, weighted with the new flux.*
FEN BAR	$\bar{FN}$		$= \sum_I WN(I) \cdot \sum_{g=1}^G \frac{n_g(I)}{V_g}$ , average inverse velocity weighted with the new flux.*
F FAKE			Internal parameter in convergence test for $S_n$ (= 0 if converged).
FF BAR	$\bar{FF}$		$= \sum_I WN(I) \cdot F(I)$ , the fissions for new $S_n$ calculation, weighted with the new flux.*
FF BAR P	$\bar{FF}'$		The fissions for the previous $S_n$ calculation, weighted with the new flux.*

\*These quantities lack a factor of  $4\pi$ .

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
FLAG 1			If $\alpha$ becomes negative having once been positive and if the power falls to zero or less (as determined by the test, is $Q - Q' > 0 ?$ ), FLAG 1 sets $N_{S4}$ equal to 30,000.
H(I)			$= \Delta(I) \left( \sigma_{g,n} \rho(I) + \frac{\alpha}{V_g} \right)$ for alpha calculation - intermediate term in $S_n$ calculation proportional to removal cross section
HE(I)	$E_{int}(I)$	$10^{12} \text{ ergs}$ gram	Specific internal energy of mass point I
HEO(I)	$E_0(I)$		Constant of integration in equation for internal energy. See Appendix D
HMASS(I)	$H_{mass}(I)$	grams	Mass in region between $R(I)$ and $R(I-1)$ (or mass point I), except for factor of $4\pi/3$
HP(I)	$P_H(I)$	megabars	Pressure, including viscous pressure, which satisfied last hydrocycle calculation
HPBAR	$\bar{P}_H$	megabars	Maximum pressure in system
HPT	$P_H^T$	megabars	Temporary value of $P_H(I)$ used to begin iteration on pressure each iteration
I			Mass point number
ICNTRL	$\alpha$ -control		Input controlling $\alpha$ to be used (=0 if radii are to be scaled to fit the input $\alpha$ =0 if $\alpha$ is to be calculated from the given configuration)

Fortran Symbol	Physical or Mathematical Symbol	Units	Definition
IG	g		Energy group index
IGMAX	G		Number of energy groups
IH	h		Energy group index
II			Dummy variable
IMAX	$I_{\max}$		The total number of zones (or real mass points) + 1. (R(1) = 0)
IRCNBR			Number of last memory dump
J			Dummy label used for stor- age of thermodynamic properties of materials.
JMAX	$J_{\max}$		Largest J to have appeared in the calculation at any time.
K(I)	K(I)		Material label of I'th mass point
KCALC			Internal parameter used to initiate calculation of $k_{\text{eff}}$ .
KCNTRL			Input parameter for re- questing calculation of $k_{\text{eff}}$ corresponding to initially converged alpha calculation = 01 if calculation is desired = 00 if calculation is not desired.
KP(J)	$K'(J)$		Temporary storage used for keeping track of material labels read in.
L			Dummy variable

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
LDONT			A temporary storage which denotes when it is time to print on tape, or both online and on tape.
M			Mixture number
MA	$M_a$		The number of the particular substance being used in the calculation at a given time.
MMAX	$M_{\max}$		Number of mixtures the code is to fabricate.
MN(M, IS)	$N_{M,i}$		The I'th substance to appear in the mixture M
N			Dummy variable
NDMAX	$ND_{\max}$		Number of hydrodynamic cycles between memory dumps (= 64).
NDUMP			NDMAX minus number of hydrodynamic cycles since last memory dump
NH			$NH \Delta T$ = total time elapsed. When $\Delta T$ is halved, NH is doubled. Thus it is a hydrodynamic cycle number, after a fashion
NIT	$N_{it}$		Number of iterations in pressure calculation
NITMAX	$N_{it \max}$		Maximum number of iterations allowed in the pressure calculation. (= 300). Pause 11 follows if $N_{it \max}$ is reached.

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
NL			NL <sub>max</sub> - NL is the number of hydrocycles since $\Delta T$ was doubled.
NLMAX	NL <sub>max</sub>		Minimum number of hydrocycles between doubling of $\Delta T$ (= 64).
NMAX	N <sub>max</sub>		Number of substances for which cross sections are to be read in.
NP	N <sub>p</sub>		Number of hydrodynamic cycles between detailed print-outs on-line.
NPOFF	N <sub>p</sub> , off		Number of hydrodynamic cycles between detailed-outs off-line.
NPOFFP	N <sub>p</sub> ', off		Number of hydrodynamic cycles between detailed prints off-line after VJ-OK test on relative change in alpha due to pressure build-up is passed.
NS 4	N <sub>S4</sub>		Number of hydrodynamics cycles between S <sub>n</sub> cycles.
NS4R	N <sub>S4R</sub>		Number of hydrodynamics cycles since last S <sub>n</sub> cycle.
OK1			Test parameter used in VJ-OK test. If OK-1 is exceeded, N <sub>S4</sub> is halved.
OK 2			Test parameter used in VJ-OK test. If OK-2 is exceeded, N <sub>S4</sub> → 1.
P(M, IS)			The atom fraction of I'th substance, to appear in the mixture M.

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
PBAR	$\bar{P}$	megabar cm <sup>3</sup>	$= \sum_I P_H(I) \cdot T(I)$ is $\frac{1}{4\pi} \times$ volume integral of pressure.
POWER		$10^{12} \text{ ergs}$ $\mu \text{ sec}$	Total energy generated in the reactor per $\mu\text{sec}$ .
POWNGL		$10^{12} \text{ ergs}$ $\mu \text{ sec}$	Power following burst after which negligible change in total energy occurs.
PSTAR	P*	megabars	Temporary value of $P_H(I)$ which results from iteration on pressure. Goes to $P_H^T$ if not converged, goes to $P_H^{(I)}$ if converged.
PTEST		megabars	Maximum local pressure allowed without bothering with VJ-OK test for relative change in alpha.
Q	Q	$10^{12} \text{ ergs}$	Total energy (except for factor of $\frac{4\pi}{3}$ ) at end of present hydrocycle.
QBAR	$\bar{Q}$		Internal parameter in cal- culation of energy incre- ment during time interval.
QP	Q <sub>P</sub>	$10^{12} \text{ ergs}$	Total energy at end of previous hydrocycle.
QPRIME	Q'	$10^{12} \text{ ergs}$	Total energy (except for factor of $\frac{4\pi}{3}$ )
R(I)	R(I)	cm	Outer radius of mass point, I. (R(I) = 0)
RBAR(I)	$\bar{R}(I)$	cm	$\frac{1}{2}[R(I) + R(I-1)]$ = average radius of (I-1)'th region.

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
RHO(I)	$\rho_{\text{neut}}(I)$	$10^{24} \text{ atoms/cm}^3$	Atom density of the region between R(I) and R(I - 1).
RHOT	$\rho_{\text{Hyd}}^T$	$\text{g/cm}^3$	Density of mass point I at end of new hydrocycle
RIE	Running E <sub>Internal</sub>	$10^{12} \text{ ergs/gram}$	Specific internal energy of mass point I computed in alternate fashion for comparison with E <sub>internal</sub> (I). (See Appendix D)
RKE	Running E <sub>Kinetic</sub>	$10^{12} \text{ ergs/gram}$	Kinetic energy per gram for mass point I
RL(I)	R <sub>L</sub> (I)		Lagrangian coordinate of mass point I, is invariant with time. $\rho_{\text{hyd}} R^3 = R_L^3$
RO(I)	$\rho_{\text{Hyd}}(I)$	$\frac{\text{g}}{\text{cm}^3}$	Density of mass point I at beginning of new hydrocycle.
ROLAB(M)	$\rho_{\text{Lab}}(M)$	$\frac{10^{-24} \text{ g}}{\text{atom}}$	Conversion factor between atomic density and mass density ( $\rho_{\text{hyd}} = \rho_{\text{lab}} \times \rho_{\text{neut}}$ )
ROSN(I)	RO <sub>sn</sub> (I)	$\text{g/cm}^3$	Density of mass point I during S <sub>n</sub> calculation
S(I)			$\frac{\Delta R(I)}{R(\bar{I})}$
SIG(IG, N)	$\sigma_{g,N}$	barns	Microscopic transport cross section for substance N in group g
SIGMA (IG, IH, N)	$\sigma_{gh,N}$	barns	Microscopic scattering cross section from group h to g for substance N
SO(I)	S <sub>o</sub> (I)		$= 4 \Delta(I) (\nu_g F(I) + \rho_{\text{neut}}(I) \sum_h N_h(I) \sigma_{g \leftarrow h}),$ the term in S <sub>n</sub> calculation proportional to neutron source.

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
S4R	$S_4 R$		Floating point notation for $N_{S4}$
SUM(IH)	$\Sigma_h$		SUM has no unique definition.
SUM 1	$\Sigma_1$		SUM is used to provide storage space for various numbers in the neutron flux calculations.
SUM 2	$\Sigma_2$		
T(I)		$cm^3$	$1/3 [R(I)^3 - R(I-1)^3] = \frac{1}{4\pi} \times$ volume of region between $R(I)$ and $R(I-1)$
TAU(M)	$\tau (M)$	megabars	Constant in equation of state $p = \alpha\rho + \beta\theta + \tau$
THET	$\theta$	kev	Temporary value of $\theta(I)$ used during iteration on pressure. Goes to $\theta(I)$ at end of hydrocycle when convergence is attained.
THETA(I)	$\theta(I)$	kev	Temperature of zone between $R(I)$ and $R(I-1)$
TOTIEN	$E_{internal}$	$10^{12}$ ergs	Total internal energy
TOTKE	$E_{kinetic}$	$10^{12}$ ergs	Total kinetic energy
U(I)	$U(I)$	$\frac{cm}{\mu sec}$	Velocity of i'th boundary
V(IG)	$V_g$	$\frac{cm}{\mu sec}$	Velocity of neutrons in g'th energy group
VJ		$\frac{1}{g \ cm^2}$	Input parameter for VJ - OK test on relative change in alpha. When limit is exceeded, $N_{S4}$ is reduced. See input sheets and Appendix A for exact definition.

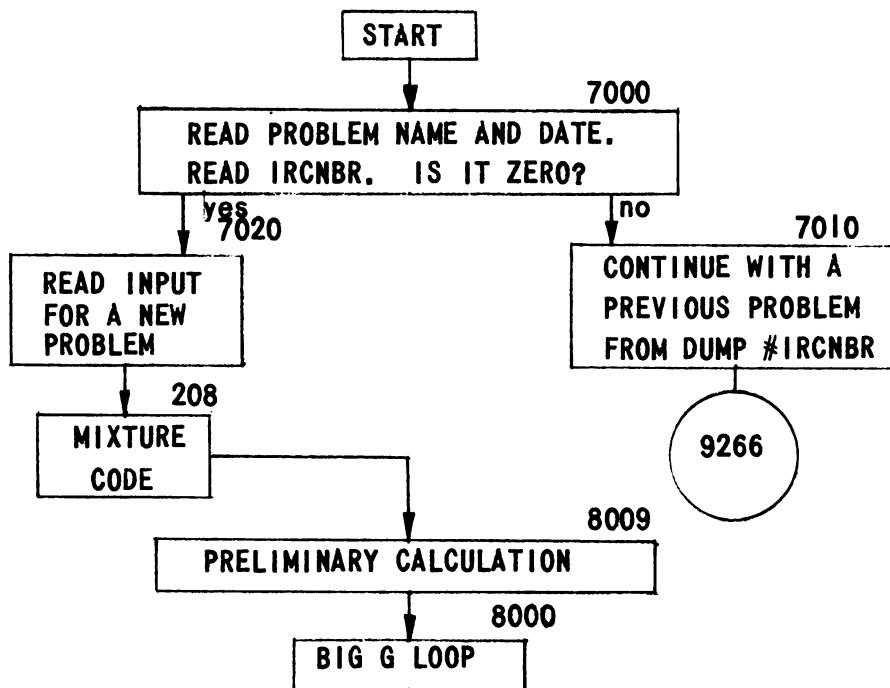
<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
VP	$P_v$	megabars	Viscous pressure (See Appendix C) $= C_{vp} \rho_{Hyd}^T \left( \rho_{Hyd}^T \cdot \Delta V \cdot \frac{\Delta R}{\Delta t} \right)^2$
W			Criterion for stability of hydrodynamic calculation. (See Appendix C). Is maximum value of $W_R$
WN(I)			$\sum_{g=1}^G N_g(I) \cdot T(I)$ , is volume element times flux for region between $R(I)$ and $R(I-1)$ *
WR			Criterion for stability of hydrodynamic calculation. (See Appendix C) $= C_{sc} \left  E_{int}(I) \right  \frac{(\Delta T)^2}{(\Delta R)^2}$ $+ 4 C_{vp} \rho_{Hyd}^T \left  \Delta V \right $
Z			Dummy internal parameter

\*These quantities lack a factor of  $4\pi$ .

#### IV. DISCUSSION OF CONTROLS OF THE PROGRAM

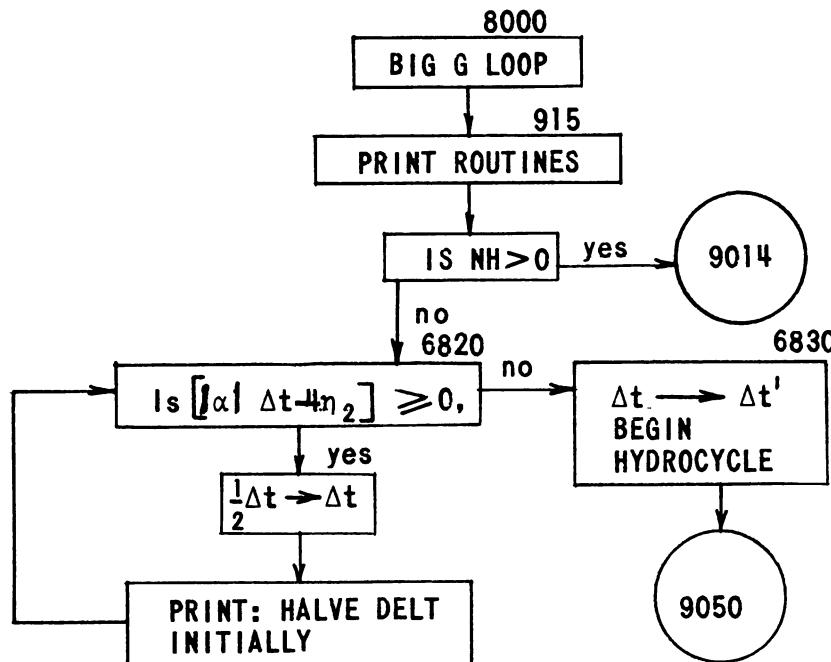
The course of the solution and many of the controls thereon are explained in this section with the aid of a flow diagram. Details of the  $S_n$  calculation, the mixture code, and various other aspects not directly pertinent to this area of understanding are left for a later section covering the entire program step by step. Order numbers corresponding to various sequences of events are usually indicated in the upper right hand corner of the boxes in the flow diagram. It is cautioned that at times steps have been omitted to simplify an explanation.

The first illustration outlines the steps followed at the start of a problem.

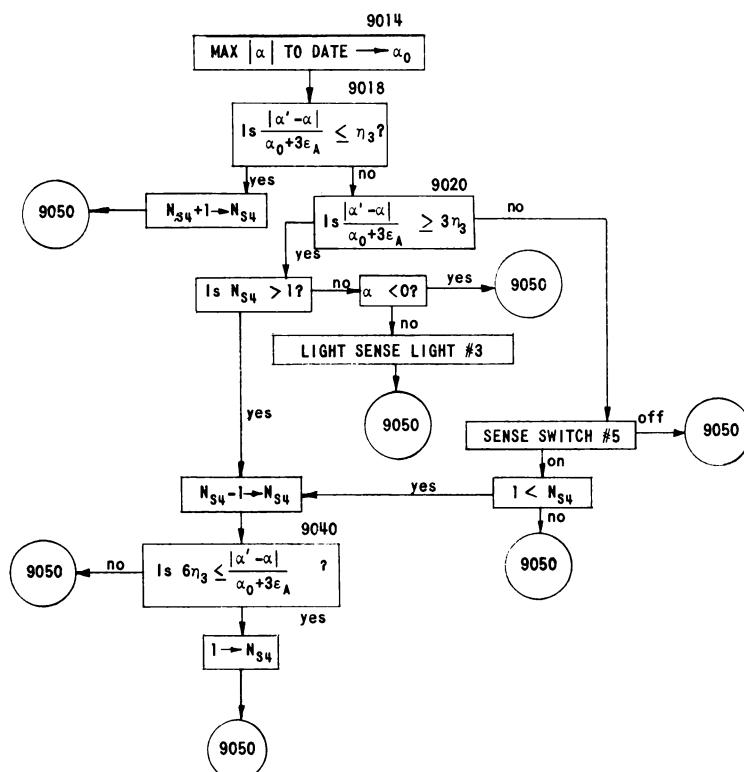


The  $S_n$  calculation (or Big G Loop) is treated like a black box in this section. It is noted that the problem originator can request the computing machine to scale the radii to provide some initial alpha. Also, the machine will calculate and print the  $k_{eff}$  of the initially converged configuration if so requested, enabling a determination of the neutron life-time,  $\ell = K_{ex}/\alpha$ .

When the  $S_n$  calculation has converged, the program begins to exercise control on  $\Delta t$ , the time interval, as follows.

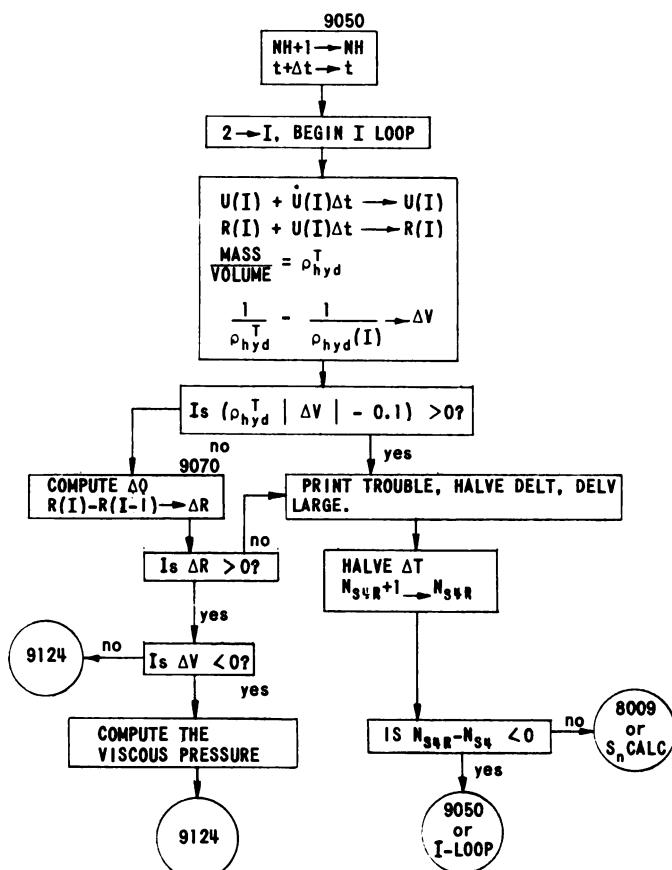


Thus, if  $\alpha\Delta t$ , the fractional change in power per hydrocycle, is too great in the original specification,  $\Delta t$  is reduced. At Order 9014, further controls are exercised following all neutronics calculations except the first.



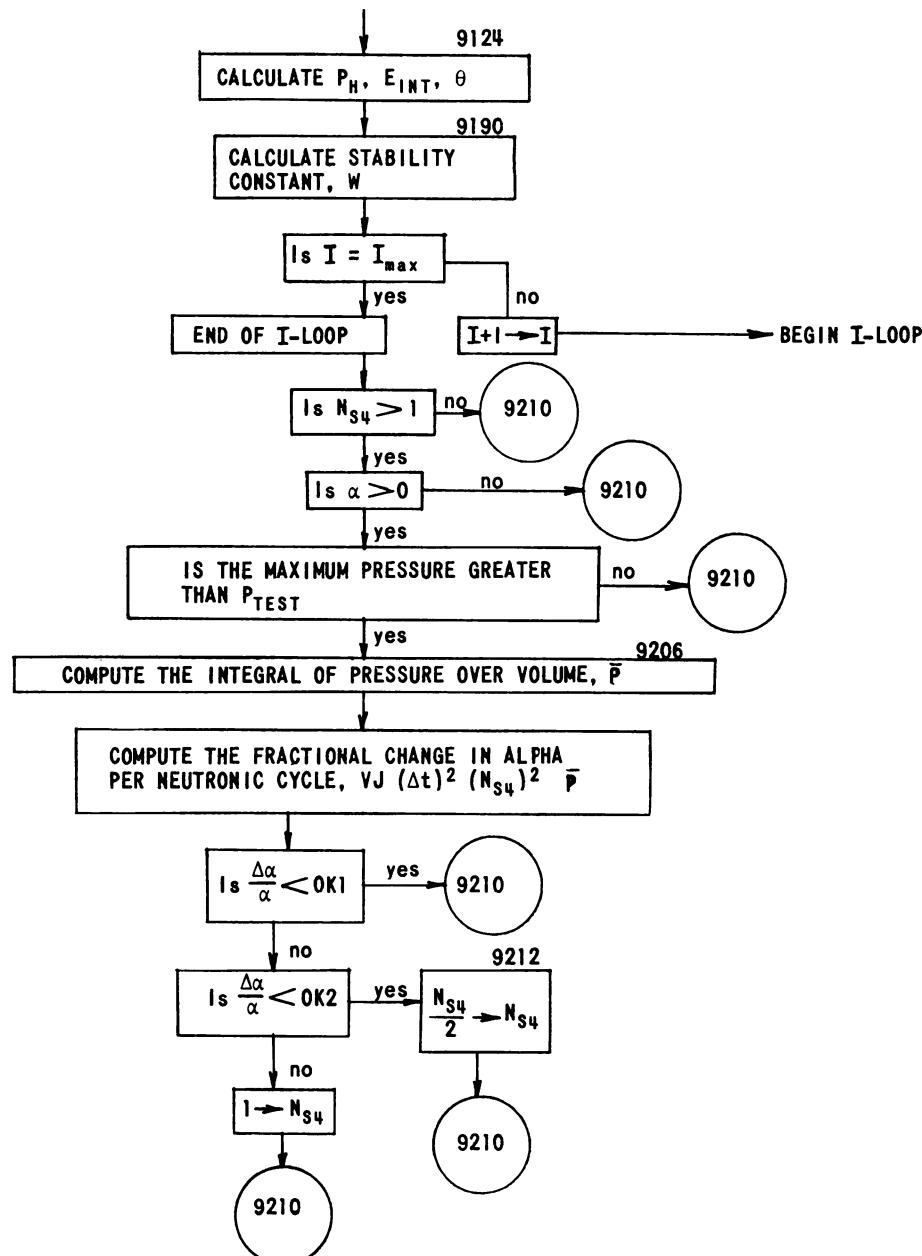
In this sequence the last two alphas are compared to see if alpha is changing too slowly or too rapidly between successive  $S_n$  calculations. If the difference is very small,  $N_{S4}$ , the number of hydrocycles per neutron cycle, is increased by one. This number starts at unity and slowly builds up during a typical burst where a step function of reactivity is inserted at very low power. The program then sends the computation to Order 9050 to begin a hydrocycle. If the difference in alphas, compared to the maximum alpha encountered, exceeds  $\eta_3$  but not  $3\eta_3$ , the hydrocycle begins unless the operator had decided, based on observation of the output, that  $N_{S4}$  should be reduced. In this case he turns on (or depresses) Sense Switch No. 5, which reduces  $N_{S4}$  by one before performing the hydrocycle. If  $3\eta_3$  is exceeded,  $N_{S4}$  is reduced by one and the comparison is again made, this time with the upper limit,  $6\eta_3$ . If this is not exceeded, the hydrocycle proceeds. If it is,  $N_{S4}$  is set all the way back to unity before the hydrocycle begins. However, if  $N_{S4}$  was already unity when  $3\eta_3$  was exceeded, sense light No. 3 is turned on before beginning the hydrocycle. Following the cycle, the time interval  $\Delta t$  will be halved, since there is no further recourse to  $N_{S4}$  to control the variation in alpha between successive  $S_n$  calculations.

We continue from 9050.



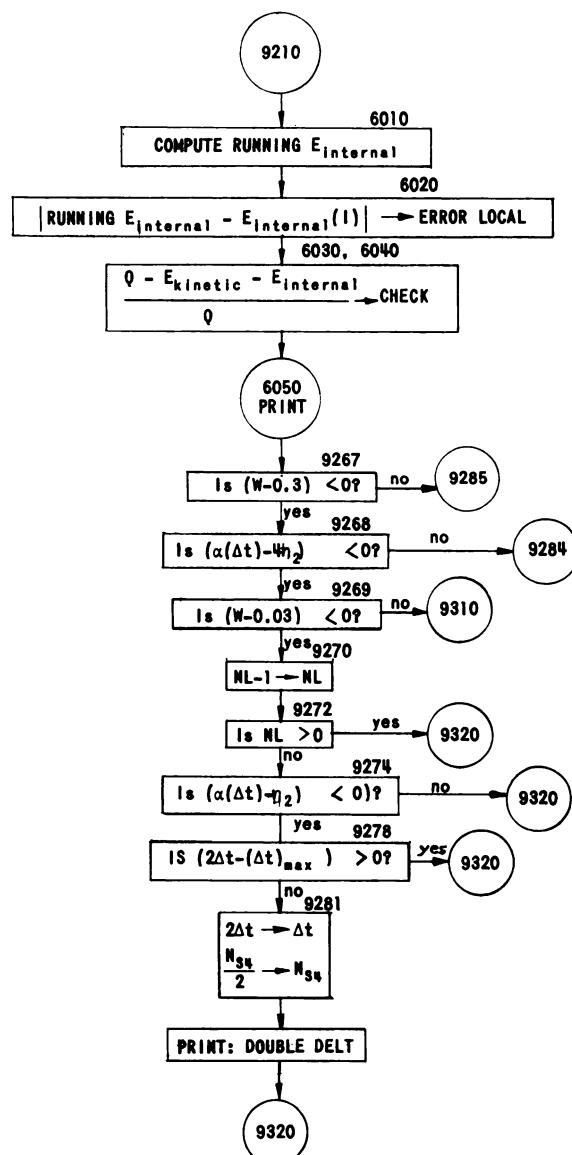
In this last set of steps control is exercised on the density change occurring in any volume element in a single hydrocycle. If it is too great,  $\Delta t$  is halved. Or, if the motion of one radial boundary should be so great as to cross the next boundary, the time interval is also halved. The presence of these serious difficulties in the course of the solution is printed on the output for the benefit of the operator.

The viscous pressure is a mechanism devised to permit calculation without the ordinary difficulties which would accompany the passage of strong shock waves. (See Appendix C).



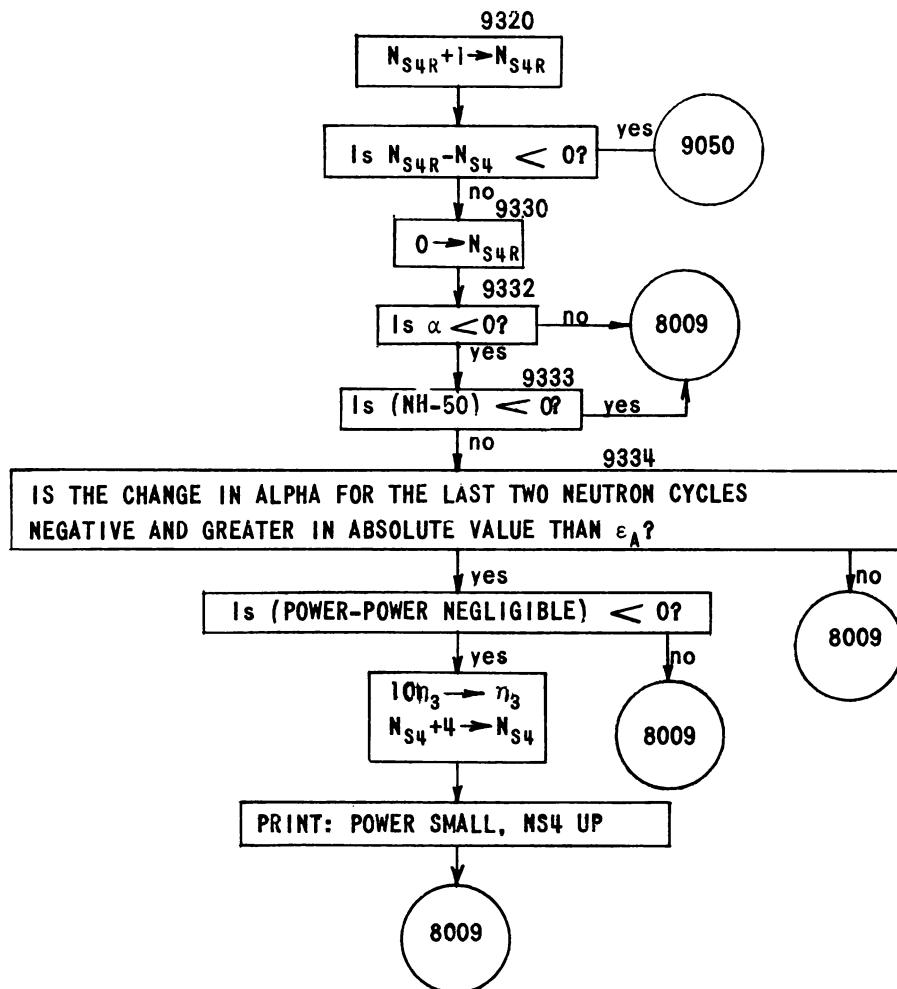
In this sequence a criterion for stability of the calculation is computed which is designed to prevent the generation of excessively high changes in density per hydrocycle. The criterion, W, will be examined later in the program. The controls then ask a series of questions designed to exercise a control on the rate of change of alpha per neutronics cycle during the peak of the burst. Not wishing to keep  $N_{S4}$  small during the low power portion, a test is installed to reduce  $N_{S4}$  when the rate of change of alpha becomes significant. (See Appendix A).

From Order 9210, the program goes on to a pair of checks on the numerical accuracy of the computation. First the internal energy at each mass point is computed in an alternate fashion and compared with the previous calculation. Second, the sum of kinetic and internal energies is computed and compared with Q.



Following the check on numerical accuracy, which is merely printed out for the information of the problem originator, a series of questions are asked to determine whether the time interval  $\Delta t$  is appropriate. If  $W$ , the stability function, is larger than 0.3,  $\Delta t$  is halved (9285, 9290). If the fractional change of power per cycle,  $\alpha\Delta t$ , exceeds  $4\eta_2$ ,  $\Delta t$  is halved, assuming the stability test has not already done so (9284, 9290). If the problem has gone through  $N_{Max}$  hydrocycles since the last doubling of  $\Delta t$ , and if  $W$  and  $\alpha\Delta t$  are sufficiently small,  $\Delta t$  is doubled.

When the above tests are completed  $N_{S4R} + 1 \rightarrow N_{S4R+1}$  and if  $N_{S4R} < N_{S4}$ , a new hydrocycle is begun at Order 9050. Otherwise, a final series of controls is exercised before sending the problem back to the neutronics cycle (8009).



This last series of tests is devised to reduce the number of time-consuming neutronics calculations after the burst when  $\alpha$  has turned negative and the power has fallen to a low value. This can also be taken as a signal to the operator to terminate the problem if there is no desire to study post-burst phenomena.

## V. DETAILED FLOW DIAGRAM AND EXPLANATORY NOTES

### Notes on Sheet No. 1

Since there are many possible reasons for wishing to rerun a portion of a previous problem, or extending a solution timewise, a provision has been made for starting up a problem anew from a previous dump. Automatic dumping on tape at regular intervals is provided (Order No. 9263) to facilitate such procedures. Sense switch No. 1 provides the operator the opportunity to alter the memory when rerunning a problem from the middle. It also enables one to use the proper precautions when working from a consolidated tape. (The term "on" is used in the flow diagrams to indicate a switch is "depressed.")

### Notes on Sheet No. 2

As mentioned previously, the problem originator can specify a configuration and take the starting alpha which accompanies it, or can specify an alpha, guess a configuration, and let the program vary all radii linearly to achieve this alpha before beginning the hydrodynamics solution. If ICNTRL (or  $\alpha$ -control) is zero, the program proceeds to the usual calculation of alpha, first setting  $\alpha_3$  slightly different from  $\alpha_4$  to prevent premature convergence on the first  $S_n$  calculation. If ICNTRL is unity, the guessed outer radius goes to  $\alpha_4$ ; as the calculation progresses, the successively adjusted values of R (IMAX) are compared for the test of convergence, and a special convergence criterion,  $\epsilon_R$  is used.

A complete on-line print-out of input data is normally obtained at the beginning of a new problem. This can be prevented to save machine time by turning on Sense Switch No. 6. There is no provision for off-line print-out of input data at the present time.

### Notes on Sheet No. 3

The following is an elaboration of the procedure for calculating mixtures.

Each of the  $N_{max}$  substances is assigned a number  $N = 1, 2, \dots, N_{max}$ . For each such  $N$  a set of cross section tables is read in.

If  $M_{max} = 0$ , there is no mixing to be performed and the mixture code is by-passed.

Otherwise, for the integers  $M = 1, 2, \dots, M_{max}$ , in that order, the computer mixes substances numbered  $N_{M,1}, N_{M,2}, \dots, N_{M,i_M}$  in the proportions  $P_{M,1}, P_{M,2}, \dots, P_{M,i_M}$  (atom fraction) and assigns this new mixture the number  $N_{M,i_M} + 1$  where  $i_M$  is the smallest integer such that  $N_{M,i_M} + 2 = 0$ .

Each region is assigned its material label K, that of the material of which it is composed.

Input functions of mixture numbers (ROLAB (N), ALPHA (N), ...., BCV (N); see (7110),) must be (see (7080) to (7120)) read in that order of mixture numbers obtained by starting from the mesh point I = 2 and recording each N = K (I) as it appears (if it has not appeared before).

#### Notes on Sheet No. 4

To expedite the preparation of this over-all program an existing  $S_4$  program in Fortran was borrowed and tied into the over-all calculation. This calculation employs cross sections in barns and uses a material density in atoms/cc. Since the hydrodynamics calculation requires a density in grams/cc, it was necessary to employ more than one definition of density. The method used is as follows:

RO (I) is the hydrodynamic density,  $\rho_{Hyd}(I)$ , g/cc.

RHO (I) is the neutronic density,  $\rho_{neut}(I)$ , atoms/cc  $\times 10^{-24}$

ROLAB M is a conversion factor between the two previous quantities ( $\rho_{Hyd} = \rho_{lab} \cdot \rho_{neut}$ ), and equals the average grams/atom  $\times 10^{24}$  for mixture M.

If the problem originator sets KCNTRL equal to unity, he is requesting the value of keff corresponding to the original configuration, or alpha. The program is arranged to converge first on alpha, then to set KCALC equal to unity and send the computation back to Order No. 8000 to rebegin the Big G loop. The test for KCALC then routes the solution away from the alpha solution to the convergence test on keff.

The  $S_4$  calculation itself is conventional<sup>(5,6,7)</sup> except for a slight variation in the manner of iterating or achieving convergence. This is similar to the approach adopted in reference 6 (pgs. 11, 21) in that the various sums are performed with a semi-empirical weight function,

$$WN(I) = T(I) \cdot \left( \sum_{g=1}^6 N_g(I) \right) \text{ (Order No. 8301)} \text{ rather than merely a volume}$$

term T(I). (See Order No. 301, for example, defining  $\overline{FE}'$ .) The procedure used for calculating the next  $\alpha$  is identical to that in reference 6. For the convergence on radius or keff, however, the sums of weighted fissions and elastic collisions are employed in a somewhat different manner.

#### Notes on Sheet No. 8

Under Order No. 6801 the initial values of keff 1,2,3,4 are arranged to insure a minimum of four iterations before convergence of the keff calculation.

Under Order No. 6810, when  $NH = 0$  the Lagrangian coordinates  $R_L$  (I) are computed. These are time independent and serve throughout the problem when the mass of a mass point is needed to calculate the total value of a quantity at a mass point from the value per gram. They are also used in the calculation of acceleration, at the beginning of the I loop (below Order No. 9066).

#### Notes on Sheet No. 9

Since the simple linear equation of state is generally not adequate over the entire temperature range, and since one frequently wishes to provide a threshold temperature above which the steep rise in pressure begins, the equation of state may yield negative pressures for low temperatures. In this event Order No. 6833 substitutes zero for the hydrodynamic pressure,  $P_H$ .

The constants  $\epsilon_0$  (I) are discussed in Appendix D. They are utilized in an accuracy check involving an energy balance. Running  $E_{kinetic}$ ,  $E_{kinetic}$  and  $E_{internal}$  are normally lacking in the factor  $\frac{4\pi}{3}$  which is supplied directly before printout.

The outer boundary of the system is a free surface with zero pressure. This is accomplished mathematically by defining the pressure at the center of the next (fictitious) mass point as the negative of the pressure at the center of the outermost true mass point.

#### Notes on Sheet No. 10

The three quantities  $Q$ ,  $Q'$  and  $Q_p$  are defined as follows.

At the beginning of a new hydrocycle the energy  $Q$  (less a factor  $\frac{4\pi}{3}$ ) is stored as  $Q'$ , the energy after the previous increment in time. The new  $Q$  is then calculated by adding in the energy rise during the present time increment. Thus the primed quantity is always the one previous in time.  $Q_p$  is "Q to be printed," i.e.,  $Q$  multiplied by the  $\frac{4\pi}{3}$  factor.

#### Notes on Sheet No. 11

The new hydrocycle begins with a calculation of the new velocity and requires a new acceleration. From Appendix B we see that the velocity at time  $(n + 1/2) \Delta t$  is computed using the acceleration at time  $(n)\Delta t$ . We may write 9 (Chapt. 10)

$$U^{n+\frac{1}{2}}(I) = U^{n-\frac{1}{2}}(I) - \Delta t \frac{1}{\rho_{Hyd}} \frac{\partial P_H}{\partial R}$$

The Lagrangian coordinates,  $R_L$ , are defined by the relation  $\rho R^2 dR = R_L^2 dR_L$ , so that

$$\frac{1}{\rho} = \frac{R^2}{R_L^2} \frac{\partial R}{\partial R_L}$$

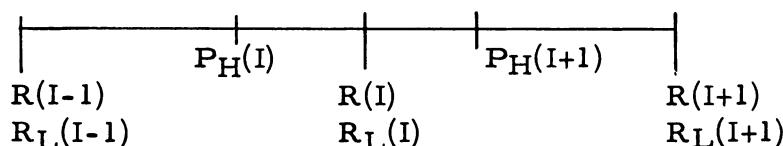
Thus,

$$U^{n+\frac{1}{2}}(I) = U^{n-\frac{1}{2}}(I) - \Delta t \frac{R^2}{R_L^2} \frac{\partial P_H}{\partial R_L}$$

or

$$U^{n+\frac{1}{2}}(I) = U^{n-\frac{1}{2}}(I) - \frac{\Delta t R^2(I)}{R_L^2(I)} \cdot \frac{P_H(I+1) - P_H(I)}{\frac{1}{2}[R_L(I+1) - R_L(I-1)]} .$$

On a diagram in space, these variables are located as follows:



The calculation of the new density,  $\rho_{Hyd}^T$ , follows directly from the definition of the Lagrangian coordinates.

Below Order No. 9082, the question "Is  $\Delta V < 0?$ " is asked to determine whether a compression or rarefaction wave is traversing that mass point. For a compression, the viscous pressure is computed and added to the true hydro-pressure, as explained in Appendix C.

An iterative procedure called the modified Euler method is used in the pressure calculation. At Order No. 9124 the previous pressure is guessed to be the answer at the next time interval. The temperature is calculated from energy considerations, and then a new pressure is calculated using the equation of state. This pressure is compared with the first guess, and if sufficiently different is used as the next guess. This sub-cycle is then repeated. In the convergence test (Order No. 9150)  $\epsilon_1$  is a small pressure to provide some denominator if  $P_H = 0$ . It should be negligible compared to  $P_H$  at the values of interest.

The thermodynamic considerations are presented in Appendix D. A different equation of state could be used with appropriate changes in the program.

#### Notes on Sheet No. 12

The VJ-OK test, included to provide more frequent calculation of alpha when alpha starts to change rapidly under pressure buildup, is

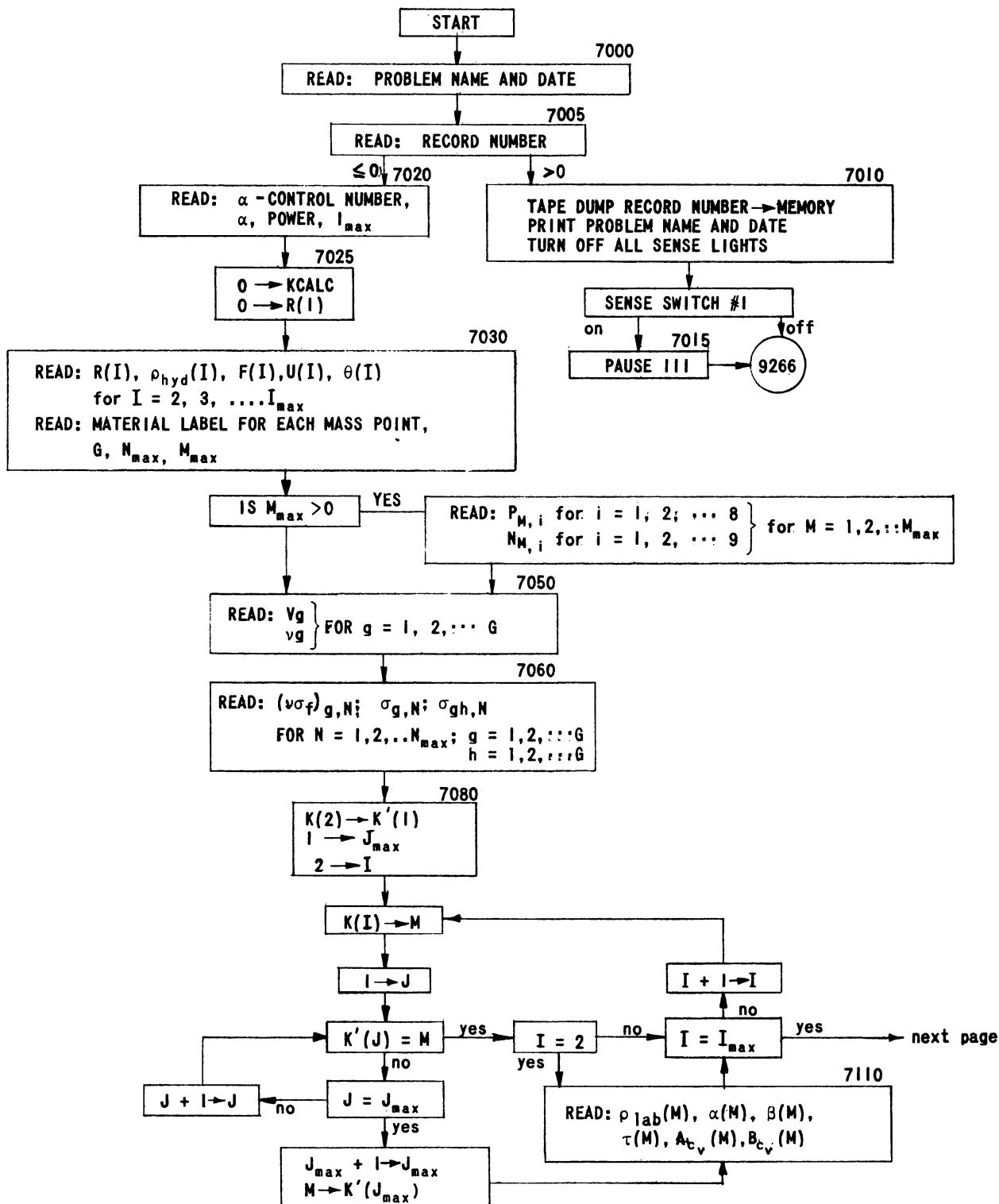
discussed in Appendix A. With Order No. 9213 the number of hydrocycles between off-line prints can be reduced at this point in the computations, thereby providing more frequent detailed results.

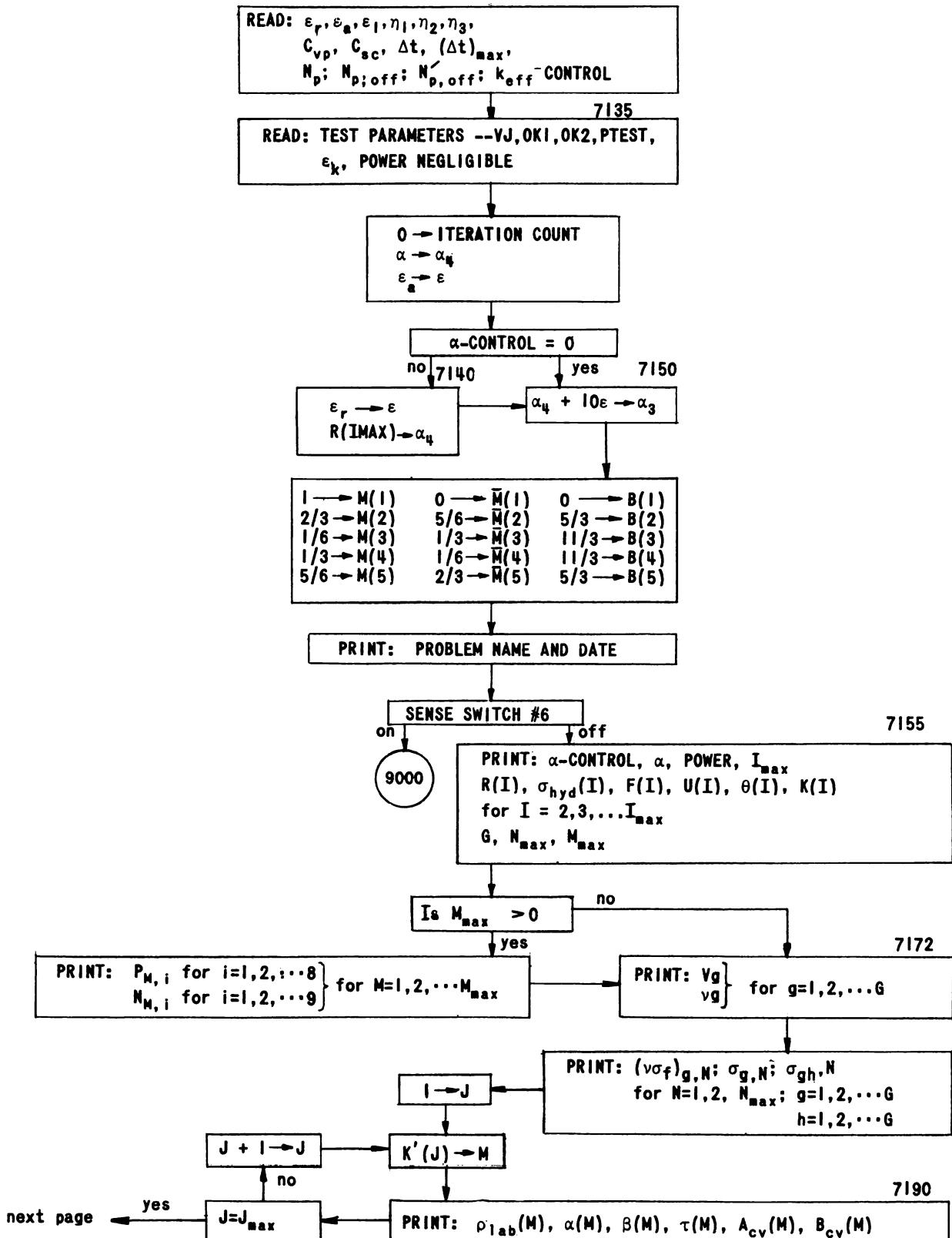
Notes on Sheet No. 13

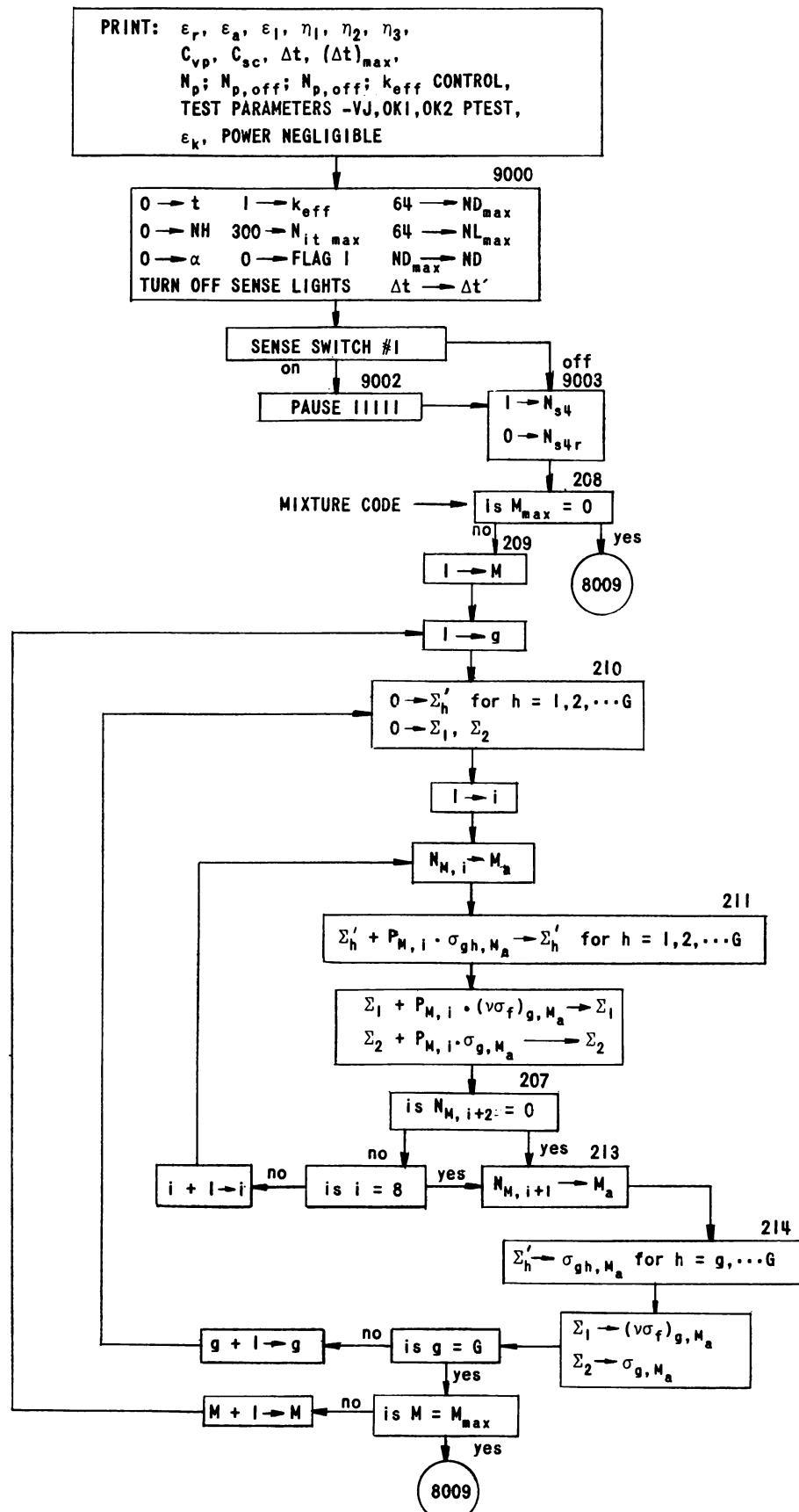
The error checks are discussed in Appendix D. Briefly, the internal energy of each mass point is computed in an alternate manner and compared to that resulting from the normal procedure. Similarly, the total energy is computed in an alternate fashion and a comparison made.

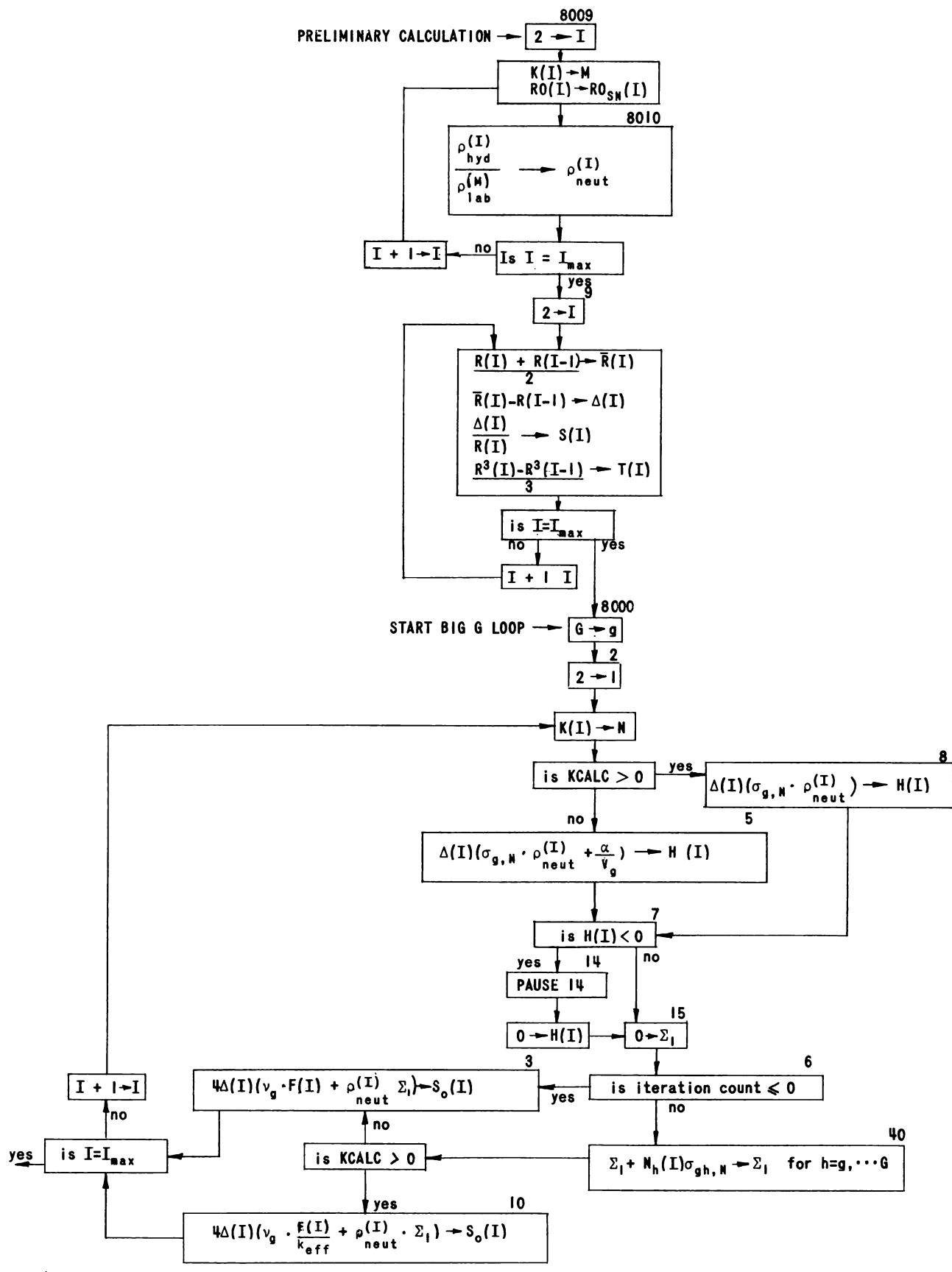
Notes on Sheet No. 15

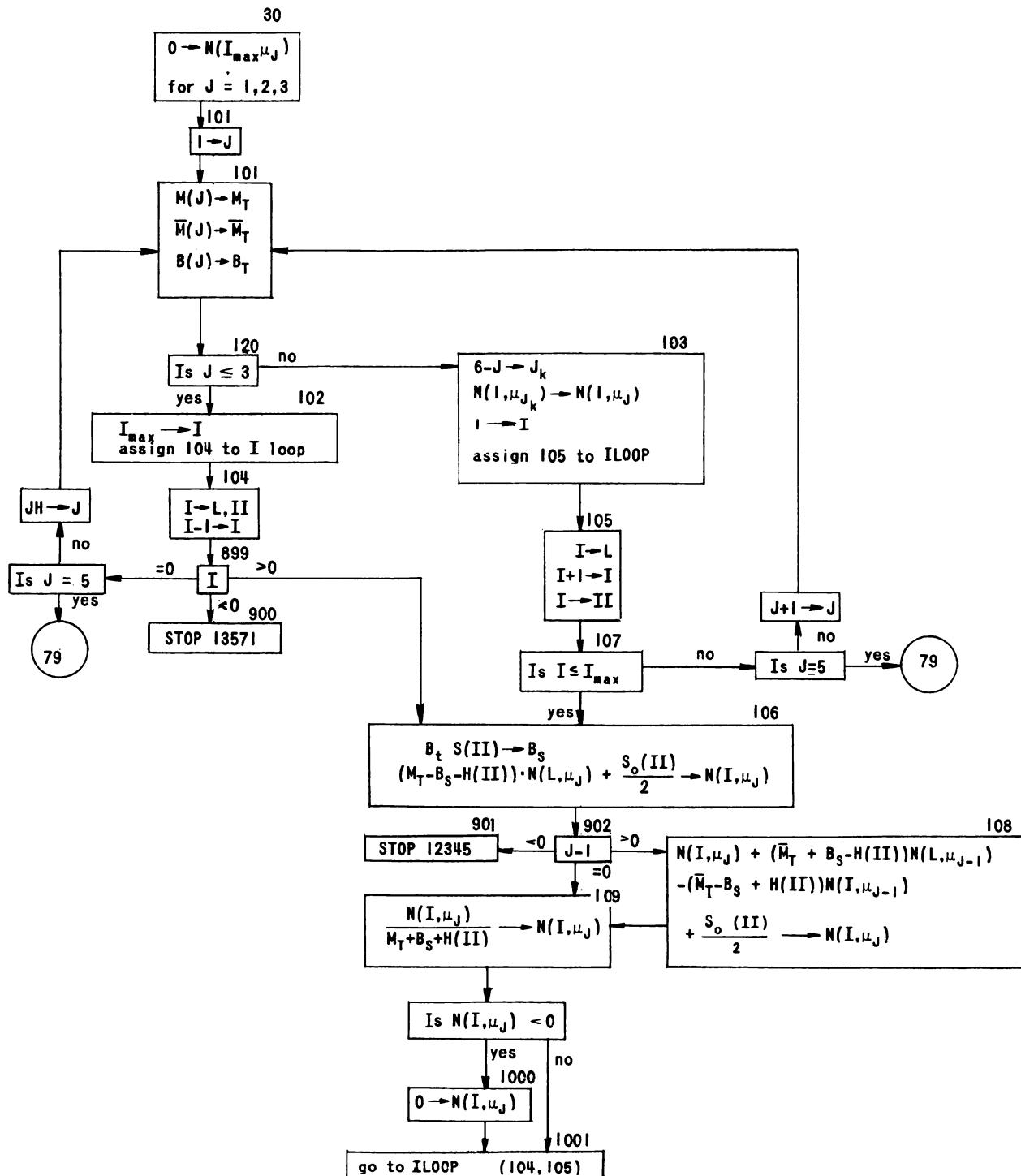
The reasons for the different shifts in  $\Delta t$  and  $\Delta t'$  when the time interval is halved or doubled are discussed in Appendix B.

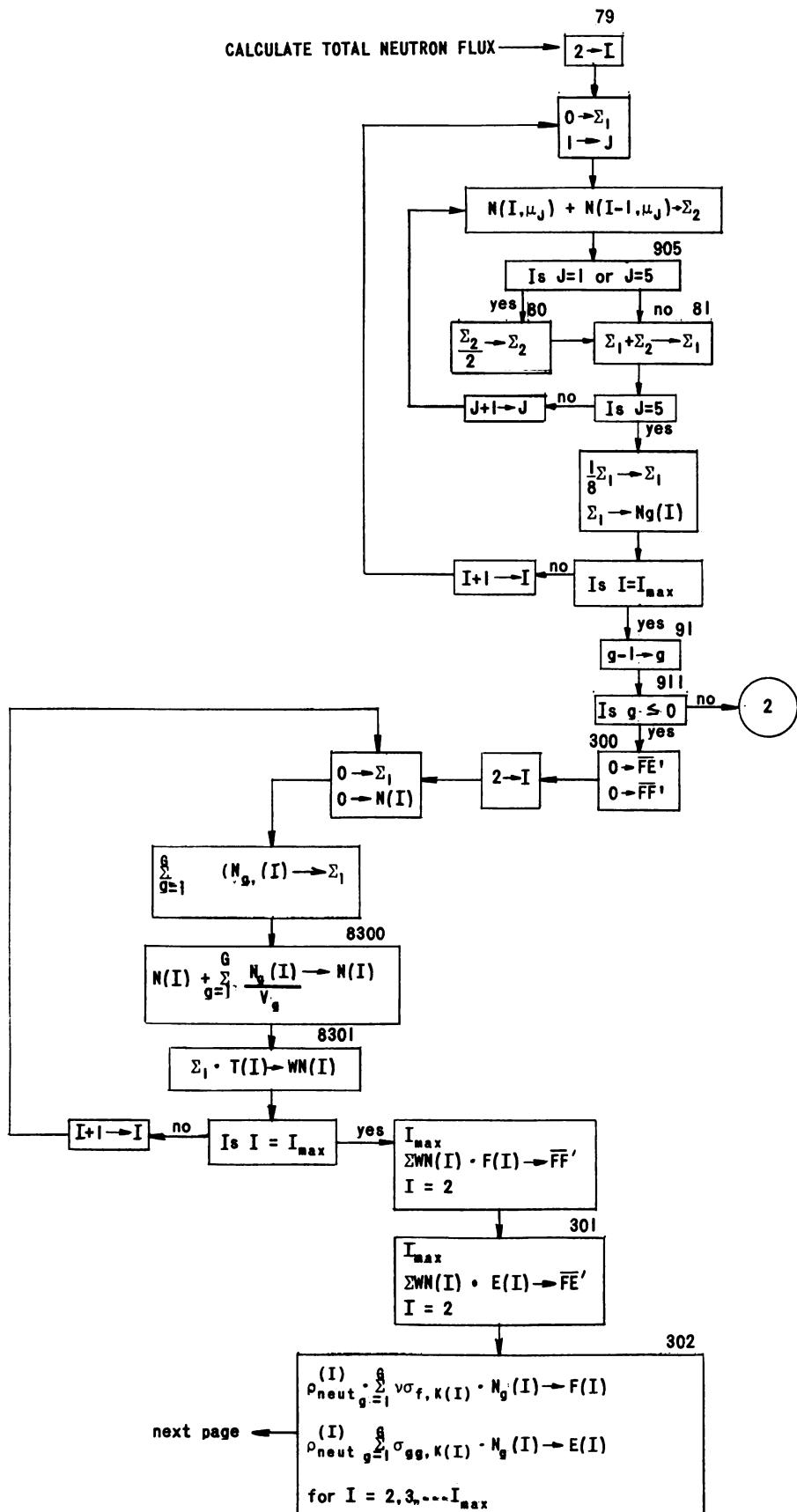


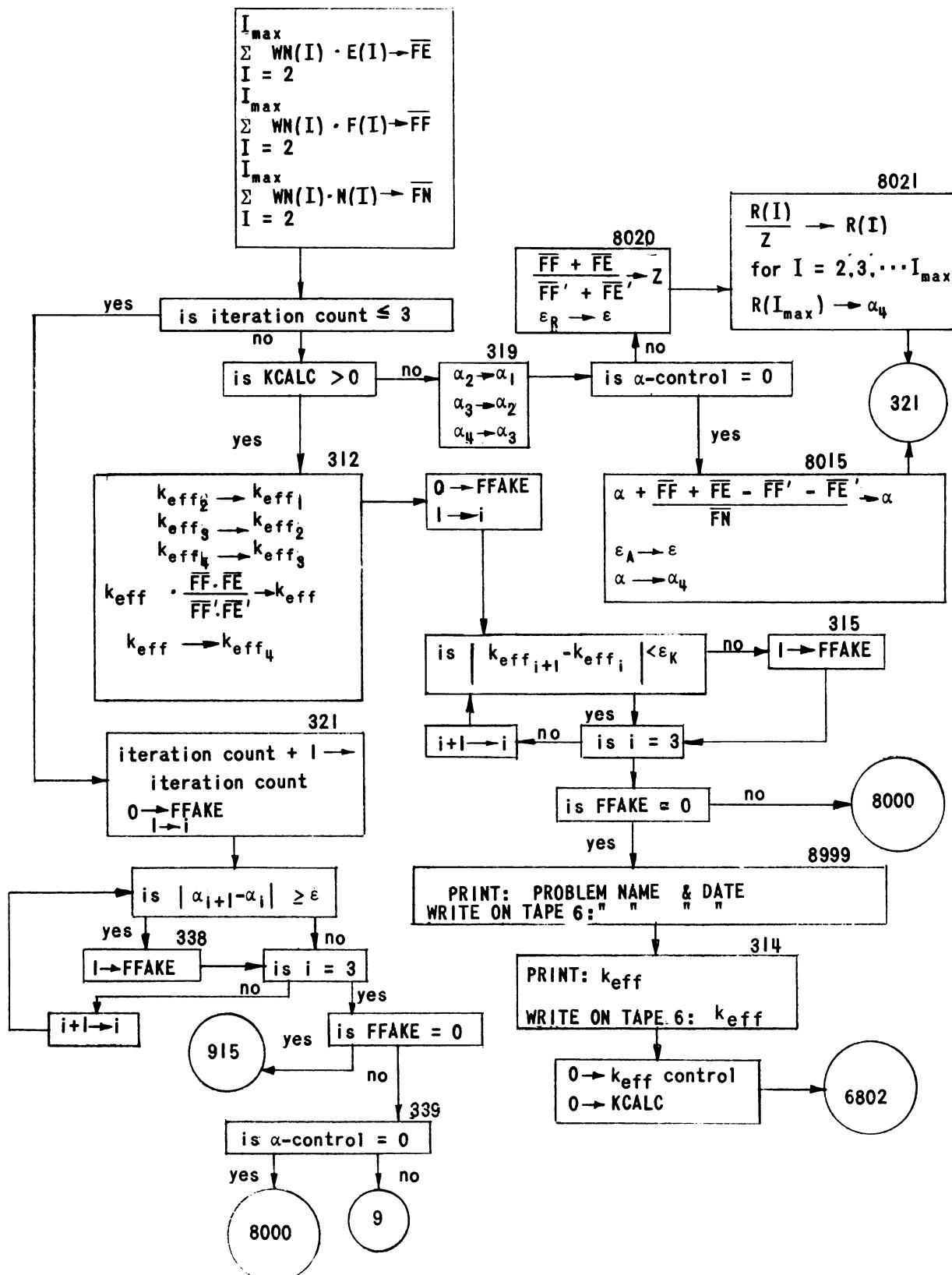


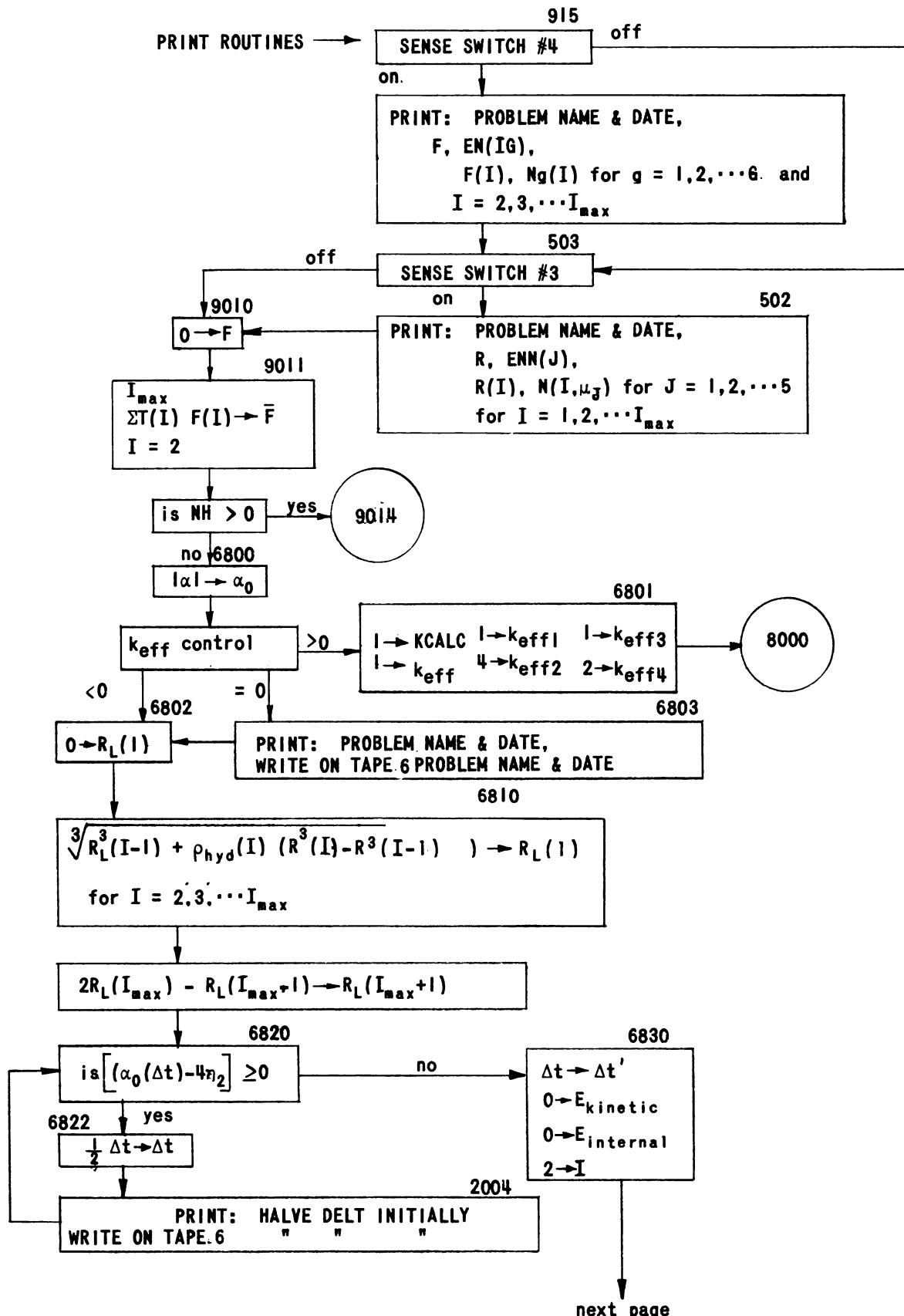


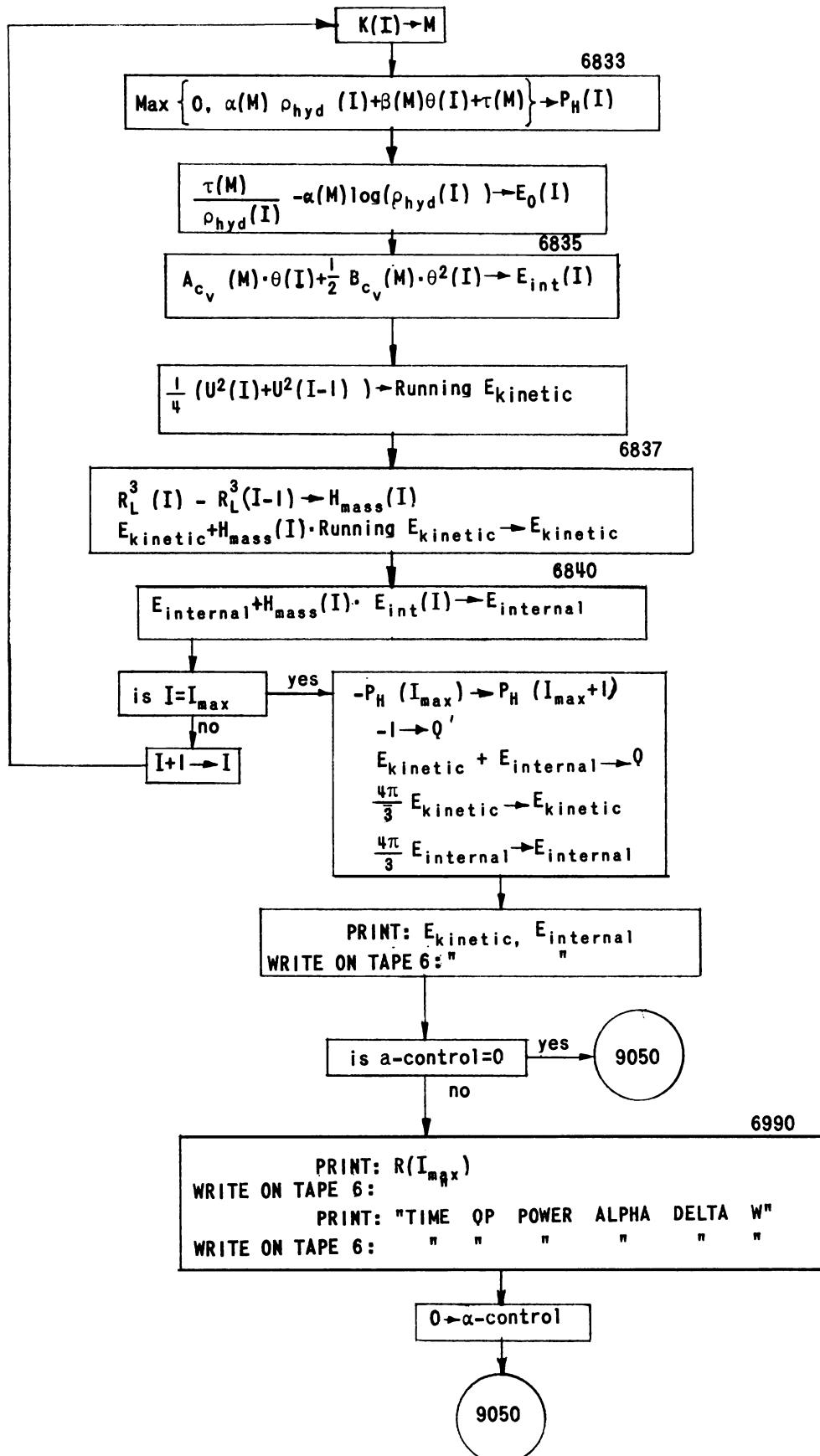


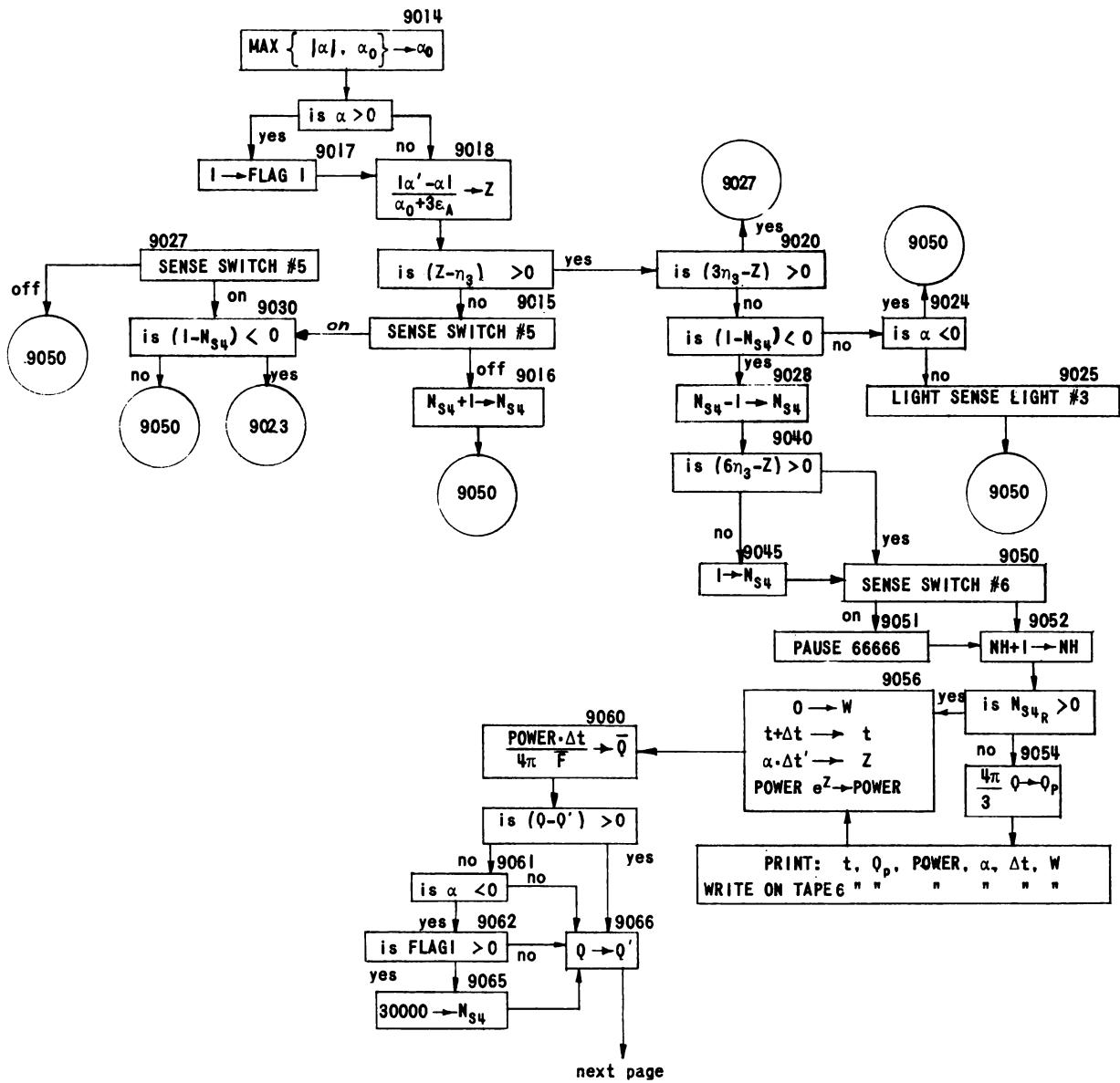


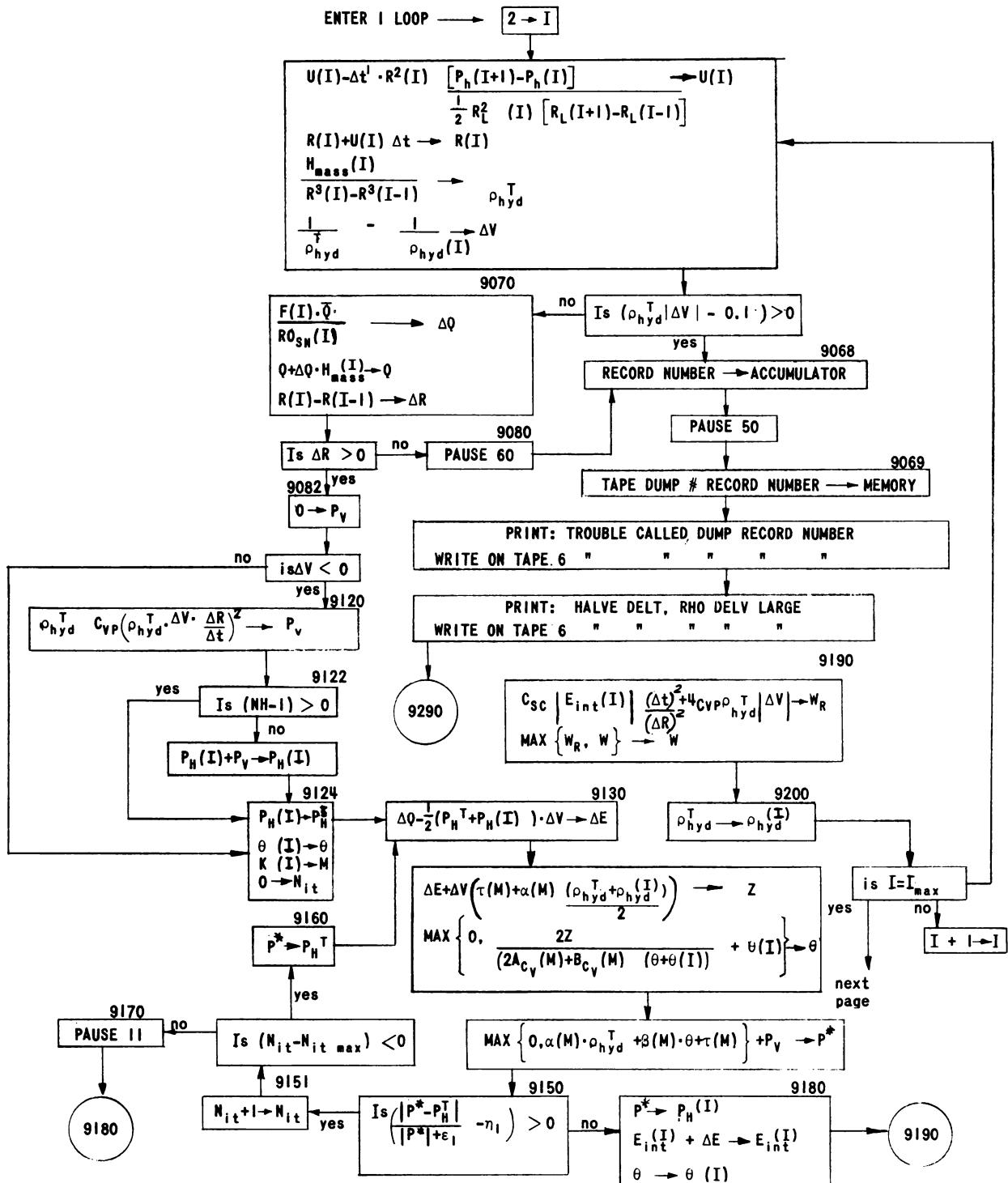


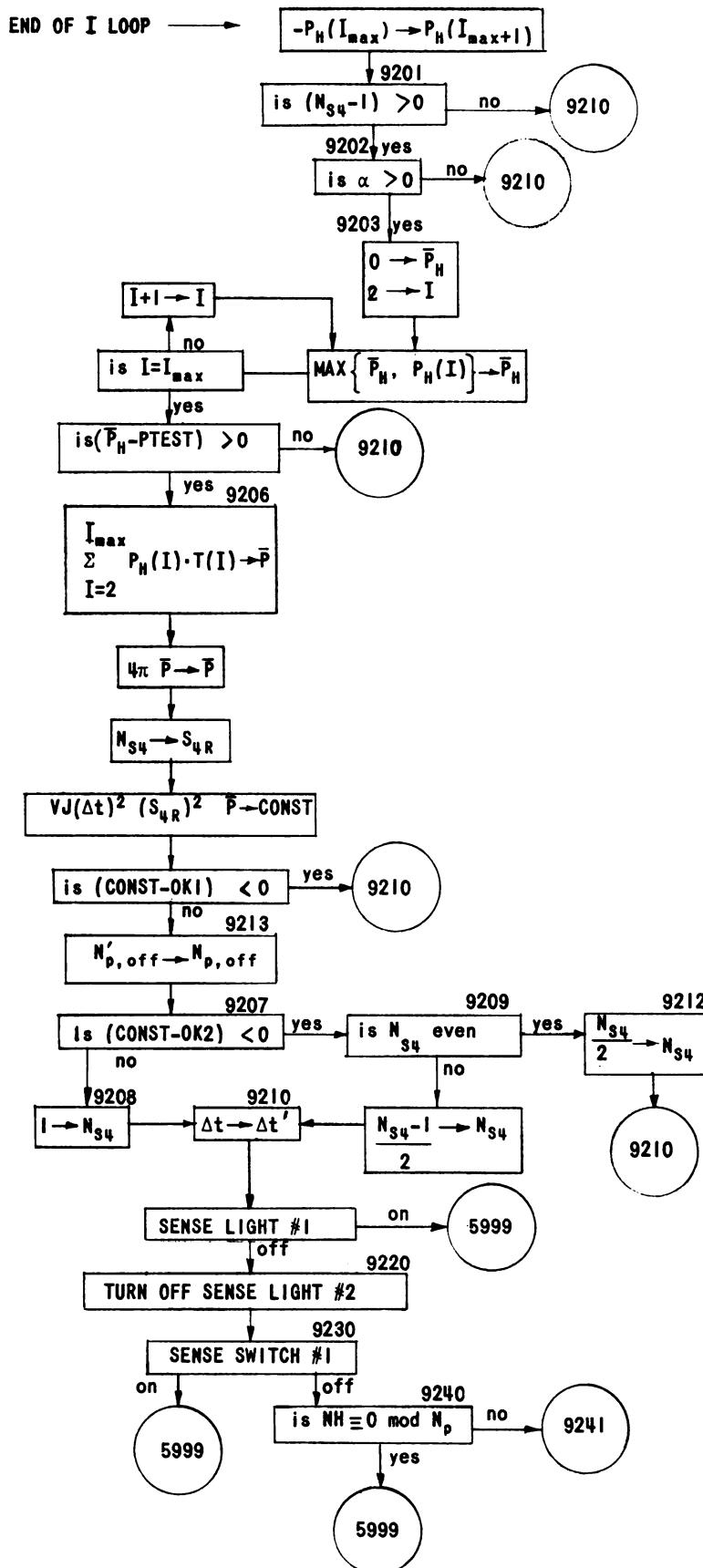


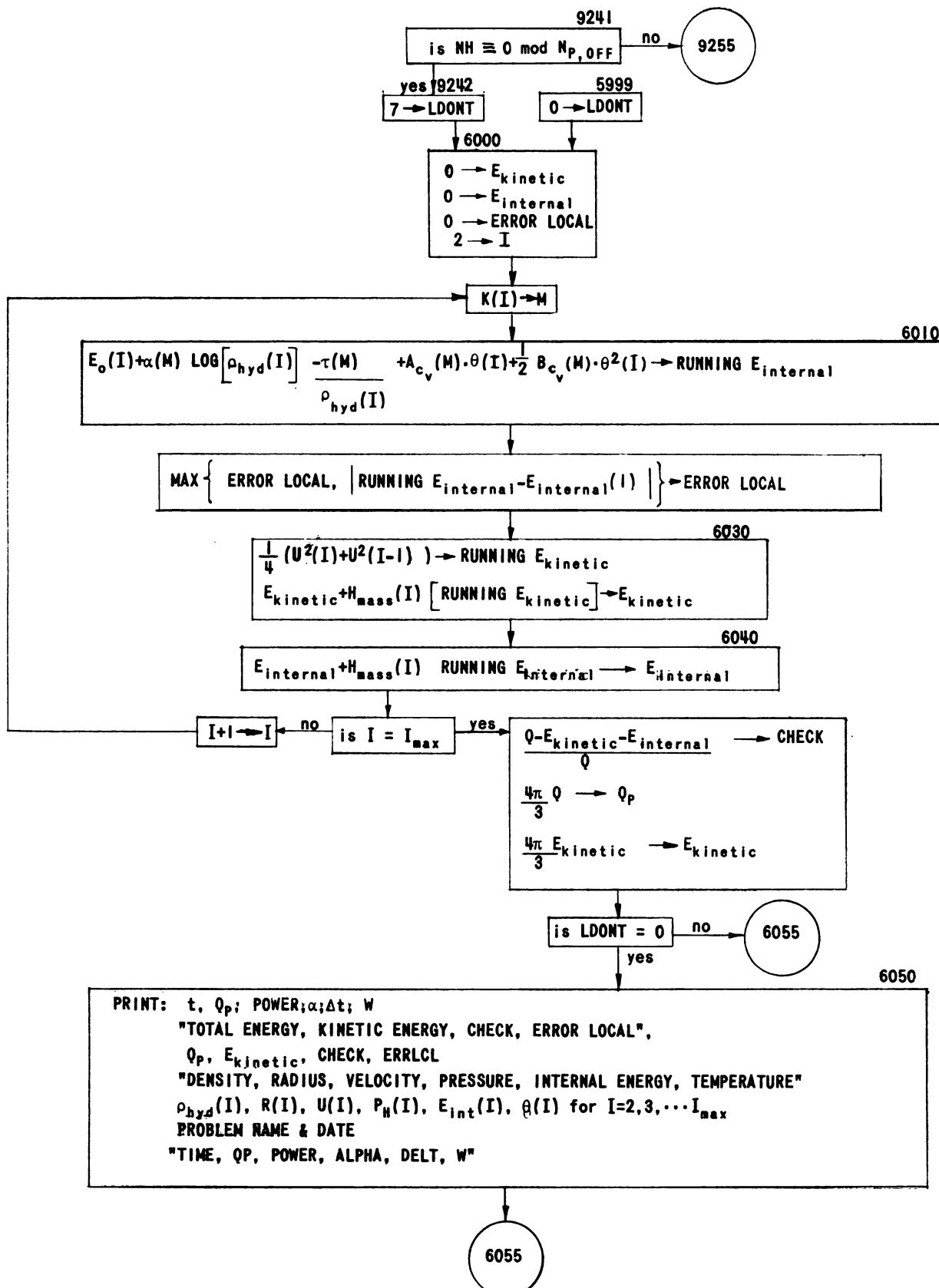




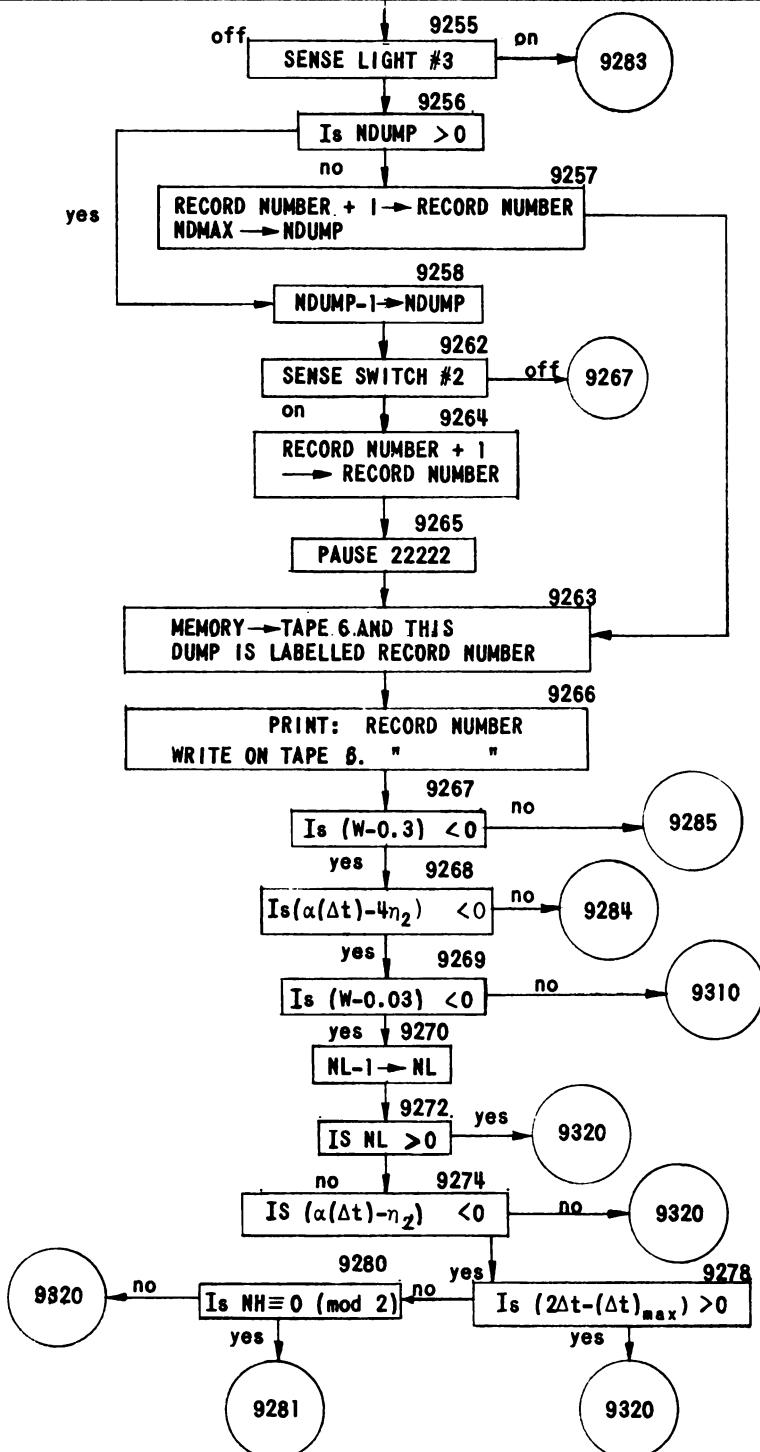


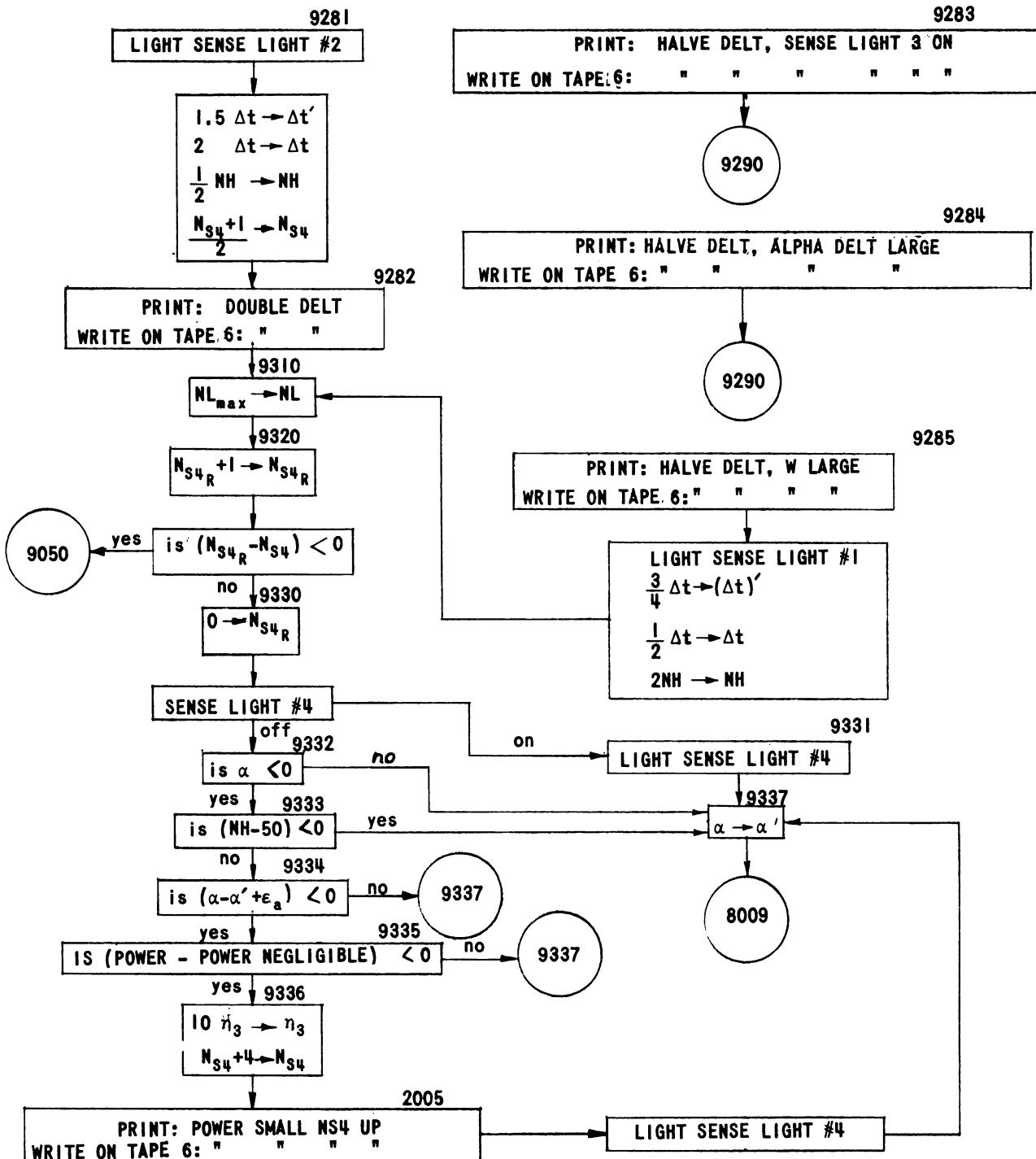






PRINT ON TAPE 6 t,  $Q_p$ , POWER,  $\alpha$ ,  $\Delta t$ , W  
 "TOTAL ENERGY, KINETIC ENERGY, CHECK, ERROR LOCAL"  
 $Q_p$ ,  $E_{kinetic}$  CHECK, ERRLEL  
 "DENSITY, RADIUS, VELOCITY, PRESSURE, INTERNAL ENERGY, TEMPERATURE"  
 $\rho_{hyd}^{(I)}$ ,  $R(I)$ ,  $U(I)$ ,  $P_h(I)$ ,  $E_{int}(I)$ ,  $\theta(I)$  for  $I = 2, 3, \dots, I_{max}$   
 PROBLEM NAME & DATE  
 "TIME, QP, POWER, ALPHA, DELT. W"





## VI. FORTRAN LISTING OF PROGRAM

```

C      AX-1      MARCH 19, 1959
      DIMENSION RO(40), R(40), U(40), HP(41), HE(40), THETA(40),
1          RL(41), K(40), RHO(40), F(40), E(40), RBAR(40),
2          EN(7,40), DELTA(40), S(40), T(40), H(40), SO(40),
3          ENN(40,5), ROLAB(8), ALPH(8), BETA(8), TAU(8),
4          ACV(8), BCV(8), KP(8), V(7), ANU(7), SUM(7),
5          WN(40), ANUSIG(7,8), SIG(7,8), SIGMA(7,7,8),
6          P(8,8), MN(8,9), A(4), AM(5), AMBAR(5),
7          B(5), ENNN(40), HE0(40), HMASS(40), AK(4), ROSN(40)
9900 FORMAT(54H1PROBLEM NAME 25 DECEMBER 1957
9910 FORMAT (1P6E12.6)
9911 FORMAT (1H 1P6E15.6)
9915 FORMAT (1H 9I6)
9920 FORMAT (36I2)
9921 FORMAT (1H 36I3)
9922 FORMAT (18I4)
9930 FORMAT (9F8.7)
9931 FORMAT (1H 9F11.7)
9940 FORMAT (9I8)
9941 FORMAT (1H 9I11)
9942 FORMAT (18H      K EFFECTIVE = 1P1E15.6)
9943 FORMAT (27H      TOTAL KINETIC ENERGY = 1P1E15.6, 28H      TOTAL INTER
1NAL ENERGY = 1P1E15.6)
9944 FORMAT (29H      INITIAL MAXIMUM RADIUS = 1P1E15.6)
9980 FORMAT (10HOF, EN(I))
9981 FORMAT (1P9E13.5)
9982 FORMAT (60HO      TOTAL ENERGY   KINETIC ENERGY      CHECK      ERROR
1LOCAL)
9983 FORMAT (90HO      DENSITY      RADIUS      VELOCITY      PRES
1SURE INTERNAL ENERGY      TEMPERATURE)
9984 FORMAT (6H DUMP I2)
9985 FORMAT (10HOR, ENN(J))
9986 FORMAT (85H      TIME      QP      POWER      ALP
1HA      DELT      W)
9987 FORMAT (22H TROUBLE. CALLED DUMP I2)
7000 READ 9900
7005 READ 9920, IRCNBR
    IF(IRCNR) 7020, 7020, 7010
7010 PAUSE7010
    PRINT 9900
    SENSE LIGHT 0
    IF(SENSE SWITCH 1) 7015, 9266
7015 PAUSE 111
    GO TO 9266
7020 READ 9920, ICNTRL
    READ 9910, ALPHA
    READ 9910, POWER
    READ 9920, IMAX
7025 KCALC = 0
    R(1)=0.0
    DO 7030 I=2,IMAX
7030 READ 9910, R(I), RO(I), F(I), U(I), THETA(I)

```

```

READ 9920, (K(I), I=2,IMAX)
READ 9920, IGMAX
READ 9920, NMAX, MMAX
IF(MMAX) 7050, 7050, 7040
7040 DO 7045 M=1,MMAX
    READ 9930, (P(M,IS), IS=1,8)
7045 READ 9940, (MN(M,IS), IS=1,9)
7050 READ 9910, (V(IG), IG=1,IGMAX), (ANU(IG), IG=1,IGMAX)
7060 DO 7070 N=1,NMAX
    DO 7070 IG=1,IGMAX
7070 READ 9910, ANUSIG(IG,N), SIG(IG,N), (SIGMA(IG,IH,N), IH=1,IGMAX)
7080 KP(1)=K(2)
    JMAX=1
    DO 7120 I=2,IMAX
        M=K(I)
        DO 7090 J=1,JMAX
            IF(M-KP(J)) 7090, 7100, 7090
7090 CONTINUE
    JMAX=JMAX+1
    KP(JMAX)=M
    GO TO 7110
7100 IF(I-2) 7120, 7110, 7120
7110 READ 9910, (ROLAB(M), ALPH(M), BETA(M), TAU(M), ACV(M), BCV(M))
7120 CONTINUE
    READ 9910, EPSR, EPSA, EPS1, ETA1, ETA2, ETA3
    READ 9910, CVP, CSC
    READ 9910, DELT, DTMAX
7130 READ 9922, NP, NPOFF, NPOFFP, KCNTRL
7135 READ 9910, VJ,OK1, OK2, PTEST, EPSK, POWNGL
    AITCT=0
    A(4)=ALPHA
    EPS = EPSA
    IF(ICNTRL) 7140, 7150, 7140
7140 EPS = EPSR
    A(4) = R(IMAX)
7150 A(3)=A(4)+10.0*EPS
    AM(1)=1.0
    AM(2)=0.6666667
    AM(3)=0.1666667
    AM(4)=0.3333333
    AM(5)=0.8333333
    AMBAR(1)=0.0
    AMBAR(2)=0.8333333
    AMBAR(3)=0.3333333
    AMBAR(4)=0.1666667
    AMBAR(5)=0.6666667
    B(1)=0.0
    B(2)=1.6666667
    B(3)=3.6666667
    B(4)=3.6666667
    B(5)=1.6666667
    PRINT 9900

```

```

      T
IF(SENSE SWITCH 6) 9000, 7155
7155 PRINT 9921,ICNTRL
      PRINT 9911, ALPHA
      PRINT 9911, POWER
      PRINT 9921, IMAX
      DO 7160 I=2,IMAX
7160 PRINT 9911, R(I), RO(I), F(I), U(I), THETA(I)
      PRINT 9921, (K(I), I=2,IMAX)
      PRINT 9921, IGMAX
      PRINT 9921, NMAX, MMAX
      IF(MMAX) 7172, 7172, 7168
7168 DO 7170 M=1,MMAX
      PRINT 9931, (P(M,IS), IS=1,8)
7170 PRINT 9941, (MN(M,IS), IS=1,9)
7172 PRINT 9911, (V(IG), IG=1,IGMAX), (ANU(IG), IG=1,IGMAX)
      DO 7180 N=1,NMAX
      DO 7180 IG=1,IGMAX
7180 PRINT 9911, ANUSIG(IG,N), SIG(IG,N), (SIGMA(IG,IH,N), IH=1,IGMAX)
      DO 7190 J=1,JMAX
      M=KP(J)
7190 PRINT 9911, (ROLAB(M), ALPH(M), BETA(M), TAU(M), ACV(M), BCV(M))
      PRINT 9911, EPSR, EPSA, EPS1, ETA1, ETA2, ETA3
      PRINT 9911, CVP, CSC
      PRINT 9911, DELT, DTMAX
      PRINT 9915, NP, NPOFF, NPOFFP, KCNTRL
      PRINT 9911, VJ, OK1, OK2, PTEST, EPSK, POWNGL
9000 TIME=0.
      NH=0
      ALPHAP=0.0
      SENSE LIGHT 0
      AKEFF = 1.0
      NITMAX=300
      FLAG1 = 0.0
      NDMAX = 64
      NLMAX = 64
      NDUMP = NDMAX
      DELTP=DELT
      IF(SENSE SWITCH 1) 9002, 9003
9002 PAUSE 11111
9003 NS4=1
      NS4R=0
C
C      MIXTURE CODE
C
208 IF(MMAX) 209,8009,209
209 DO 215 M=1,MMAX
      DO 215 IG=1,IGMAX
      DO 210 IH=IG,IGMAX
210 SUM(IH) = 0.
      SUM1 = 0.
      SUM2 = 0.
      DO 212 IS=1,8

```

```

        MA = MN(M,IS)
        DO 211 IH=IG,IGMAX
211  SUM(IH) = SUM(IH) + P(M,IS)*SIGMA(IG,IH,MA)
        SUM1 = SUM1 + P(M,IS)*ANUSIG(IG,MA)
        SUM2 = SUM2 + P(M,IS)*SIG(IG,MA)
207  IF(MN(M,IS+2)) 212, 213, 212
212  CONTINUE
213  MA = MN(M,IS+1)
        DO 214 IH=IG,IGMAX
214  SIGMA(IG,IH,MA) = SUM(IH)
        ANUSIG(IG,MA) = SUM1
215  SIG(IG,MA) = SUM2
C
C      PRELIMINARY CALCULATION
C
8009  DO 8010 I=2,IMAX
        M=K(I)
        ROSN(I)=RO(I)
8010  RHO(I)=RO(I)/ROLAB(M)
        9 DO 13 I=2,IMAX
        RBAR(I) = (R(I) + R(I-1))/2.
        DELTA(I) = RBAR(I) - R(I-1)
        S(I) = DELTA(I)/RBAR(I)
13   T(I) = (R(I)**3-R(I-1)**3)/3.0
C
C      START BIG G LOOP
C
8000  IG=IGMAX
2  DO 11 I=2,IMAX
        N = K(I)
        IF(KCALC) 5, 5, 8
5   H(I)=DELTA(I)*(SIG(IG,N)*RHO(I)+ALPHA/V(IG))
        GO TO 7
8   H(I) = DELTA(I)*SIG(IG,N)*RHO(I)
7   IF(H(I)) 14, 15, 15
14  PAUSE 14
        H(I) = 0.
15  SUM1 = 0.
6   IF(AITCT) 3, 3, 40
40  DO 4 IH=IG,IGMAX
        4 SUM1 = SUM1 + EN(IH,I)*SIGMA(IG,IH,N)
        IF(KCALC) 3, 3, 10
10   SO(I) = 4.0*DELTA(I)*(ANU(IG)*F(I)/AKEFF + RHO(I)*SUM1)
        GO TO 11
3   SO(I) = 4.*DELTA(I)*(ANU(IG)*F(I) + RHO(I)*SUM1)
11  CONTINUE
        DO 30 J=1,3
30   ENN(IMAX,J) = 0.
101  DO 110 J=1,5
        AMT = AM(J)
        AMBART = AMBAR(J)
        BT = R(J)

```

```

120 IF(J - 3) 102, 102, 103
102 I = IMAX
    ASSIGN 104 TO ILOOP
104 L = I
    II = I
    I = I - 1
899 IF(I) 900, 110, 106
900 STOP 13571
103 JK = 6 - J
    ENN(1,J) = ENN(1,JK)
    I = 1
    ASSIGN 105 TO ILOOP
105 L = I
    I = I + 1
    II = I
107 IF(I - IMAX) 106, 106, 110
106 BS = BT*S(II)
    ENN(I,J) = (AMT - BS - H(II))*ENN(L,J) + SO(II)/2.
902 IF(J - 1) 901, 109, 108
901 STOP 12345
108 ENN(I,J) = ENN(I,J) + (AMBART + BS - H(II))*ENN(L,J-1)
    1 - (AMBART - BS + H(II))*ENN(I,J-1) + SO(II)/2.
109 ENN(I,J) = ENN(I,J)/(AMT + BS + H(II))
    IF(ENN(I,J)) 1000, 1001, 1001
1000 ENN(I,J) = 0
1001 GO TO ILOOP, (104,105)
110 CONTINUE
C
C      CALCULATE TOTAL NEUTRON FLUX
C
79 DO 84 I=2,IMAX
    SUM1 = 0.
    DO 81 J=1,5
        SUM2 = ENN(I,J) + ENN(I-1,J)
905 GO TO (80, 81, 81, 81, 80), J
80 SUM2 = SUM2/2.
81 SUM1 = SUM1 + SUM2
    SUM1 = SUM1/8.
84 EN(IG,I) = SUM1
91 IG = IG - 1
911 IF(IG) 300, 300, 2
300 FEBARP = 0.
    FFBARP = 0.
    DO 8301 I=2,IMAX
        SUM1 = 0.0
        ENNN(I) = 0.0
        DO 8300 IG=1,IGMAX
            SUM1 = SUM1 + EN(IG,I)
8300 ENNN(I) = ENNN(I) + EN(IG,I)/V(IG)
8301 WN(I) = SUM1*T(I)
        DO 301 I=2,IMAX
            FFBARP = FFBARP + WN(I)*F(I)

```

```

301 FEBARP = FEBARP + WN(I)*E(I)
307 DO 302 I=2,IMAX
      SUM1 = 0.
      SUM2 = 0.
      N = K(I)
      DO 303 IG=1,IGMAX
          SUM1 = SUM1 + ANUSIG(IG,N)*EN(IG,I)
303  SUM2 = SUM2 + SIGMA(IG,IG,N)*EN(IG,I)
      F(I) = SUM1*RHO(I)
302  E(I) = SUM2*RHO(I)
      FEBAR = 0.
      FFBAR = 0.
      FENBAR = 0.
      DO 310 I=2,IMAX
          FEBAR = FEBAR + WN(I)*E(I)
          FFBAR = FFBAR + WN(I)*F(I)
310  FENBAR = FENBAR + WN(I)*ENNN(I)
913  IF(AITCT-3.) 321, 321, 305
305  IF(KCALC) 319,319,311
311  DO 312 I=1,3
312  AK(I) = AK(I+1)
      AKEFF = AKEFF*FFBAR*FEBAR/(FFBARP*FEBARP)
      AK(4) = AKEFF
      FFAKE = 0.0
      DO 313 I = 1,3
          IF(ABSF(AK(I+1)-AK(I))-EPSK) 313, 315, 315
315  FFAKE = 1.0
313  CONTINUE
      IF(FFAKE) 8000, 8999, 8000
8999 PRINT 9900
      WRITE OUTPUT TAPE 6, 9900
314 PRINT 9942, AKEFF
306 WRITE OUTPUT TAPE 6, 9942, AKEFF
      KCNTRL = 0
      KCALC = 0
      GO TO 6802
319 DO 325 I=1,3
325  A(I)=A(I+1)
      IF(ICNTRL) 8020, '8015, 8020
8015 ALPHA = ALPHA + (FFBAR + FEBAR - FFBARP - FEBARP)/FENBAR
      EPS = EPSA
      A(4)=ALPHA
      GO TO 321
8020 Z = (FFBAR + FEBAR)/(FFBARP + FEBARP)
      EPS = EPSR
      DO 8021 I=2,IMAX
8021 R(I)=R(I)/Z
      A(4)=R(IMAX)
321 AITCT=AITCT+1.0
      FFAKE = 0.0
      DO 330 I=1,3
          IF(ABSF(A(I+1)-A(I))-EPS) 330, 338, 338

```

```

338 FFAKE = 1.0
330 CONTINUE
  IF(FFAKE) 339, 915, 339
339 IF(ICNTRL) 9, 8000, 9
C
C      PRINT ROUTINES
C
915 IF(SENSE SWITCH 4) 331, 503
331 PRINT 9900
PRINT 9980
DO 501 I=2,IMAX
501 PRINT 9981, F(I), (EN(IG,I), IG=1,IGMAX)
503 IF(SENSE SWITCH 3) 502, 9010
502 PRINT 9900
PRINT 9985
PRINT 9911, (R(I), (ENN(I,J), J=1,5), I=1,IMAX)
9010 FBAR = 0.
DO 9011 I=2,IMAX
9011 FBAR = FBAR + T(I)*F(I)
IF(NH) 6800, 6800, 9014
6800 ALPHA0=ABSF(ALPHA)
IF(KCNTRL) 6802, 6803, 6801
6801 KCALC = 1
AKEFF = 1.0
AK(1) = 1.0
AK(2) = 4.0
AK(3) = 1.0
AK(4) = .2.0
GO TO 8000
6803 PRINT 9900
WRITE OUTPUT TAPE 6, 9900
6802 RL(1)=0.0
DO 6810 I=2,IMAX
6810 RL(I)=CUBERTF(RL(I-1)**3+RO(I)*(R(I)**3-R(I-1)**3))
RL(IMAX+1)=2.0*RL(IMAX)-RL(IMAX-1)
6820 IF(ALPHA0*DELT-4.0*ETA2) 6830, 6822, 6822
6822 DELT=0.5*DELT
2004 FORMAT(21H HALVE DELT INITIALLY)
PRINT 2004
WRITE OUTPUT TAPE 6, 2004
GO TO 6820
6830 DELTP=DELT
TOTKE=0.0
TOTIEN=0.0
DO 6840 I=2,IMAX
M=K(I)
6833 HP(I)=MAX1F(0.0,(ALPH(M)*RO(I)+BETA(M)*THETA(I)+TAU(M)))
HE0(I)=TAU(M)/RO(I) - ALPH(M)*LOGF(RO(I))
6835 HE(I)=ACV(M)*THETA(I)+0.5*BCV(M)*THETA(I)**2
RKE=0.25*(U(I)**2 + U(I-1)**2)
6837 HMASS(I)=RL(I)**3 - RL(I-1)**3
TOTKE=TOTKE + HMASS(I)*RKE

```

```

6840 TOTIEN=TOTIEN + HMASS(I)*HE(I)
    HP(IMAX+1)=-HP(IMAX)
    QPRIMF = -1.0
    Q=TOTKE + TOTIEN
    TOTKE=4.18879*TOTKE
    TOTIEN=4.18879*TOTIEN
    PRINT 9943, TOTKE, TOTIEN
    WRITE OUTPUT TAPE 6,9943, TOTKE, TOTIEN
    IF(ICNTRL) 6990, 9050, 6990
6990 PRINT 9944, R(IMAX)
    WRITE OUTPUT TAPE 6,9944, R(IMAX)
    PRINT 9986
    WRITE OUTPUT TAPE 6, 9986
    ICNTRL=0
    GO TO 9050
9014 ALPHAO = MAX1F(ABSF(ALPHA), ALPHAO)
    IF(ALPHA) 9018, 9018, 9017
9017 FLAG1 = 1.0
9018 Z = ARSF(ALPHAP-ALPHA)/(ALPHAO + 3.0*EPSA)
    IF(Z-FTA3) 9015, 9015, 9020
9015 IF(SENSE SWITCH 5) 9030, 9016
9016 NS4=NS4+1
    GO TO 9050
9020 IF(3.0*ETA3-Z) 9022, 9022, 9027
9022 IF(1-NS4) 9023, 9024, 9024
9023 NS4=NS4-1
    GO TO 9040
9024 IF(ALPHA) 9050, 9025, 9025
9025 SENSE LIGHT 3
    GO TO 9050
9027 IF(SENSE SWITCH 5) 9030, 9050
9030 IF(1-NS4) 9023, 9050, 9050
9040 IF(6.0*ETA3-Z) 9045, 9045, 9050
9045 NS4=1
9050 IF(SENSE SWITCH 6) 9051,9052
9051 PAUSE 66666
9052 NH=NH+1
    IF(NS4R) 9054, 9054, 9056
9054 QP=4.18879*Q
    PRINT 9911, TIME, QP, POWER, ALPHA, DELT,W
    WRITE OUTPUT TAPE 6, 9911, TIME, QP, POWER, ALPHA, DELT, W
9056 W = 0.0
    TIME=TIME+DELT
    Z=ALPHA*DELTP
    POWER=EXP(Z)*POWER
9060 QBAR=POWER*DELT/(12.56637*FBAR)
    IF(Q-QPRIME) 9061, 9061, 9066
9061 IF(ALPHA) 9062, 9066, 9066
9062 IF(FLAG1) 9066, 9066, 9065
9065 NS4 = 30000
9066 QPRIMF = Q
C

```

```

C      ENTER I LOOP
C
DO 9200 I=2,IMAX
U(I)=U(I) - DELTP*R(I)**2*(HP(I+1)-HP(I))/  

X      (0.5*RL(I)**2*(RL(I+1)-RL(I-1)))
R(I)=R(I)+U(I)*DELT
RHOT=HMASS(I)/(R(I)**3-R(I-1)**3)
DELV=1.0/RHOT-1.0/RO(I)
IF(RHOT*ABSF(DELV)-0.1) 9070, 9070, 9068
9068 IRCNBR = IRCNBR
PAUSE 50
9069 PAUSE
PRINT 9987, IRCNBR
WRITE OUTPUT TAPE 6, 9987, IRCNBR
2003 FORMAT(27H HALVE DELT, RHO DELV LARGE)
PRINT 2003
WRITE OUTPUT TAPE 6, 2003
GO TO 9290
9070 DELQ=F(I)*QBAR/ROSN(I)
Q = Q + DELQ*HMASS(I)
DELR=R(I)-R(I-1)
IF(DELR) 9080, 9080, 9082
9080 PAUSE 60
GO TO 9068
9082 VP=0.0
IF(DELV) 9120, 9124, 9124
9120 VP=CVP*RHOT*(RHOT*DELV*DELR/DELT)**2
9122 IF(NH-1) 9123, 9123, 9124
9123 HP(I)=HP(I)+VP
9124 HPT=HP(I)
THET=THETA(I)
M=K(I)
NIT=0
9130 DELE=DELQ-0.5*(HPT+HP(I))*DELV
Z=DELF+DELV*(TAU(M)+ALPH(M)*0.5*(RHOT+RO(I)))
THET=MAX1F(0.0, (THETA(I)+2.0*Z/(2.0*ACV(M)+  

X      BCV(M)*(THET+THETA(I)))))

9140 PSTAR=MAX1F(0.0, (ALPH(M)*RHOT+BETA(M)*THET+TAU(M))+VP
9150 IF(ABSF(PSTAR-HPT)/(ABSF(PSTAR)+EPS1)-ETA1) 9180, 9180, 9151
9151 NIT=NIT+1
IF(NIT-NITMAX) 9160, 9170, 9170
9160 HPT=PSTAR
GO TO 9130
9170 PAUSE 11
9180 HP(I)=PSTAR
HE(I)=HE(I)+DELE
THETA(I)=THET
9190 WR = CSC*ABSF(HE(I))*DELT**2/DELR**2+4.0*CVP*RHOT*ABSF(DELV)
W = MAX1F(WR,W)
9200 RO(I)=RHOT
C
C      END OF I LOOP

```

```

C
      HP(IMAX+1)=-HP(IMAX)
9201 IF(NS4-1) 9210, 9210, 9202
9202 IF(ALPHA) 9210, 9210, 9203
9203 HPBAR = 0.
      DO 9204 I=2,IMAX
9204 HPBAR = MAX1F(HPBAR,HP(I))
      IF(HPRAR-PTEST) 9210, 9210, 9205
9205 PBAR = 0.
      DO 9206 I=2,IMAX
9206 PBAR = PBAR + HP(I)*T(I)
      PBAR = PBAR*12.56637
      S4R = NS4
      CONST = VJ*DELT**2*S4R**2*PBAR
      IF(CONST-OK1) 9210, 9213, 9213
9213 NPOFF = NPOFFP
9207 IF(CONST-OK2) 9209, 9208, 9208
9208 NS4 = 1
      GO TO 9210
9209 IF(XMODF(NS4,2)) 9211, 9212, 9211
9211 NS4 = (NS4-1)/2
      GO TO 9210
9212 NS4 = NS4/2
9210 DELTP=DELT
      IF(SENSE LIGHT 1) 5999,9220
9220 IF(SENSE LIGHT 2) 9230, 9230
9230 IF(SENSE SWITCH 1) 5999, 9240
9240 IF(XMODF(NH,NP)) 5999, 5999, 9241
9241 IF(XMODF(NH,NPOFF)) 9242, 9242, 9255
9242 LDONT = 7
      GO TO 6000
5999 LDONT = 0
6000 TOTKE=0.0
      TOTIEN=0.0
      ERRCL=0.0
      DO 6040 I=2,IMAX
      M=K(I)
6010 RIE=HF0(I)+ALPH(M)*LOGF(RO(I))-TAU(M)/RO(I) +
      X      ACV(M)*THETA(I)+0.5*BCV(M)*THETA(I)**2
6020 ERRCL=MAX1F(ERRCL, ABSF(RIE-HE(I)))
6030 RKE=0.25*(U(I)**2 + U(I-1)**2)
      TOTKE=TOTKE+HMASS(I)*RKE
6040 TOTIEN=TOTIEN+HMASS(I)*RIE
      CHECK=(Q-TOTKE-TOTIEN)/Q
      QP=4.18879*Q
      TOTKE=4.18879*TOTKE
      IF(LDONT) 6055, 6050, 6055
6050 PRINT 9911, TIME, QP, POWER, ALPHA, DELT, W
      PRINT 9982
      PRINT 9911, QP, TOTKE, CHECK, ERRCL
      PRINT 9983
9250 PRINT 9911, (RO(I),R(I),U(I),HP(I),HE(I),THETA(I),I=2,IMAX)

```

```

PRINT 9900
PRINT 9986
6055 WRITE OUTPUT TAPE 6, 9911, TIME, QP, POWER, ALPHA, DELT, W
      WRITE OUTPUT TAPE 6, 9982
      WRITE OUTPUT TAPE 6, 9911, QP, TOTKE, CHECK, ERRLCL
      WRITE OUTPUT TAPE 6, 9983
      WRITE OUTPUT TAPE 6, 9911, (RO(I),R(I),U(I),HP(I),HE(I),THETA(I),I
      I=2,IMAX)
      WRITE OUTPUT TAPE 6, 9900
      WRITE OUTPUT TAPE 6, 9986
9255 IF(SENSE LIGHT 3) 9283, 9256
9256 IF(NDUMP) 9257, 9258
9257 IRCNBR = IRCNBR + 1
      NDUMP = NDMAX
      GO TO 9263
9258 NDUMP = NDUMP-1
9262 IF(SENSE SWITCH 2) 9264, 9267
9264 IRCNBR=IRCNBR+1
9265 PAUSE?2222
9263 PAUSE
9266 PRINT 9984, IRCNBR
      WRITE OUTPUT TAPE 6, 9984, IRCNBR
9267 IF(W-0.3) 9268, 9285, 9285
9268 IF(ALPHA*DELT-4.0*ETA2) 9269, 9284, 9284
9269 IF(W-0.03) 9270, 9310, 9310
9270 NL = NL-1
9272 IF(NL) 9274,9274,9320
9274 IF(ALPHA*DELT-ETA2) 9278, 9320, 9320
9278 IF(2.0*DELT-DTMAX) 9280, 9280, 9320
9280 IF(XMODF(NH,2)) 9320,9281,9320
9281 SENSE LIGHT 2
      DELTP=1.5*DELT
      DELT=2.0*DELT
      NH=NH/2
      NS4=(NS4+1)/2
9282 FORMAT(12H DOUBLE DELT)
      PRINT 9282
      WRITE OUTPUT TAPE 6, 9282
      GO TO 9310
2000 FORMAT(29H HALVE DELT, SENSE LIGHT 3 ON)
9283 PRINT 2000
      WRITE OUTPUT TAPE 6, 2000
      GO TO 9290
2001 FORMAT(28H HALVE DELT, ALPHADELT LARGE)
9284 PRINT 2001
      WRITE OUTPUT TAPE 6, 2001
      GO TO 9290
2002 FORMAT(20H HALVE DELT, W LARGE)
9285 PRINT 2002
      WRITE OUTPUT TAPE 6, 2002
9290 SENSE LIGHT 1
      DELTP=0.75*DELT

```

```
DELT=0.5*DELT
NH=2*NH
9310 NL=NLMAX
9320 NS4R=NS4R+1
    IF(NS4R-NS4) 9050,9330,9330
9330 NS4R=0
    IF(SENSE LIGHT 4) 9331, 9332
9331 SENSE LIGHT 4
    GO TO 9337
9332 IF(ALPHA) 9333, 9337, 9337
9333 IF(NH-50) 9337, 9334, 9334
9334 IF(ALPHA-ALPHAP+EPSA) 9335, 9337, 9337
9335 IF(POWER-POWNGL) 9336, 9337, 9337
9336 ETA3 = 10.0*ETA3
    NS4 = NS4+4
2005 FORMAT(19H POWER SMALL NS4 UP)
    PRINT 2005
    WRITE OUTPUT TAPE 6, 2005
    SENSE LIGHT 4
9337 ALPHAP = ALPHA
    GO TO 8009
```

## STORAGE FOR VARIABLES APPEARING IN DIMENSION OR EQUIVALENCE SENTENCES

	DEC	OCT	DEC	OCT	DEC	OCT	DEC	OCT	DEC	OCT	DEC	OCT
H	32165	76645	HP	32647	77607		HMASS	31869	76175	HE	32606	77536
F	32405	77225	E	32365	77155		EN	31785	76051	NN	31505	75421
DELTA	32285	77035	B	31954	76322		BETA	32069	76505	BCV	32045	76455
ANUSIG	31305	75111	ANU	32022	76426		AM	31964	76334	AMBAR	31959	76327
AK	31829	76125	ACV	32053	76465		KP	32037	76445	K	32485	77345
P	31193	74731	RBAR	32325	77105		RHO	32445	77275	RL	32526	77416
RO	32767	77777	ROSN	31825	76121		R	32727	77727	SIGMA	31057	74521
SO	32125	76575	S	32245	76765		SUM	32015	76417	TAU	32061	76475
T	32205	76715	U	32687	77657		V	32029	76435	WN	32008	76410

## STORAGE FOR VARIABLES WHICH DO NOT APPEAR IN DIMENSION OR EQUIVALENCE SENTENCES

	DEC	OCT	DEC	OCT	DEC	OCT	DEC	OCT	DEC	OCT	DEC	OCT
I\$	30665	73711	I	30664	73710		IRCNBR	30663	73707	IMAX	30662	73706
II	30660	73704	IG	30659	73703		IGMAX	30658	73702	ICNTR	30657	73701
HPBAR	30655	73677	FLAG1	30654	73676		FFBAR	30653	73675	FFBAP	30652	73674
FENBAR	30650	73672	FEBAR	30649	73671		FEBAR	30648	73670	FBAR	30647	73667
ETA2	30645	73665	ETA1	30644	73664		ERRLCL	30643	73663	EPS	30642	73662
EPSK	30640	73660	EPSA	30639	73657		EPS1	30638	73656	DTMAX	30637	73655
DELT	30635	73653	DELT	30634	73652		DELR	30633	73651	DELQ	30632	73650
CVP	30630	73646	CSC	30629	73645		CONST	30628	73644	CHECK	30627	73643
BS	30625	73641	AMT	30624	73640		AMBART	30623	73637	ALPHA	30622	73636
ALPHAO	30620	73634	AKEFF	30619	73633		AITCT	30618	73632	JK	30617	73631
J	30615	73627	KCALC	30614	73626		KCNTRL	30613	73625	LDONT	30612	73624
MA	30610	73622	MMAX	30609	73621		M	30608	73620	NDMAX	30607	73617
NH	30605	73615	NITMAX	30604	73614		NIT	30603	73613	NUMAX	30602	73612
NMAX	30600	73610	NPOFFF	30599	73607		NPOFF	30598	73606	NP	30597	73605
NS4R	30595	73603	NS4	30594	73602		OK1	30593	73601	OK2	30592	73600
POWER	30590	73576	POWNLG	30589	73575		PSTAR	30588	73574	PTEST	30587	73573
QPRIMF	30585	73571	QP	30584	73570		Q	30583	73567	RHOT	30582	73566
RKF	30580	73564	S4R	30579	73563		SUM1	30578	73562	SUM2	30577	73561
TIMF	30575	73557	TOTIEN	30574	73556		TOTKE	30573	73555	VJ	30572	73554
WR	30570	73552	W	30569	73551		Z	30568	73550	Z	30567	73553

## EXTERNAL FORMULA NUMBERS WITH CORRESPONDING INTERNAL FORMULA NUMBERS AND OCTAL LOCATIONS

EFN	IFN	LOC									
990n	2	00000	9910	3	00000	9911	4	00000	9915	5	00000
9921	7	00000	9922	8	00000	9930	9	00000	9931	10	00000
9941	12	00000	9942	13	00000	9943	14	00000	9944	15	00000
9981	17	00000	9982	18	00000	9983	19	00000	9984	20	00000
998k	22	00000	9987	23	00000	7000	24	00000	7000	25	00007
7005	28	00023	7010	30	00031	7015	35	00046	7020	37	00050
7025	49	00132	7030	52	00141	7030	54	00157	7040	68	00242
7045	80	00304	7050	81	00311	7050	89	00341	7060	90	00343
7070	98	00425	7080	99	0044	7090	105	00475	7100	109	00511
7110	115	00537	7120	116	00544	7130	126	00624	7130	128	00641
7135	131	00662	7140	136	00677	7150	138	00704	7155	157	00762

Original from

TECHNICAL REPORT ARCHIVE &amp; IMAGE LIBRARY

7160	170	01045	172	01063	186	01146	193	01172	198	01210
7161	179	01216	7172	01246	7180	01310	7186	01332	7190	219
7162	207	01246	9000	01521	9002	01550	9003	01551	208	255
7163	224	01400	240	01521	252	01550	265	01666	207	268
7164	256	01557	210	01621	211	01666	215	01774	215	269
7165	270	01737	214	01764	215	01774	8009	02013	8010	278
7166	279	02033	13	02050	8000	02070	284	02070	285	02077
7167	8	290	02150	7	291	02157	14	292	02162	15
7168	296	02174	4	297	02214	10	299	02232	3	294
7169	304	02301	101	305	02306	120	309	02324	102	301
7170	315	02361	900	316	02364	103	317	02370	321	02413
7171	325	02437	902	327	02457	901	328	02463	108	329
7172	332	02532	1001	333	02537	110	334	02542	79	335
7173	8n	340	02577	81	341	02602	84	343	02614	91
7174	30n	346	02632	8300	353	02656	8301	354	02670	301
7175	303	364	03001	302	366	03016	310	373	03050	373
7176	311	376	03067	312	377	03070	315	383	03120	312
7177	8999	387	03137	314	390	03152	314	392	03164	306
7178	319	399	03207	325	400	03210	8015	402	03220	8020
7179	321	411	03264	338	415	03301	330	416	03305	339
7180	331	420	03317	331	421	03326	501	425	03357	501
7181	502	433	03411	502	434	03420	9010	445	03465	9011
7182	6801	451	03512	6803	458	03527	6803	459	03536	6802
7183	6820	466	03615	6822	467	03626	2004	468	03640	6830
7184	6835	481	03724	6837	483	03753	6840	485	03772	6990
7185	9014	510	04126	9017	512	04142	9018	513	04144	9015
7186	9020	518	04170	9022	519	04175	9023	520	04201	9024
7187	9027	525	04213	9030	526	04215	904c	527	04222	9045
7188	9051	530	04233	9052	531	04234	9054	533	04242	9056
7189	9061	546	04340	9062	547	04343	9065	548	04347	9066
7190	9069	558	04461	2003	565	00020	9070	571	04537	9080
7191	9120	579	04570	9122	580	04606	9123	581	04612	9124
7192	9140	589	04703	9150	590	04721	9151	591	04741	9160
7193	9180	596	04754	9190	599	04763	9200	601	05023	9201
7194	9203	605	05044	9204	607	05051	9205	609	05065	9206
7195	9207	617	05136	9208	618	05143	9209	620	05146	9211
7196	9210	624	05171	9220	626	05176	9230	627	05200	9240
7197	9242	630	05220	5999	632	05223	6000	633	05225	6010
7198	6030	640	05306	6040	642	05324	6050	647	05351	6050
7199	9250	662	05460	6055	667	05504	6055	669	05523	9255
7200	9257	689	05645	9258	692	05653	9262	693	05656	9264
7201	9263	696	05664	9266	697	05665	9266	699	05677	9267
7202	9269	705	05731	9270	706	05735	9272	707	05740	9274
7203	9280	710	05755	9281	711	05764	9282	716	00140	2000
7204	9282	724	06042	2001	728	00010	9284	729	06056	9284
7205	9285	735	06101	9285	736	06110	9290	739	06123	9310
7206	9330	746	06150	9331	748	06154	9332	750	06156	9333
7207	9335	753	06173	9336	754	06177	2005	756	00010	9337

### SUBROUTINES OBTAINED FROM LIBRARY

(DBC)	DEC	OCT	(CSH)	DEC	OCT	(BCD)	DEC	OCT	(FIL)	DEC
(RTN)	4181	10125	(SPH)	4030	07676	(STH)	4111	10017	(LOG)	4141
CUBERT	4870	11406	(SPH)	4661	11065	(STH)	4757	11225	(LOG)	4765

In the preparation of this report certain superfluous material was inadvertently included as pages 62, 63, and 64. This has been deleted, but the page numbers from 65 on have been maintained to expedite publication.

## VII. ROLE OF SENSE SWITCHES, SENSE LIGHTS AND FLAGS

### Sense Switch No. 1

At Order No. 7010, this switch, if on (depressed), calls for Pause 111 to allow time for modifications in a problem being rerun from a dump. Again at Order 9000, depressing this switch produces Pause 11111 after the print-out of input data and before the beginning of the mixture code. Finally, at Order 9230, if this switch is depressed, an on-line and off-line print-out of  $t$ ,  $Q_p$ , power, alpha, etc., is provided independent of whether  $NH \equiv 0 \pmod{N_p}$ .

### Sense Switch No. 2

At Order No. 9262, depressing this switch produces a dump of the memory on Tape 6.

### Sense Switch No. 3

At Order No. 503, following Order No. 915, depressing this switch provides an on-line print-out of the radii and of ENN(I,J), the angular flux distribution for Group 1, the lowest energy group (or, in a one-group problem, the only group).

### Sense Switch No. 4

At Order No. 915, depressing this switch provides an on-line print-out of F(I), the fission source, for all mass points and of EN(IG,I), the flux, for all groups and mass points.

### Sense Switch No. 5

At Order No. 9015, depressing this switch sends the computation to Order No. 9023 where  $N_{S4}$  is reduced by one if it is not already unity.

### Sense Switch No. 6

At Order No. 7150, this switch bypasses the normal on-line print-out of input data if depressed. At Order No. 9050, this switch, if depressed, produces Pause 66666 before beginning the next series of hydrocycles.

### Sense Light No. 1

At Order No. 9210, if this sense light is on, an energy balance is made and an on-line and off-line print-out of  $t$ ,  $Q_p$ , power,  $\alpha$ ,  $\Delta t$ , etc. is provided, independent of whether  $NH = 0 \pmod{N_p}$ . This light is lit at Order No. 9290 where  $\Delta t$  is halved.

Sense Light No. 2

At Order No. 9281, if the course of the problem permits a doubling of  $\Delta t$ , this sense light is lit. It is automatically turned off at Order No. 9220 following the next hydrocycle.

Sense Light No. 3

At Order No. 9255, this sense light, if on, sends the computation to Order Nos. 9283 and 9290 where  $\Delta t$  will be halved. The light will be turned on at Order No. 9025 if the fractional change in alpha between the last two  $S_4$  calculations exceeds  $3\eta_3$ .

Sense Light No. 4

At Order No. 2005, if the burst has gone through its peak and has reached a condition of negative alpha and low power, sense light No. 4 is lit and the fact that this condition has been attained is printed.

Flag 1

If alpha becomes negative after having been positive, and if the total energy shows no change or a net decrease during the hydrocycle, this flag sends  $N_{S4}$  to 30,000 (Order Nos. 9017, 9062, 9065) terminating any further  $S_n$  calculations. At this condition the burst is over, the power is essentially zero. The total energy may therefore actually not change (within limits of accuracy), and approximations in the solution might even produce a slight wavering in an essentially constant quantity.

### VIII. LIST OF PAUSES AND STOPS

#### Order No.

7010	<b>Pause 7010</b>	This is a dummy pause to provide an address in memory where a transfer to the tape recall routine must be placed. If the problem is being run from restart, the dump numbered ICRNBR is read from tape into memory at this time.
7015	<b>Pause 111</b>	Optional pause (Sense Switch No. 1) to allow modification of memory or any other steps when beginning problem from a dump.
9002	<b>Pause 11111</b>	Optional pause (Sense Switch No. 2) following print-out of input data.
14	<b>Pause 14</b>	If $H(I)$ should be negative, this pause results. When problem is continued, $H(I)$ is set equal to zero.
900	<b>Stop 13571</b>	The problem is stopped if $I < 0$ results somehow.
901	<b>Stop 12345</b>	The problem is stopped if $J = 0$ , falling outside the proper range 1-5.
9051	<b>Pause 66666</b>	This is an optional pause (Sense Switch No. 6) at the beginning of the hydrocycle.
9068	<b>Pause 50</b>	This pause occurs after continuing from Pause 60, or if excessive change occurs in $\rho_{Hyd}^T  \Delta V $ , both serious troubles. Continuing the problem leads to dummy pause 9069.
9069	<b>Dummy Pause</b>	If the problem is continued after Pause 50, Order No. 9069 institutes a dummy pause to provide an address in memory where a transfer to the tape recall routine must be placed. The latest dump of the problem is read from tape into memory at this time. The problem then continues with $\Delta t$ halved.
9080	<b>Pause 60</b>	This pause indicates radii crossing. Continuing the problem leads to Pause 50.

## Order No.

9170	Pause 11	If the hydrocycle calculation of the new pressure, an iterative process, does not converge as requested in 300 cycles, (Nit Max) Pause 11 results. On continuing the problem, the last calculated pressure is accepted as correct.
9265	Pause 22222	This pause follows Order No. 9262, where if Sense Switch No. 2 is on, a dump of the memory is called for, even though $N_{\text{dump}} > 0$ .
9263	Dummy Pause	This is a dummy pause to provide the address in memory where a transfer to the tape dump routine must be placed. The contents of the memory are written on Tape 5 at this time.

## IX. OPERATING INSTRUCTIONS

Deck Composition:

1. The FORTRAN compiled binary deck with the transfer card removed and 170<sub>8</sub> punched in row 12L of the fourth card instead of the usual 140<sub>8</sub> - 255 cards.
2. The "Tape Dump and Recall Routine" - 1 card. (See Appendix F.1)
3. Binary correction cards (transfers to the "Tape Dump and Recall Routine") - 3 cards.
4. Transfer card 170<sub>8</sub> - 1 card.
5. Input data cards.

Reader: 72-72 board.

Punch: Not used.

Printer: SHARE board No. 2.

Tapes: No. 5 should be blank for routine memory dumps and No. 6 should be blank for output.

Sense Switch Settings: Normally all switches are up. See the section on Sense Switches for details.

Underflow Switch: On

Running Procedure:

1. Ready the card deck in the reader.
2. Ready the printer.
3. Mount and ready tapes No. 5 and 6.
4. Clear and load cards.

Program Stops:

51<sub>8</sub> This occurs if memory and tape transmission differ in the Tape Dump and Recall Routine portion of the program. Continuing will cause the tape unit to backspace one record and come to stop 52.

52<sub>8</sub> This occurs after the tape has been backspaced one record. Continuing will cause another attempt to execute the "Tape Dump and Recall Routine."

Since this is a FORTRAN compiled program the stops listed under the section "Error Stops in Object Program" of the FORTRAN Preliminary Operator's Manual are applicable. For additional stops see the section on Pauses.

#### Problem Termination:

The program does not terminate itself. Unless one wishes to observe post-burst phenomena, the appearance of "Power Small NS4 Up" on the on-line output indicates a good stopping point. Tape No. 6 should be printed off-line under program control. Tape No. 5 should be saved if restarting the problem from a dump is anticipated (see Appendix F.2). Neither tape has an end-of-file on it.

#### Restart Procedure:

To restart a problem from a dump, follow the same procedure as for a new problem with the following exceptions:

1. Tape No. 5 should contain the dump.
2. Input data consist only of a title card and an IRCNBR card containing the number of the dump from which restart is desired.

#### Running Time:

The sample problem ran for 40 minutes before being terminated.

## X. SAMPLE PROBLEM

### A. Input Data

The specification of the problem will be made here in three different forms, all equivalent. First, a set of notes, as might be prepared by a physicist will be presented. The same problem will then be shown on the standard input sheets in slightly more cryptic fashion. Finally, the same data will be listed on the input sheet used by the card puncher in a form similar to that in which it is printed out.

A few general comments precede this presentation. It is first noted that the mass point  $I = \text{unity}$  is always reserved for the central point,  $R = 0$ , and the first real mass point and the first non-zero radius corresponds to  $I = 2$ .

It is noted that cross sections are stored in barns, necessitating the use of different "densities" in the neutronics and hydrodynamics equations, as was discussed previously in the section "Detailed Flow Diagram and Explanatory Notes." It is also necessary that mixtures be specified as atomic fractions,  $P_i$ , where  $\sum_i P_i = 1$ .

It is noted that in the section "Properties of Materials" a material should be listed only once, even if it reappears as one moves outward radially.

The size of the various convergence and comparison criteria specified herein are subject to revision in accordance with the needs and peculiarities of the problem. They generally represent a compromise between the need for accuracy and the desire to minimize the machine time consumed.

EPSR, EPSC, and EPSK are the convergence criteria for the various types of  $S_n$  calculations. Running time will be particularly sensitive to EPSC, since this number controls the oft-repeated alpha calculation. ETA 2 limits the maximum fractional change in power per hydrocycle. Once set, it implies an inverse relationship between the initial alpha and the initial  $\Delta t$ . Unless conditions dictate otherwise, it is reasonable to choose the largest initial  $\Delta t$  which satisfies the ETA 2 test.

$\Delta t_{\text{Max}}$ , NP, NPOFF, and NPOFFP do not directly affect accuracy and, hence, are somewhat arbitrary, depending on the wishes of the problem initiator. ETA 1 and ETA 3 control the accuracy of the solution and, hence, must represent a balance between accuracy and machine time. As with many of the other control criteria, experience and subjective judgment play a major role in fixing these parameters. The numbers used in the test problem have been satisfactory for studies on accidents in fast reactors.

## 1. Physicist's Specifications

Problem: Geneve 10 Rerun March 20, 1959. Ax-1

Specify initial alpha =  $0.013084 \mu\text{sec}^{-1}$ . Vary radii to fit.

Two region problem (Spherical core surrounded by concentric blanket).

Core radius                    23.75 cm

Blanket radius                44.70 cm

Core Density                  7.92 g/cc

Blanket Density              15.83 g/cc

Core composition

(atomic fraction)            0.36 Substance 1

                                  0.64 Substance 2

Blanket composition         1.0 Substance 3

Use 25 uniformly spaced mass points in core, 14 mass points in blanket.

All mass points initially at rest.

Core temp. =  $10^{-4}$  kev.

Blanket temp. =  $5 \times 10^{-5}$  kev.

No fission in blanket. Guess smooth flux curve in core with edge to center ratio = 0.4.

Initial power =  $10^{12}$  ergs/ $\mu\text{sec}$ .

Use 1 group cross sections

$V_g = 1.695 \times 10^2 \text{ cm}/\mu\text{sec}$ .

Substance 1 =  $U^{235}$

Substance 2 =  $U^{238}$

Substance 3 =  $U^{238}$  with no fission allowed.

### Equation of State Parameters

$$P = \alpha \rho + \beta \theta + \tau$$

$$\alpha = .02873 \text{ cm}^2/\mu\text{sec}^2$$

$$\beta = 278.46 \text{ g/cm } \mu\text{sec}^2$$

For core, set  $\tau = -0.3946$ . Then the pressure calculated from equation of state will be negative for the original density until  $\theta = 6 \times 10^{-4}$  kev. Program will keep pressure zero until this threshold temperature is reached.

For blanket, set  $\tau = -0.4687189$ , so that pressure initially is exactly zero from the equation of state.

**Specific heat parameters:**

$$\frac{\partial E}{\partial \theta} = A_{cv} + B_{cv} \theta$$

$$A_{cv} = 12.163 \text{ cm}^2/\mu\text{sec}^2 \text{ kev}$$

$$B_{cv} = 5.78 \times 10^3 \text{ cm}^2/\mu\text{sec}^2 \text{ kev}^2$$

**Accuracy Criteria**

EPSR	$3 \times 10^{-6}$ cm
EPSA	$5 \times 10^{-5}$ $\mu\text{sec}^{-1}$
EPS1	$10^{-4}$ gm/cm $\mu\text{sec}^2$
ETA1	$10^{-3}$
ETA2	$1.5 \times 10^{-2}$
ETA3	$3 \times 10^{-2}$
CVP	2
CSC	3 (An estimate of the maximum value of $\gamma(\gamma - 1)$ reached during the burst for the equation of state parameters used.)
$\Delta t$	$2 \mu\text{sec}$
$\Delta t_{Max}$	$16 \mu\text{sec}$
NP	100
NPOFF	15
NPOFFP	3
KCNTRL	01
VJ	$6.6 \times 10^{-7}$ (This was guessed from a previous problem and may not conform exactly to present specifications.)
OK1	0.01
OK2	0.04
PTEST	$10^{-4}$
EPSK	$5 \times 10^{-6}$
POWNGL	1

## 2. Formal Presentation of Specifications

**INPUT SHEETS - Ax I**

Problem Name and Date Geneve 10 Rerun March 20, 1959

Record Number (choose one)	$\begin{cases} 00 \text{ if beginning new problem} \\ > 0 \text{ if restarting from tape, omit rest of form} \end{cases}$	00
$\alpha$ Control (choose one)	$\begin{cases} 00 \text{ to find } \alpha \text{ for given configuration. A guess is required for } \alpha. \\ 01 \text{ to scale radii given } \alpha \text{ below} \end{cases}$	01
$\alpha (\mu\text{sec}^{-1})$		$1.3084 \times 10^{-2}$
Power ( $10^{12}$ ergs/ $\mu\text{sec}$ )		1
I Max = Total Number of Zones + 1 (I Max $\leq 40$ )		40

**ZONE DATA**

The following must be filled out for each i ( $2 \leq i \leq I_{\text{Max}}$ )

	RADIUS (cm)	DENSITY (gm/cm <sup>3</sup> )	RELATIVE FISSION DENSITY	VELOCITY (cm/ $\mu\text{sec}$ )	TEMPERATURE (kev)
i = 2	.95	7.92	1	0	$10^{-4}$
i = 3	1.90	7.92	1	0	$10^{-4}$
i = 4	2.85	7.92	.99	0	$10^{-4}$
i = 5	3.80	7.92	.98	0	$10^{-4}$
i = 6	4.75	7.92	.97	0	$10^{-4}$
i = 7	5.70	7.92	.95	0	$10^{-4}$
i = 8	6.65	7.92	.93	0	$10^{-4}$
i = 9	7.60	7.92	.91	0	$10^{-4}$
i = 10	8.55	7.92	.89	0	$10^{-4}$
i = 11	9.50	7.92	.87	0	$10^{-4}$

	RADIUS (cm)	DENSITY (gm/cm <sup>3</sup> )	RELATIVE FISSION DENSITY	VELOCITY (cm/μ sec)	TEMPERATURE (kev)
i = 12	10.45	7.92	.85	0	10 <sup>-4</sup>
i = 13	11.40	7.92	.82	0	10 <sup>-4</sup>
i = 14	12.35	7.92	.79	0	10 <sup>-4</sup>
i = 15	13.30	7.92	.76	0	10 <sup>-4</sup>
i = 16	14.25	7.92	.73	0	10 <sup>-4</sup>
i = 17	15.20	7.92	.70	0	10 <sup>-4</sup>
i = 18	16.15	7.92	.67	0	10 <sup>-4</sup>
i = 19	17.10	7.92	.64	0	10 <sup>-4</sup>
i = 20	18.05	7.92	.61	0	10 <sup>-4</sup>
i = 21	19.00	7.92	.58	0	10 <sup>-4</sup>
i = 22	19.95	7.92	.55	0	10 <sup>-4</sup>
i = 23	20.90	7.92	.52	0	10 <sup>-4</sup>
i = 24	21.85	7.92	.48	0	10 <sup>-4</sup>
i = 25	22.80	7.92	.44	0	10 <sup>-4</sup>
i = 26	23.75	7.92	.40	0	10 <sup>-4</sup>
i = 27	24.70	15.83	0	0	5 x 10 <sup>-5</sup>
i = 28	25.65	15.83	0	0	5 x 10 <sup>-5</sup>
i = 29	26.60	15.83	0	0	5 x 10 <sup>-5</sup>
i = 30	27.55	15.83	0	0	5 x 10 <sup>-5</sup>
i = 31	28.50	15.83	0	0	5 x 10 <sup>-5</sup>
i = 32	30.30	15.83	0	0	5 x 10 <sup>-5</sup>
i = 33	32.10	15.83	0	0	5 x 10 <sup>-5</sup>
i = 34	33.90	15.83	0	0	5 x 10 <sup>-5</sup>
i = 35	35.70	15.83	0	0	5 x 10 <sup>-5</sup>
i = 36	37.50	15.83	0	0	5 x 10 <sup>-5</sup>
i = 37	39.30	15.83	0	0	5 x 10 <sup>-5</sup>
i = 38	41.10	15.83	0	0	5 x 10 <sup>-5</sup>
i = 39	42.90	15.83	0	0	5 x 10 <sup>-5</sup>
i = 40	44.70	15.83	0	0	5 x 10 <sup>-5</sup>

**COMPOSITION**

**Definitions;**

A **Substance** has its own cross section cards.

A **Mixture** is made by the code out of substances.

**Materials** are those mixtures and/or substances that make up the actual system.

Write material label for each mass point:

$\frac{4}{2}$   $\frac{4}{3}$   $\frac{4}{4}$   $\frac{4}{5}$   $\frac{4}{6}$   $\frac{4}{7}$   $\frac{4}{8}$   $\frac{4}{9}$   $\frac{4}{10}$   $\frac{4}{11}$   $\frac{4}{12}$   $\frac{4}{13}$   $\frac{4}{14}$   $\frac{4}{15}$   $\frac{4}{16}$   $\frac{4}{17}$   $\frac{4}{18}$   $\frac{4}{19}$   $\frac{4}{20}$

$\frac{4}{21}$   $\frac{4}{22}$   $\frac{4}{23}$   $\frac{4}{24}$   $\frac{4}{25}$   $\frac{4}{26}$   $\frac{3}{27}$   $\frac{3}{28}$   $\frac{3}{29}$   $\frac{3}{30}$   $\frac{3}{31}$   $\frac{3}{32}$   $\frac{3}{33}$   $\frac{3}{34}$   $\frac{3}{35}$   $\frac{3}{36}$   $\frac{3}{37}$   $\frac{3}{38}$   $\frac{3}{39}$   $\frac{3}{40}$

G Max = number of energy groups ( $\leq 7$ ) 1

N Max 3 M Max 1

N Max = number of different substances for which cross sections are to be read in ( $\leq 8$ )

M Max = number of mixtures ( $\leq 8$ )

Label the substances with the integers 1, 2, . . . N Max

Label the mixtures with the integers N Max + 1, N Max + 2, N Max + M Max

If N Max + M Max  $> 8$ , some mixtures must be stored at positions previously occupied by substances, wiping out all knowledge of those substances at the time the mixtures are stored therein. The maximum number of materials is 8.

The proportions, P(M, IS), are stated as atomic fractions, and add up to unity for each mixture.

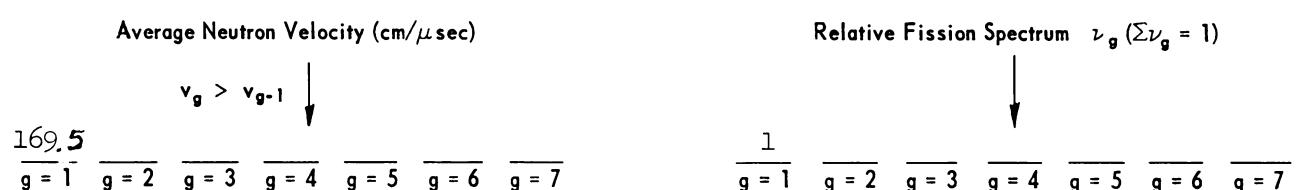
Proportions: .36 .64 \_\_\_\_\_

Substance Label: 1 2 \_\_\_\_\_ 4  
Mixture Label

Proportions: \_\_\_\_\_

Substance Label: \_\_\_\_\_ Mixture Label

### NEUTRON CONSTANTS



### Cross Sections (barns)

Note:  $\nu$  = average number of neutrons emitted per fission

$$\sigma_{tr} = \sigma_f + \sigma_{cap} + \sigma_{el. scat} + \sigma_{inel. scat} = \sigma_{total} \text{ (if scattering is isotropic)}$$

### Substance 1

	$(\nu \sigma_f)_g$	$(\sigma_{tr})_g$	$(\sigma_{scat})_g \leftarrow 1$	$(\sigma_{scat})_g \leftarrow 2$	$(\sigma_{scat})_g \leftarrow 3$	$(\sigma_{scat})_g \leftarrow 4$	$(\sigma_{scat})_g \leftarrow 5$	$(\sigma_{scat})_g \leftarrow 6$	$(\sigma_{scat})_g \leftarrow 7$
g = 1	3.75	7.0	5.3	—	—	—	—	—	—
g = 2	—	—	—	—	—	—	—	—	—
g = 3	—	—	—	—	—	—	—	—	—
g = 4	—	—	—	—	—	—	—	—	—
g = 5	—	—	—	—	—	—	—	—	—
g = 6	—	—	—	—	—	—	—	—	—
g = 7	—	—	—	—	—	—	—	—	—

Substance 2

	$(\nu \sigma_f)_g$	$(\sigma_{tr})_g$	$(\sigma_{scat})_{g \leftarrow 1}$	$(\sigma_{scat})_{g \leftarrow 2}$	$(\sigma_{scat})_{g \leftarrow 3}$	$(\sigma_{scat})_{g \leftarrow 4}$	$(\sigma_{scat})_{g \leftarrow 5}$	$(\sigma_{scat})_{g \leftarrow 6}$	$(\sigma_{scat})_{g \leftarrow 7}$
$g = 1$	.25	7.0	6.7						
$g = 2$									
$g = 3$									
$g = 4$									
$g = 5$									
$g = 6$									
$g = 7$									

Substance 3

	$(\nu \sigma_f)_g$	$(\sigma_{tr})_g$	$(\sigma_{scat})_{g \leftarrow 1}$	$(\sigma_{scat})_{g \leftarrow 2}$	$(\sigma_{scat})_{g \leftarrow 3}$	$(\sigma_{scat})_{g \leftarrow 4}$	$(\sigma_{scat})_{g \leftarrow 5}$	$(\sigma_{scat})_{g \leftarrow 6}$	$(\sigma_{scat})_{g \leftarrow 7}$
$g = 1$	0	7.0	6.8						
$g = 2$									
$g = 3$									
$g = 4$									
$g = 5$									
$g = 6$									
$g = 7$									

Substance 4

	$(\nu \sigma_f)_g$	$(\sigma_{tr})_g$	$(\sigma_{scat})_{g \leftarrow 1}$	$(\sigma_{scat})_{g \leftarrow 2}$	$(\sigma_{scat})_{g \leftarrow 3}$	$(\sigma_{scat})_{g \leftarrow 4}$	$(\sigma_{scat})_{g \leftarrow 5}$	$(\sigma_{scat})_{g \leftarrow 6}$	$(\sigma_{scat})_{g \leftarrow 7}$
$g = 1$									
$g = 2$									
$g = 3$									
$g = 4$									
$g = 5$									
$g = 6$									
$g = 7$									

## **PROPERTIES OF MATERIALS**

For each material in order from center outward:

## ACCURACY CRITERIA

#### **Definitions:**

**EPSR** Tolerance for outer radius when  $\alpha$ -control  $\neq 0$

### EPSA Tolerance in $\alpha$ 's found by S<sub>1</sub>

#### EPS1 Largest negligible pressure for equation of state iteration convergence.

## ETA1 Fractional pressure tolerance for equation of state iteration convergence

ETA2 1/4 the maximum tolerated value of  $a \wedge t$

### ETA3 Tolerance for the change in $\alpha$ between successive $S_4$ cycles

EPSR (cm)	EPSC ( $\mu \text{ sec}^{-1}$ )	EPS1 (g/cm $\mu \text{ sec}^2$ )	ETA1 $10^{-3}$	ETA2 $1.5 \times 10^{-2}$	ETA3 $3 \times 10^{-2}$
$3 \times 10^{-6}$	$5 \times 10^{-5}$	$10^{-4}$			
C <sub>vp</sub>	Viscous pressure coefficient	2		Courant stability constant	3
	for shock smearing			equals high estimate for $\gamma(\gamma-1)$	
$\Delta t$	( $\mu \text{ sec}$ )	2		$\Delta t_{\max}$ ( $\mu \text{ sec}$ )	16

**NP** Number of hydrodynamic cycles between detailed print on primary output.  
**NPOFF** Number of hydrodynamic cycles between detailed print offline.  
**NPOFFP** Revised number of hydrodynamic cycles between detailed print offline; effective when VJ limit on pressure is reached.  
**KCNTRL** 01 if calculation of  $k_{\text{eff}}$  is desired  
 00 if calculation of  $k_{\text{eff}}$  is not desired

<u>100</u>	<u>15</u>	<u>3</u>	<u>1</u>
NP	NPOFF	NPOFFP	KCNTRL

Limits on alpha change between  $S_4$  calculations

$$VJ \approx \left( \frac{\sqrt{q}}{b} \right)^5 \times \frac{1}{\alpha_{\max} \ell \rho}, \text{ in units of g}^{-1} \text{ cm}^{-2}$$

$$\text{where } 1 - q = \frac{\text{flux at core edge}}{\text{flux at center}}$$

b = core radius, cm

$\ell$  = neutron lifetime

$\rho$  = density, g/cm<sup>3</sup>

OK1 = dimensionless test parameter ( $\approx .01$ )

OK2 = dimensionless test parameter ( $\approx .04$ )

PTEST = maximum local pressure allowed without testing for  $\frac{d^2(\alpha)}{dt^2}$ , in megabars

EPSK Convergence criterion on k calculation

POWNGL Power following burst after which negligible change in total energy occurs.

<u><math>6.6 \times 10^{-7}</math></u>	<u><math>10^{-2}</math></u>	<u><math>4 \times 10^{-2}</math></u>	<u><math>10^{-4}</math></u>	<u><math>5 \times 10^{-6}</math></u>	<u>1</u>
VJ	OK1	OK2	PTEST	EPSK	POWNGL

For Ax-1', do not fill in POWNGL; state Ax-1' is to be used.

C. Input Sheets Used by Card-Punchers

**704 INPUT DATA  
FORM II**

PROBLEM GENEVE 10 RERUN		ORIGINATOR		DATA I.D.		DATE MARCH 20, 1959 PAGE 1 OF 4	
1	2	3	4	5	6	7	8
1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0
1GE,NEVE,10,RERUN,MARCH,20,1959							
0.0,							
0.1,							
.1..3.0.8 4.0.0,-0.2							
.1..0.0.0 0.0.0,+0.0							
4.0,							
.9..5.0.0 0.0.0,-0.1	.7..9.2.0 0.0.0,+0.0	.1..0.0.0 0.0.0,+0.0	.0..0.0.0 0.0.0,+0.0	.0..0.0.0 0.0.0,+0.0	.1..0.0.0 0.0.0,-0.4		
.1..9.0.0 0.0.0,+0.0		.1..0.0.0 0.0.0,+0.0					
.2..8.5.0 0.0.0,+0.0		.9..9.0.0 0.0.0,-0.1					
.3..8.0.0 0.0.0,+0.0		.9..8.0.0 0.0.0,-0.1					
.4..7.5.0 0.0.0,+0.0		.9..7.0.0 0.0.0,-0.1					
.5..7.0.0 0.0.0,+0.0		.9..5.0.0 0.0.0,-0.1					
.6..6.5.0 0.0.0,+0.0		.9..3.0.0 0.0.0,-0.1					
.7..6.0.0 0.0.0,+0.0		.9..1.0.0 0.0.0,-0.1					
.8..5.5.0 0.0.0,+0.0		.8..9.0.0 0.0.0,-0.1					
.9..5.0.0 0.0.0,+0.0		.8..7.0.0 0.0.0,-0.1					
.1..1.4.5 0.0.0,+0.1		.8..5.0.0 0.0.0,-0.1					
.1..1.4.0 0.0.0,+0.1		.8..2.0.0 0.0.0,-0.1					
.1..2.3.5 0.0.0,+0.1		.7..9.0.0 0.0.0,-0.1					
.1..3.3.0 0.0.0,+0.1		.7..6.0.0 0.0.0,-0.1					
1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0	1 2 3 4 5 6 7 8 9 0
1	2	3	4	5	6	7	8

AMD-9 (2-58)

**704 INPUT DATA  
FORM II**

PROBLEM GENEVE 10 RERUN ORIGINATOR

DATA I.D. DATE MARCH 20, 1959 PAGE 2 OF 4

1	2	3	4	5	6	7	8
1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0							
1.. 4.2.5 0.0.0.+0.1	7.. 9.2.0 0.0.0.+0.0	.7.. 3.0.0 0.0.0.-0.1	.0.. 0.0.0 0.0.0.+0.0	.1.. 0.0.0 0.0.0.-0.4			I = 1.6.
1.. 5.2.0 0.0.0.+0.1		.7.. 0.0.0 0.0.0.-0.1					I = 1.7.
1.. 6.1.5 0.0.0.+0.1		.6.. 7.0.0 0.0.0.-0.1					I = 1.8.
1.. 7.1.0 0.0.0.+0.1		.6.. 4.0.0 0.0.0.-0.1					I = 1.9.
1.. 8.0.5 0.0.0.+0.1		.6.. 1.0.0 0.0.0.-0.1					I = 2.0.
1.. 9.0.0 0.0.0.+0.1		.5.. 8.0.0 0.0.0.-0.1					I = 2.1.
1.. 9.9.5 0.0.0.+0.1		.5.. 5.0.0 0.0.0.-0.1					I = 2.2.
2.. 0.9.0 0.0.0.+0.1		.5.. 2.0.0 0.0.0.-0.1					I = 2.3.
2.. 1.8.5 0.0.0.+0.1		.4.. 8.0.0 0.0.0.-0.1					I = 2.4.
2.. 2.8.0 0.0.0.+0.1		.4.. 4.0.0 0.0.0.-0.1					I = 2.5.
2.. 3.7.5 0.0.0.+0.1		.4.. 0.0.0 0.0.0.-0.1					I = 2.6.
2.. 4.7.0 0.0.0.+0.1	1.. 5.8.3.0.0.0.+0.1	.0.. 0.0.0 0.0.0.+0.0		.5.. 0.0.0 0.0.0.-0.5			I = 2.7.
2.. 5.6.5 0.0.0.+0.1							I = 2.8.
2.. 6.6.0 0.0.0.+0.1							I = 2.9.
2.. 7.5.5 0.0.0.+0.1							I = 3.0.
2.. 8.5.0 0.0.0.+0.1							I = 3.1.
3.. 0.3.0 0.0.0.+0.1							I = 3.2.
3.. 2.1.0 0.0.0.+0.1							I = 3.3.
3.. 3.9.0 0.0.0.+0.1							I = 3.4.
3.. 5.7.0 0.0.0.+0.1							I = 3.5.
1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0							
1	2	3	4	5	6	7	8

AMD-9 (2-56)

**704 INPUT DATA FORM II**

PROBLEM GENEVE 10 RERUN ORIGINATOR

DATA I.D.

DATE MARCH 20, 1959 PAGE 3 OF 4

**704 INPUT DATA  
FORM II**

PROBLEM GENEVE 10 RERUN ORIGINATOR

DATA I.D.

DATE MARCH 20, 1959 PAGE 4 OF 4

AMD-9 (2-58)

## B. Results

The on-line print-out for the complete problem is included herein. First, a complete reproduction of the input data is printed, in exactly the same array as it is presented to the card punchers. Since a calculation of  $k_{eff}$  was requested, this number is printed, followed by the initial total kinetic energy, total internal energy and initial maximum radius.

At time equal to zero, a short print-out is made, consisting of Time,  $Q_p$ , Power, Alpha,  $\Delta t$  and W. As the calculation progresses, similar short prints are repeated following each  $S_n$  calculation. Dumps are noted as they occur during the process.

When a "long" print-out is in order ( $NH \equiv 0 \bmod N_p$ ) first the total energy, the kinetic energy and the checks on the energy computation are printed. This is followed by a detailed listing of the density, radius, velocity, pressure, internal energy and temperature of each mass point. This latter print-out is time-consuming; hence, the program was revised to permit infrequent on-line, long prints, coupled with frequent off-line, long prints. The latter are dumped on tape and are available for off-line print-out on separate equipment, if needed.

GENEVE 10 RERUN MARCH 20 1959

1	1•308400E-02	7•920000E 00	1•000000E 00	10•000000E-05
	1•000000E 00	7•920000E 00	1•000000E 00	10•000000E-05
40	9•500000E-01	7•920000E 00	9•900000E-01	10•000000E-05
	1•900000E 00	7•920000E 00	8•000000E-01	10•000000E-05
	2•850000E 00	7•920000E 00	7•000000E-01	10•000000E-05
	3•800000E 00	7•920000E 00	8•000000E-01	10•000000E-05
	4•750000E 00	7•920000E 00	7•000000E-01	10•000000E-05
	5•700000E 00	7•920000E 00	5•000000E-01	10•000000E-05
	6•650000E 00	7•920000E 00	3•000000E-01	10•000000E-05
	7•600000E 00	7•920000E 00	1•000000E-01	10•000000E-05
	8•550000E 00	7•920000E 00	9•000000E-01	10•000000E-05
	9•500000E 00	7•920000E 00	7•000000E-01	10•000000E-05
	1•045000E 01	7•920000E 00	5•000000E-01	10•000000E-05
	1•140000E 01	7•920000E 00	2•000000E-01	10•000000E-05
	1•235000E 01	7•920000E 00	9•000000E-01	10•000000E-05
	1•330000E 01	7•920000E 00	7•000000E-01	10•000000E-05
	1•425000E 01	7•920000E 00	6•000000E-01	10•000000E-05
	1•520000E 01	7•920000E 00	3•000000E-01	10•000000E-05
	1•615000E 01	7•920000E 00	7•000000E-01	10•000000E-05
	1•710000E 01	7•920000E 00	4•000000E-01	10•000000E-05
	1•805000E 01	7•920000E 00	1•000000E-01	10•000000E-05
	1•900000E 01	7•920000E 00	8•000000E-01	10•000000E-05
	1•995000E 01	7•920000E 00	5•000000E-01	10•000000E-05
	2•090000E 01	7•920000E 00	2•000000E-01	10•000000E-05
	2•185000E 01	7•920000E 00	1•000000E-01	10•000000E-05
	2•280000E 01	7•920000E 00	4•000000E-01	10•000000E-05
	2•375000E 01	7•920000E 00	4•000000E-01	10•000000E-05
	2•470000E 01	1•583000E 01	0•	5•000000E-05
	2•565000E 01	1•583000E 01	0•	5•000000E-05
	2•660000E 01	1•583000E 01	0•	5•000000E-05
	2•755000E 01	1•583000E 01	0•	5•000000E-05
	2•850000E 01	1•583000E 01	0•	5•000000E-05
	3•030000E 01	1•583000E 01	0•	5•000000E-05
	3•210000E 01	1•583000E 01	0•	5•000000E-05
	3•390000E 01	1•583000E 01	0•	5•000000E-05
	3•570000E 01	1•583000E 01	0•	5•000000E-05
	3•750000E 01	1•583000E 01	0•	5•000000E-05
	3•930000E 01	1•583000E 01	0•	5•000000E-05
	4•110000E 01	1•583000E 01	0•	5•000000E-05
	4•290000E 01	1•583000E 01	0•	5•000000E-05

4•470000E 01	1•583000E 01	0•	0•	5•000000E-05
4 4 4 4	4 4 4 4	4 4 4 4	4 4 4 4	4 4 4 4
3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3
1				
3 1	0•360000 0•640000 -0•	-0•	-0•	-0•
1	1 2	4	-0	-0
1•695000E 02	1•000000E 00	5•300000E 00		
3•750000E 00	7•000000E 00	6•700000E 00		
2•500000E-01	7•000000E 00	6•800000E 00		
0•	7•000000E 00	2•784600E 02	-3•946000E-01	5•780000E 03
3•960000E 02	2•873000E-02	2•784600E 02	-4•687189E-01	5•780000E 03
3•960000E 02	2•873000E-02	10•000000E-05	10•000000E-04	1•500000E-02
3•000000E-06	5•000000E-05			
2•000000E 00	3•000000E 00			
2•000000E 00	1•600000E 01			
100 15	3 1	4•000000E-02	10•000000E-05	5•000000E-06
6•600000E-07	10•000000E-03			1•000000E 00

	INITIAL MAXIMUM RADIUS =	TOTAL KINETIC ENERGY =	TOTAL INTERNAL ENERGY =	W
TIME	4.400910E 01	0.	3.484515E 03	1.308400E-02
QP	1.000000E 00	1.000000E 00	1.306381E-02	2.000000E 00
0.	3.486570E 03	1.026513E 00	1.306669E-02	2.000000E 00
2.000000E 00	3.490840E 03	1.081580E 00	1.306910E-02	2.000000E 00
6.000000E 00	3.497678E 03	1.169789E 00	1.307150E-02	2.000000E 00
1.200000E 01	3.507671E 03	1.298716E 00	1.307318E-02	2.000000E 00
2.000000E 01	3.521725E 03	1.480072E 00	1.307486E-02	2.000000E 00
3.000000E 01	3.541205E 03	1.731467E 00	1.307654E-02	2.000000E 00
4.200000E 01	3.568153E 03	2.079270E 00	1.307702E-02	2.000000E 00
5.600000E 01	3.605640E 03	2.563162E 00	1.307847E-02	2.000000E 00
7.200000E 01	3.658339E 03	3.243418E 00	1.307943E-02	2.000000E 00
9.000000E 01	3.733451E 03	4.213092E 00	1.307967E-02	2.000000E 00
1.100000E 02				2.878439E-02
DUMP 1	3.200000E 02	3.8422258E 03	5.617822E 00	1.307967E-02
1.560000E 02	4.002723E 03	7.689500E 00	1.308039E-02	2.000000E 00
1.820000E 02	4.243975E 03	1.080431E 01	1.308087E-02	2.000000E 00
2.000000E 02	4.466130E 03	1.367270E 01	1.308087E-02	2.000000E 00
TOTAL ENERGY	4.466130E 03	KINETIC ENERGY	CHECK 0.	ERROR LOCAL 2.656016E-06
			-1.378316E-04	
DENSITY	9.353166E-01	VELOCITY	PRESSURE 0.	INTERNAL ENERGY 4.609830E-03
7.920000E 00	1.870633E 00	-0.	0.	4.603765E-03
7.919999E 00	2.805949E 00	-0.	0.	4.591511E-03
7.920000E 00	3.741266E 00	-0.	0.	4.573052E-03
7.919999E 00	4.676582E 00	-0.	0.	4.548420E-03
7.919999E 00	5.611899E 00	-0.	0.	4.517679E-03
7.919999E 00	6.547217E 00	-0.	0.	4.480917E-03
7.919999E 00	7.482533E 00	-0.	0.	4.438245E-03
7.919999E 00	8.417846E 00	-0.	0.	4.389797E-03
7.919998E 00	9.353163E 00	-0.	0.	4.335721E-03
7.919998E 00	1.028848E 01	-0.	0.	4.276185E-03
7.919998E 00	1.122380E 01	-0.	0.	4.211373E-03
7.919998E 00	1.215911E 01	-0.	0.	4.141483E-03
7.919998E 00	1.309443E 01	-0.	0.	4.066724E-03
7.919998E 00	1.402975E 01	-0.	0.	3.987319E-03
7.919998E 00	1.496507E 01	-0.	0.	3.903497E-03
7.919998E 00	1.590038E 01	-0.	0.	3.815498E-03

7• 919998E 00	1• 683569E 01	0• 0•
7• 919997E 00	1• 777101E 01	-0• 0•
7• 919997E 00	1• 870633E 01	-0• 0•
7• 919997E 00	1• 964164E 01	-0• 0•
7• 919996E 00	2• 057696E 01	-0• 0•
7• 919997E 00	2• 151228E 01	-0• 0•
7• 919995E 00	2• 244760E 01	-0• 0•
7• 919995E 00	2• 328291E 01	-0• 0•
7• 919998E 00	2• 338291E 01	-0• 0•
1• 583000E 01	2• 431823E 01	-0• 0•
1• 583000E 01	2• 525355E 01	-0• 0•
1• 583000E 01	2• 618887E 01	-0• 0•
1• 583000E 01	2• 712418E 01	-0• 0•
1• 583000E 01	2• 805950E 01	-0• 0•
1• 583000E 01	2• 983168E 01	-0• 0•
1• 583000E 01	3• 160386E 01	-0• 0•
1• 583000E 01	3• 337602E 01	-0• 0•
1• 582999E 01	3• 514820E 01	-0• 0•
1• 582999E 01	3• 692038E 01	-0• 0•
1• 583000E 01	3• 869256E 01	-0• 0•
1• 582999E 01	4• 046474E 01	-0• 0•
1• 582999E 01	4• 223692E 01	-0• 0•
1• 582999E 01	4• 400910E 01	-0• 0•

GENEVE 10 RERUN MARCH 20 1959		TIME		POWER		ALPHA		DELTA		<sup>W</sup>	
2•100000E	02	4•614118E	03	1•558345E	01	1•308135E-02	2•000000E	00	7•019199E-02		
2•400000E	02	5•194141E	03	2•307269E	01	1•308255E-02	2•000000E	00	9•746438E-02		
DUMP	2										
2•620000E	02	5•790050E	03	3•076770E	01	1•307606E-02	2•000000E	00	1•350541E-01		
2•700000E	02	6•052932E	03	3•416063E	01	1•291253E-02	2•000000E	00	1•561587E-01		
2•740000E	02	6•194982E	03	3•597139E	01	1•263538E-02	2•000000E	00	1•673742E-01		
2•800000E	02	6•422045E	03	3•880450E	01	1•173227E-02	2•000000E	00	1•928673E-01		
2•820000E	02	6•501495E	03	3•972579E	01	1•123132E-02	2•000000E	00	1•980252E-01		
2•840000E	02	6•582751E	03	4•062824E	01	1•061646E-02	2•000000E	00	1•919355E-01		
2•860000E	02	6•665751E	03	4•150012E	01	9•864639E-03	2•000000E	00	1•957814E-01		
2•880000E	02	6•750404E	03	4•232701E	01	8•957334E-03	2•000000E	00	1•996146E-01		
2•900000E	02	6•836587E	03	4•309212E	01	7•876132E-03	2•000000E	00	2•178121E-01		
2•920000E	02	6•924139E	03	4•377629E	01	6•601209E-03	2•000000E	00	2•293675E-01		
HALVE DELT, SENSE LIGHT 3 ON											
2•940000E	02	7•012855E	03	4•435807E	01	5•114744E-03	1•000000E	00	2•192134E-01		
2•950000E	02	7•057554E	03	4•469970E	01	5•114744E-03	1•000000E	00	8•427610E-02		
TOTAL ENERGY				KINETIC ENERGY	CHECK		ERROR LOCAL				
7•057554E	03	1•252171E	01	-4•590405E-04		9•519746E-06					

DENSITY		RADIUS		VELOCITY		PRESSURE		INTERNAL ENERGY		TEMPERATURE	
7•484143E	00	9•531319E-01	2•407454E-04	4•925818E-02	1•321355E-04	4•980521E-02	1•319808E-02	8•218011E-04	8•227578E-04	8•200302E-04	
7•493912E	00	1•905539E	00	1•461096E-03	4•903755E-02	1•315292E-02	1•309500E-02	8•186132E-04	8•158509E-04	8•123501E-04	
7•493629E	00	2•858224E	00	2•419077E-03	4•895018E-02	1•301343E-02	1•291162E-02	8•092295E-04	8•092295E-04	8•092295E-04	
7•504321E	00	3•809892E	00	2•837079E-03	4•849854E-02	1•279374E-02	1•265076E-02	8•039881E-04	8•039881E-04	8•039881E-04	
7•515374E	00	4•760746E	00	3•736507E-03	4•791449E-02	1•231175E-02	1•231175E-02	7•992186E-04	7•992186E-04	7•992186E-04	
7•528976E	00	5•710589E	00	4•365463E-03	4•764249E-02	1•211524E-02	1•211524E-02	7•867189E-04	7•867189E-04	7•867189E-04	
7•549754E	00	6•658724E	00	5•095267E-03	4•669176E-02	1•249247E-02	1•249247E-02	7•794144E-04	7•794144E-04	7•794144E-04	
7•567464E	00	7•605683E	00	5•717149E-03	4•609189E-02	1•231175E-02	1•231175E-02	7•718863E-04	7•718863E-04	7•718863E-04	
7•592811E	00	8•550646E	00	6•363582E-03	4•503848E-02	1•141318E-02	1•141318E-02	7•628349E-04	7•628349E-04	7•628349E-04	
7•617350E	00	9•493879E	00	6•965566E-03	4•420762E-02	1•14415E-02	1•14415E-02	7•533214E-04	7•533214E-04	7•533214E-04	
7•648377E	00	1•043473E	01	7•512518E-03	4•308627E-02	1•085900E-02	1•085900E-02	7•430835E-04	7•430835E-04	7•430835E-04	
7•680144E	00	1•137329E	01	8•007845E-03	3•738020E-02	1•66610E-02	1•66610E-02	7•329179E-04	7•329179E-04	7•329179E-04	
7•716881E	00	1•230911E	01	8•478864E-03	4•204543E-02	1•055997E-02	1•055997E-02	7•208111E-04	7•208111E-04	7•208111E-04	
7•752517E	00	1•324249E	01	8•894262E-03	4•054883E-02	1•024234E-02	1•024234E-02	7•075534E-04	7•075534E-04	7•075534E-04	
7•791894E	00	1•417309E	01	9•367871E-03	3•903099E-02	9•909864E-03	9•909864E-03	9•565789E-03	9•565789E-03	9•565789E-03	
7•833664E	00	1•510078E	01	9•557108E-03	3•738020E-02	1•085900E-02	1•085900E-02	7•430835E-04	7•430835E-04	7•430835E-04	
7•881988E	00	1•602497E	01	9•646610E-03	3•593785E-02	1•055997E-02	1•055997E-02	7•329179E-04	7•329179E-04	7•329179E-04	
7•926625E	00	1•694623E	01	9•939646E-03	3•384898E-02	1•024234E-02	1•024234E-02	7•208111E-04	7•208111E-04	7•208111E-04	
7•970825E	00	1•786472E	01	9•889098E-03	3•142713E-02	9•909864E-03	9•909864E-03	2•938053E-02	2•938053E-02	2•938053E-02	
8•023799E	00	1•877955E	01								

8•058807E 00	1•969283E 01	9•354209E-03	2•562169E-02	6•776275E-04
8•126535E 00	2•060099E 01	8•658014E-03	2•413655E-02	6•653063E-04
8•100561E 00	2•151433E 01	2•032907E-03	1•578500E-02	6•357862E-04
7•936677E 00	2•244760E 01	2•877922E-10	6•016498E-05	8•004120E-03
7•919998E 00	2•338291E 01	-0•	0•	7•562369E-03
1•583000E 01	2•431823E 01	-0•	0•	6•153750E-04
1•583000E 01	2•525355E 01	-0•	0•	6•153750E-04
1•583000E 01	2•618887E 01	-0•	0•	6•153750E-04
1•583000E 01	2•712418E 01	-0•	0•	6•153750E-04
1•583000E 01	2•805950E 01	-0•	0•	6•153750E-04
1•583000E 01	2•983168E 01	-0•	0•	6•153750E-04
1•583000E 01	3•160386E 01	-0•	0•	6•153750E-04
1•583000E 01	3•337602E 01	-0•	0•	6•153750E-04
1•582999E 01	3•514820E 01	-0•	0•	6•153750E-04
1•582999E 01	3•692038E 01	-0•	0•	6•153750E-04
1•583000E 01	3•869256E 01	-0•	0•	6•153750E-04
1•582999E 01	4•046474E 01	-0•	0•	6•153750E-04
1•582999E 01	4•223692E 01	-0•	0•	6•153750E-04
1•582999E 01	4•400910E 01	0•	0•	6•153750E-04

GENEVE 10 RERUN MARCH 20 1959		POWER		ALPHA		DELT		W	
TIME	QP								
HALVE DELT, SENSE LIGHT 3 ON									
2•950000E 02	7•057554E 03	4•469970E 01		4•275073E-03		5•000000E-01		8•427610E-02	
2•955000E 02	7•079975E 03	4•484325E 01		4•275073E-03		5•000000E-01		3•101643E-02	
TOTAL ENERGY		KINETIC ENERGY	CHECK	ERROR LOCAL					
7•079975E 03	1•350323E 01	-4•988344E-04		9•519630E-06					
DENSITY	RADIUS	VELOCITY		PRESSURE	INTERNAL ENERGY				
7•481986E 00	9•532235E-01	1•832310E-04		5•029360E-02	1•328717E-02				
7•483834E 00	1•906310E 00	1•541746E-03		5•007831E-02	1•326452E-02				
7•483896E 00	2•859438E 00	2•428255E-03		4•934222E-02	1•321954E-02				
7•496565E 00	3•811334E 00	2•884498E-03		4•944069E-02	1•316300E-02				
7•505908E 00	4•762645E 00	3•797786E-03		4•882175E-02	1•307953E-02				
7•520732E 00	5•712786E 00	4•393979E-03		4•834875E-02	1•297824E-02				
7•540719E 00	6•661322E 00	5•194831E-03		4•799533E-02	1•285901E-02				
7•559311E 00	7•608573E 00	5•779899E-03		4•712015E-02	1•271605E-02				
7•584273E 00	8•553883E 00	6•473626E-03		4•647534E-02	1•255657E-02				
7•609310E 00	9•497405E 00	7•052238E-03		4•545819E-02	1•237529E-02				
7•640404E 00	1•043855E 01	7•629301E-03		4•462197E-02	1•217775E-02				
7•672613E 00	1•137735E 01	8•116051E-03		4•352798E-02	1•196060E-02				
7•709292E 00	1•231343E 01	8•634149E-03		4•246773E-02	1•172641E-02				
7•745423E 00	1•324701E 01	9•051432E-03		4•099948E-02	1•147246E-02				
7•784577E 00	1•417786E 01	9•538440E-03		3•944508E-02	1•120181E-02				
7•827812E 00	1•510563E 01	9•705800E-03		3•790197E-02	1•091598E-02				
7•876376E 00	1•602990E 01	9•861428E-03		3•645849E-02	1•061536E-02				
7•920403E 00	1•695132E 01	1•018808E-02		3•429620E-02	1•029561E-02				
7•966570E 00	1•786977E 01	1•009850E-02		3•201226E-02	9•962271E-03				
8•020249E 00	1•878451E 01	9•909690E-03		2•999489E-02	9•616482E-03				
8•056527E 00	1•969758E 01	9•505358E-03		2•630742E-02	9•250290E-03				
8•122704E 00	2•060574E 01	9•505549E-03		2•466803E-02	8•882461E-03				
8•124196E 00	2•151614E 01	3•625286E-03		1•822741E-02	8•481242E-03				
7•951445E 00	2•244760E 01	6•091743E-06		1•910850E-04	8•046777E-03				
7•920021E 00	2•338291E 01	-0•		4•681418E-10	7•602204E-03				
1•583000E 01	2•431823E 01	-0•		0•	6•153750E-04				
1•583000E 01	2•525355E 01	-0•		0•	6•153750E-04				
1•583000E 01	2•618887E 01	-0•		0•	6•153750E-04				
1•583000E 01	2•712418E 01	-0•		0•	6•153750E-04				
1•583000E 01	2•805950E 01	-0•		0•	6•153750E-04				
1•583000E 01	2•983168E 01	-0•		0•	6•153750E-04				
1•583000E 01	3•160386E 01	-0•		0•	6•153750E-04				
1•583000E 01	3•337602E 01	-0•		0•	6•153750E-04				

0.0	3.514820E-01	-0.0	6.0153750E-04	4.999997E-05
0.0	3.692038E-01	-0.0	6.0153750E-04	4.999997E-05
0.0	3.869256E-01	-0.0	6.0153750E-04	4.999999E-05
0.0	4.046474E-01	-0.0	6.0153750E-04	4.999998E-05
0.0	4.223692E-01	-0.0	6.0153750E-04	4.999997E-05
0.0	4.400910E-01	-0.0	6.0153750E-04	4.999997E-05

GENEVE 10 RERUN MARCH 20 1959		TIME		POWER		ALPHA		W	
2•95500E	02	7•079975E	03	4•484325E	01	3•829388E-03	3•101643E-02	5•000000E-01	3•101643E-02
2•96000E	02	7•102438E	03	4•492919E	01	3•373051E-03	5•000000E-01	5•000000E-01	2•742106E-02
2•96500E	02	7•124940E	03	4•500503E	01	2•902788E-03	3•258085E-02	5•000000E-01	3•258085E-02
2•97000E	02	7•147474E	03	4•507040E	01	2•416258E-03	3•735047E-02	5•000000E-01	3•735047E-02
2•97500E	02	7•170036E	03	4•512488E	01	1•913964E-03	4•068206E-02	5•000000E-01	4•068206E-02
2•98000E	02	7•192619E	03	4•516808E	01	1•394506E-03	4•232702E-02	5•000000E-01	4•232702E-02
2•98500E	02	7•215218E	03	4•519958E	01	8•567256E-04	4•214406E-02	5•000000E-01	4•214406E-02
2•99000E	02	7•237827E	03	4•521895E	01	3•018303E-04	4•009234E-02	5•000000E-01	4•009234E-02
2•99500E	02	7•260439E	03	4•522577E	01	-2•711039E-04	3•624670E-02	5•000000E-01	3•624670E-02
3•000000E	02	7•283048E	03	4•521964E	01	-2•711039E-04	3•206001E-01	5•000000E-01	3•206001E-01
TOTAL ENERGY		KINETIC ENERGY		CHECK		ERROR LOCAL		9•519164E-06	
7•283048E	03	2•097754E	01	-4•672505E	-04				
TIME		QP		VELOCITY		PRESSURE		INTERNAL ENERGY	
7•401031E	00	9•566864E	-01	1•424552E	-03	5•353012E	-02	1•389095E	-02
7•393915E	00	1•913910E	00	1•696909E	-03	5•248137E	-02	1•386256E	-02
7•404357E	00	2•869995E	00	2•315887E	-03	5•273834E	-02	1•382527E	-02
7•412364E	00	3•825582E	00	3•379210E	-03	5•234674E	-02	1•376084E	-02
7•425086E	00	4•780163E	00	3•948628E	-03	5•203104E	-02	1•367740E	-02
7•441152E	00	5•733496E	00	4•823062E	-03	5•162633E	-02	1•357202E	-02
7•457356E	00	6•685685E	00	5•5287755E	-03	5•0861222E	-02	1•344403E	-02
7•481923E	00	7•635847E	00	6•323115E	-03	5•048868E	-02	1•329935E	-02
7•504809E	00	8•584374E	00	6•975247E	-03	4•957673E	-02	1•313071E	-02
7•534809E	00	9•530544E	00	7•631582E	-03	4•893916E	-02	1•294487E	-02
7•565585E	00	1•047445E	01	8•233802E	-03	4•797767E	-02	1•273753E	-02
7•600967E	00	1•141568E	01	8•869514E	-03	4•706591E	-02	1•251226E	-02
7•636243E	00	1•235442E	01	9•463822E	-03	4•575969E	-02	1•226570E	-02
7•676543E	00	1•329021E	01	1•002161E	-02	4•453489E	-02	1•20253E	-02
7•720246E	00	1•422281E	01	1•030141E	-02	4•324137E	-02	1•172205E	-02
7•769700E	00	1•515174E	01	1•072612E	-02	4•207328E	-02	1•142572E	-02
7•814853E	00	1•607768E	01	1•120278E	-02	4•015730E	-02	1•110779E	-02
7•865319E	00	1•700015E	01	1•130235E	-02	3•835686E	-02	1•077639E	-02
7•922419E	00	1•791856E	01	1•149764E	-02	3•676734E	-02	1•043189E	-02
7•973327E	00	1•883378E	01	1•156862E	-02	3•429114E	-02	1•066887E	-02
8•037897E	00	1•974442E	01	1•140977E	-02	3•262382E	-02	9•695081E	-03
8•077105E	00	2•065343E	01	1•096143E	-02	2•858021E	-02	9•296469E	-03
8•148068E	00	2•155735E	01	1•197423E	-02	2•671503E	-02	8•896784E	-03
8•215868E	00	2•245678E	01	6•082644E	-03	2•466825E	-02	8•480696E	-03
7•995130E	00	2•338293E	01	2•579092E	-05	5•399298E	-04	7•963973E	-03
1•583035E	01	2•431823E	01	1•911376E	-07	1•040176E	-05	6•153750E	-05



GENEVE	10	RERUN	MARCH	20	1959	QP	POWER	ALPHA	DELTA	W		
3.000000E	02	7.283048E	03	4.0	5.21964E	01	-8.627618E-04	5.000000E-01	3.206001E-02			
3.005000E	02	7.305648E	03	4.0	5.20014E	01	-1.472876E-03	5.000000E-01	3.893714E-02			
3.010000E	02	7.328230E	03	4.0	5.16687E	01	-2.102314E-03	5.000000E-01	4.515666E-02			
3.015000E	02	7.350790E	03	4.0	5.11941E	01	-2.750493E-03	5.000000E-01	4.991508E-02			
3.020000E	02	7.373317E	03	4.0	5.05741E	01	-3.418249E-03	5.000000E-01	5.291061E-02			
3.025000E	02	7.395807E	03	4.0	4.98046E	01	-4.103592E-03	5.000000E-01	5.394539E-02			
3.030000E	02	7.418250E	03	4.0	4.88827E	01	-4.807859E-03	5.000000E-01	5.293765E-02			
3.035000E	02	7.440639E	03	4.0	4.78049E	01	-5.530758E-03	5.000000E-01	4.991733E-02			
3.040000E	02	7.462967E	03	4.0	4.65683E	01	-6.271793E-03	5.000000E-01	4.506278E-02			
3.045000E	02	7.485225E	03	4.0	4.51701E	01	-7.031903E-03	5.000000E-01	3.865892E-02			
3.050000E	02	7.507404E	03	4.0	4.36076E	01	-7.807106E-03	5.000000E-01	3.107027E-02			
3.055000E	02	7.529497E	03	4.0	4.18793E	01	-8.601431E-03	5.000000E-01	3.322387E-02			
3.060000E	02	7.551496E	03	4.0	3.998830E	01	-9.411856E-03	5.000000E-01	3.717559E-02			
3.065000E	02	7.573391E	03	4.0	3.79174E	01	-1.023865E-02	5.000000E-01	4.049618E-02			
3.070000E	02	7.595174E	03	4.0	3.56812E	01	-1.108231E-02	5.000000E-01	4.301705E-02			
3.075000E	02	7.616837E	03	4.0	3.32737E	01	-1.194028E-02	5.000000E-01	4.459131E-02			
3.080000E	02	7.638371E	03	4.0	3.06947E	01	-1.281443E-02	5.000000E-01	4.512015E-02			
3.085000E	02	7.659767E	03	4.0	2.79440E	01	-1.370453E-02	5.000000E-01	4.455614E-02			
3.090000E	02	7.681017E	03	4.0	2.50217E	01	-1.461057E-02	5.000000E-01	4.290867E-02			
3.095000E	02	7.702113E	03	4.0	2.19281E	01	-1.553092E-02	5.000000E-01	4.024723E-02			
3.100000E	02	7.723045E	03	4.0	1.86643E	01	-1.646695E-02	5.000000E-01	3.667578E-02			
3.105000E	02	7.743806E	03	4.0	1.52314E	01	-1.741867E-02	5.000000E-01	3.235808E-02			
3.110000E	02	7.764387E	03	4.0	1.16307E	01	-1.838352E-02	5.000000E-01	3.244738E-02			
3.115000E	02	7.784779E	03	4.0	0.78644E	01	-1.936288E-02	5.000000E-01	3.186726E-02			
3.120000E	02	7.804976E	03	4.0	0.39348E	01	-2.0.35465E-02	5.000000E-01	3.182550E-02			
3.125000E	02	7.824967E	03	3.0	9.98446E	01	-2.1.36045E-02	5.000000E-01	3.300821E-02			
3.130000E	02	7.844746E	03	3.0	9.55969E	01	-2.2.238026E-02	5.000000E-01	3.374180E-02			
3.135000E	02	7.864305E	03	3.0	9.11948E	01	-2.2.341171E-02	5.000000E-01	3.399938E-02			
3.140000E	02	7.883636E	03	3.0	8.66423E	01	-2.2.445683E-02	5.000000E-01	3.377077E-02			
3.145000E	02	7.902733E	03	3.0	8.19430E	01	-2.2.551348E-02	5.000000E-01	3.305616E-02			
3.150000E	02	7.921587E	03	3.0	7.771016E	01	-2.2.658201E-02	5.000000E-01	3.185945E-02			
3.155000E	02	7.940192E	03	3.0	7.21227E	01	-2.2.766188E-02	5.000000E-01	3.021179E-02			
3.160000E	02	7.958542E	03	3.0	6.70113E	01	-2.2.875345E-02	5.000000E-01	2.814415E-02			
3.165000E	02	7.976630E	03	3.0	6.17727E	01	-2.2.985618E-02	5.000000E-01	2.663193E-02			
3.170000E	02	7.994450E	03	3.0	5.64122E	01	-2.3.096927E-02	5.000000E-01	2.630324E-02			
3.175000E	02	8.011996E	03	3.0	5.09358E	01	-2.3.209406E-02	5.000000E-01	2.788240E-02			
3.180000E	02	8.029263E	03	3.0	4.53493E	01	-2.3.322723E-02	5.000000E-01	2.865106E-02			
3.185000E	02	8.046245E	03	3.0	3.96592E	01	-2.3.437060E-02	5.000000E-01	2.894692E-02			
3.190000E	02	8.062937E	03	3.0	3.388719E	01	-2.3.552483E-02	5.000000E-01	2.985070E-02			
DUMP	3			8.0	0.79336E	03	3.0.279939E	01	-3.0.668805E-02	5.000000E-01		3.176535E-02

	TOTAL ENERGY	KINETIC ENERGY	CHECK	ERROR LOCAL	PRESSURE	INTERNAL ENERGY	TEMPERATURE
8.550175E 03	1.3668729E 02	-5.476842E-04	9.557465E-06				
3.200000E 02	8.095437E 03	3.220320E 01	-3.786118E-02	5.0000000E-01	3.297700E-02	3.336086E-02	3.3360000E-01
3.205000E 02	8.111236E 03	3.159931E 01	-3.904422E-02	5.0000000E-01	3.287899E-02	3.3360000E-01	3.287899E-02
3.210000E 02	8.126729E 03	3.098841E 01	-4.023603E-02	5.0000000E-01	2.962761E-02	2.962761E-02	2.962761E-02
3.220000E 02	8.156796E 03	2.976631E 01	-4.264045E-02	5.0000000E-01	2.618562E-02	2.618562E-02	2.618562E-02
3.230000E 02	8.185626E 03	2.852374E 01	-4.508476E-02	5.0000000E-01	2.910206E-02	2.910206E-02	2.910206E-02
3.240000E 02	8.213201E 03	2.726631E 01	-4.756128E-02	5.0000000E-01	3.433638E-02	3.433638E-02	3.433638E-02
3.250000E 02	8.239512E 03	2.599985E 01	-5.006933E-02	5.0000000E-01	3.277879E-02	3.277879E-02	3.277879E-02
3.260000E 02	8.264554E 03	2.473011E 01	-5.260200E-02	5.0000000E-01	2.701019E-02	2.701019E-02	2.701019E-02
3.270000E 02	8.288328E 03	2.346287E 01	-5.515871E-02	5.0000000E-01	3.003798E-02	3.003798E-02	3.003798E-02
3.280000E 02	8.310841E 03	2.220374E 01	-5.773410E-02	5.0000000E-01	3.424720E-02	3.424720E-02	3.424720E-02
3.290000E 02	8.332104E 03	2.095813E 01	-6.032818E-02	5.0000000E-01	3.21113E-02	3.21113E-02	3.21113E-02
3.300000E 02	8.352136E 03	1.973115E 01	-6.293555E-02	5.0000000E-01	3.166332E-02	3.166332E-02	3.166332E-02
3.310000E 02	8.370958E 03	1.852762E 01	-6.555734E-02	5.0000000E-01	2.951676E-02	2.951676E-02	2.951676E-02
3.320000E 02	8.388597E 03	1.735196E 01	-6.818837E-02	5.0000000E-01	3.170859E-02	3.170859E-02	3.170859E-02
3.330000E 02	8.405085E 03	1.620820E 01	-7.082857E-02	5.0000000E-01	3.451502E-02	3.451502E-02	3.451502E-02
3.340000E 02	8.420455E 03	1.509991E 01	-7.347678E-02	5.0000000E-01	3.247912E-02	3.247912E-02	3.247912E-02
3.350000E 02	8.434747E 03	1.403019E 01	-7.612848E-02	5.0000000E-01	3.022019E-02	3.022019E-02	3.022019E-02
3.360000E 02	8.447999E 03	1.300174E 01	-7.878513E-02	5.0000000E-01	3.324070E-02	3.324070E-02	3.324070E-02
3.370000E 02	8.460255E 03	1.201671E 01	-8.144062E-02	5.0000000E-01	3.413450E-02	3.413450E-02	3.413450E-02
3.380000E 02	8.471561E 03	1.107685E 01	-8.409400E-02	5.0000000E-01	3.29823E-02	3.29823E-02	3.29823E-02
3.390000E 02	8.481961E 03	1.018345E 01	-8.674214E-02	5.0000000E-01	3.088998E-02	3.088998E-02	3.088998E-02
3.400000E 02	8.491504E 03	9.337340E 00	-8.938380E-02	5.0000000E-01	3.029773E-02	3.029773E-02	3.029773E-02
3.415000E 02	8.504318E 03	8.165727E 00	-9.332411E-02	5.0000000E-01	3.0437118E-02	3.0437118E-02	3.0437118E-02
3.430000E 02	8.515481E 03	7.099040E 00	-9.723935E-02	5.0000000E-01	3.061961E-02	3.061961E-02	3.061961E-02
3.445000E 02	8.525148E 03	6.135555E 00	-1.011212E-01	5.0000000E-01	3.13833E-02	3.13833E-02	3.13833E-02
3.460000E 02	8.533471E 03	5.272048E 00	-1.049645E-01	5.0000000E-01	3.029773E-02	3.029773E-02	3.029773E-02
3.475000E 02	8.540595E 03	4.504028E 00	-1.087615E-01	5.0000000E-01	3.029773E-02	3.029773E-02	3.029773E-02
3.490000E 02	8.546659E 03	3.826038E 00	-1.125067E-01	5.0000000E-01	3.029773E-02	3.029773E-02	3.029773E-02
3.500000E 02	8.550175E 03	3.418915E 00	-1.125067E-01	5.0000000E-01	3.029773E-02	3.029773E-02	3.029773E-02

Original from

TECHNICAL REPORT ARCHIVE & IMAGE LIBRARY

6.555941E 00	1.000969E 01	7.335353E-03	8.817092E-03	7.723368E-04
6.632662E 00	1.098707E 01	7.141673E-03	1.304636E-02	1.580372E-02
6.689918E 00	1.196023E 01	8.478125E-03	1.456976E-02	1.553414E-02
6.724833E 00	1.293225E 01	1.074075E-02	1.315776E-02	1.523308E-02
6.754738E 00	1.390344E 01	1.233564E-02	1.077600E-02	1.490775E-02
6.836493E 00	1.486659E 01	1.103045E-02	1.342873E-02	1.457292E-02
6.960171E 00	1.581698E 01	1.056044E-02	1.981119E-02	1.423097E-02
7.001918E 00	1.676634E 01	1.437733E-02	1.717220E-02	1.383640E-02
7.028634E 00	1.771623E 01	1.493643E-02	1.264631E-02	1.341849E-02
7.193249E 00	1.864888E 01	1.161766E-02	2.124285E-02	1.302402E-02
7.318319E 00	1.957093E 01	1.3777292E-02	2.504398E-02	1.259762E-02
7.349396E 00	2.049433E 01	1.548974E-02	1.951535E-02	1.211210E-02
7.500106E 00	2.140441E 01	1.371949E-02	2.449901E-02	1.165500E-02
7.624422E 00	2.230530E 01	1.469176E-02	2.631066E-02	1.166266E-02
7.757402E 00	2.319662E 01	1.397264E-02	2.808407E-02	1.065590E-02
7.906766E 00	2.407719E 01	1.453332E-02	2.986557E-02	1.009694E-02
1.686310E 01	2.490974E 01	1.439552E-02	3.116328E-02	8.840935E-04
1.702260E 01	2.574283E 01	1.413444E-02	3.583450E-02	9.80878E-04
1.693770E 01	2.658759E 01	1.493270E-02	3.326008E-02	8.863924E-04
1.696021E 01	2.743772E 01	1.574984E-02	3.391666E-02	8.882650E-04
1.683841E 01	2.829966E 01	1.295722E-02	3.039186E-02	7.44950E-04
1.703349E 01	2.992774E 01	1.119276E-02	3.618852E-02	7.004454E-04
1.647310E 01	3.162433E 01	3.870941E-03	2.070090E-02	6.408979E-04
1.598175E 01	3.337844E 01	6.223858E-04	4.838512E-03	6.168054E-04
1.584885E 01	3.514838E 01	5.822392E-05	5.738734E-04	6.153963E-04
1.583147E 01	3.692039E 01	3.547075E-06	4.418609E-05	6.153751E-04
1.583004E 01	3.869256E 01	3.465208E-08	1.259382E-06	6.153750E-04
1.582999E 01	4.046474E 01	-0.	0.	6.153750E-04
1.582999E 01	4.223692E 01	-0.	0.	6.153750E-04
1.582999E 01	4.400910E 01	0.	0.	6.153750E-04

GENEVE 10 RERUN MARCH 20 1959		POWER		ALPHA		DELT		W	
TIME	QP	3.0231899E 00	-1.161970E-01	5.000000E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0434920E-02	
DUMP 4	3.505000E 02	8.0551790E 03	3.0231899E 00	-1.161970E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0335743E-02	
	3.520000E 02	8.0556109E 03	2.0714952E 00	-1.0198263E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0362587E-02	
	3.535000E 02	8.0559723E 03	2.0268310E 00	-1.0233918E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0309837E-02	
	3.555000E 02	8.0563617E 03	1.0772253E 00	-1.0280392E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0361232E-02	
	3.575000E 02	8.0566642E 03	1.0371868E 00	-1.0325590E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0369468E-02	
	3.595000E 02	8.0568970E 03	1.0052381E 00	-1.0369468E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0279974E-02	
POWER SMALL NS4	UP								
3.615000E 02	8.0570745E 03	8.002442E-01	-1.0412027E-01	5.000000E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0265014E-02	
3.660000E 02	8.0573310E 03	4.0239031E-01	-1.0503135E-01	5.000000E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0405175E-02	
3.710000E 02	8.0574737E 03	1.0999240E-01	-1.0597197E-01	5.000000E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0279529E-02	
3.765000E 02	8.0575432E 03	8.0305300E-02	-1.0691910E-01	5.000000E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0154983E-02	
3.825000E 02	8.0575722E 03	3.009422E-02	-1.0784988E-01	5.000000E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0112533E-02	
DUMP 5									
3.890000E 02	8.0575824E 03	9.0431836E-03	-1.0876245E-01	5.000000E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0067695E-02	
3.960000E 02	8.0575850E 03	2.0536333E-03	-1.0967015E-01	5.000000E-01	5.000000E-01	5.000000E-01	5.000000E-01	3.0020719E-02	
4.000000E 02	8.0575852E 03	1.0154784E-03	-1.0967015E-01	5.000000E-01	5.000000E-01	5.000000E-01	5.000000E-01	2.994476E-02	
TOTAL ENERGY									
8.0575852E 03	KINETIC ENERGY	1.0414158E 02	-5.0208532E-04	CHECK	ERROR LOCAL	2.0470845E-05			
DENSITY	RADIUS	VELOCITY	PRESSURE	INTERNAL ENERGY	TEMPERATURE				
4.917073E 00	1.096389E 00	1.0753956E-03	0.	1.0725101E-02	4.0417189E-05				
5.0205647E 00	2.0156736E 00	2.0818523E-03	0.	1.0722617E-02	2.0572979E-04				
5.0499321E 00	3.0188685E 00	3.0305828E-03	0.	1.0717615E-02	4.0281693E-04				
5.0537857E 00	4.0230596E 00	4.0029824E-03	0.	1.0710035E-02	4.0433258E-04				
5.0419751E 00	5.0297382E 00	5.0289495E-03	0.	1.0699883E-02	3.0721420E-04				
5.0439850E 00	6.0358381E 00	6.0441835E-03	0.	1.0687154E-02	3.0745921E-04				
6.0255999E 00	7.0328801E 00	5.0509934E-03	0.	1.0671965E-02	6.0370937E-04				
6.0094808E 00	8.0307465E 00	5.0501657E-03	0.	1.0654206E-02	6.0518982E-04				
6.0331326E 00	9.0265503E 00	4.0705751E-03	0.	1.0633964E-02	7.0214578E-04				
5.0812325E 00	1.0031525E 01	6.0145067E-03	0.	1.0611205E-02	5.0094094E-04				
5.0605493E 00	1.0139668E 01	8.0310706E-03	0.	1.0586059E-02	3.0934048E-04				
6.0437482E 00	1.0234178E 01	7.0164884E-03	0.	1.0558564E-02	7.0089424E-04				
6.0060120E 00	1.0335402E 01	8.0256142E-03	0.	1.0528728E-02	5.0586441E-04				
6.0334372E 00	1.0432737E 01	7.0440804E-03	0.	1.0496597E-02	6.0371157E-04				
6.0329760E 00	1.0530778E 01	8.0697620E-03	0.	1.0462263E-02	6.0138243E-04				
6.0527848E 00	1.0626487E 01	7.0460192E-03	8.0721617E-07	1.0425737E-02	6.0543277E-04				
6.0711025E 00	1.0720369E 01	6.0942592E-03	0.	1.0387102E-02	6.0834968E-04				
6.0821918E 00	1.0813551E 01	6.0589408E-03	0.	1.0346437E-02	6.0883366E-04				
6.0773332E 00	1.0908118E 01	8.0033070E-03	0.	1.0303804E-02	6.04868851E-04				

6•977439E 00	2•000584E 01	7•377634E-03	0•	6•739882E-04
7•033787E 00	2•093008E 01	4•673943E-03	6•565979E-05	1•212834E-02
7•226250E 00	2•183670E 01	7•127221E-03	6•102771E-04	1•164701E-02
7•305969E 00	2•274062E 01	5•481286E-03	1•880346E-05	1•114650E-02
7•365635E 00	2•364396E 01	6•677044E-03	0•	1•062398E-02
7•515942E 00	2•453581E 01	6•270953E-03	0•	1•005223E-02
1•574286E 01	2•539423E 01	4•572521E-03	5•531476E-05	6•246356E-04
1•593890E 01	2•625012E 01	5•868169E-03	3•378190E-03	6•212036E-04
1•586963E 01	2•711704E 01	5•013392E-03	1•277981E-03	6•191517E-04
1•597222E 01	2•798483E 01	6•122503E-03	4•330344E-03	6•196177E-04
1•598912E 01	2•885760E 01	6•870994E-03	4•837479E-03	6•199504E-04
1•619101E 01	3•050550E 01	7•821550E-03	1•095472E-02	6•290912E-04
1•637874E 01	3•215221E 01	9•812453E-03	1•652120E-02	6•362296E-04
1•654083E 01	3•379871E 01	9•618474E-03	2•135148E-02	6•464864E-04
1•660374E 01	3•545305E 01	1•090850E-02	2•322140E-02	6•509714E-04
1•681300E 01	3•709948E 01	1•111459E-02	2•947552E-02	6•702914E-04
1•668047E 01	3•876998E 01	7•408754E-03	2•577956E-02	6•569390E-04
1•628444E 01	4•048833E 01	3•136491E-03	1•409954E-02	6•276976E-04
1•598472E 01	4•224215E 01	8•856262E-04	4•775890E-03	6•168221E-04
1•585960E 01	4•401074E 01	3•281066E-04	8•954424E-04	6•154275E-04
				5•013203E-05

## APPENDIX A

### DETAILS OF THE VJ-OK-1 TEST

Before the addition of the VJ-OK-1 test to the program it was observed that in the typical problem having a step function reactivity input at zero time and low power,  $N_{S_4}$  would build up appreciably by the time high power and the accompanying shutoff mechanism were reached. As a result alpha would change considerably from  $S_4$  calculation to  $S_4$  calculation during shutoff. Since alpha is held constant between such neutronic calculations, some error in the time variation of power would result.

It was desirable that  $N_{S_4}$  be large before the burst to conserve machine time. A means of reducing its size at the beginning of the burst was needed. It was decided to obtain the necessary signal by observing  $\ddot{\rho}$ , the time rate of change of the reactivity inserted per unit time by the feedback mechanism. When the ratio  $\frac{\ddot{\rho}}{\dot{\rho}}$  became large, alpha would start changing rapidly and  $N_{S_4}$  should be reduced.

Thus, in a power series expansion of reactivity,

$$\rho = \rho_0 + \dot{\rho} \Delta t + \frac{1}{2} \ddot{\rho} (\Delta t)^2 + \dots ,$$

the term in the second derivative is watched, and

when

$$\frac{\frac{1}{2} \ddot{\rho} (\Delta t)^2}{\rho_{\text{initial}}} > \text{OK}_1$$

$N_{S_4}$  is modified.

Equation 14 from Appendix C of reference 1 provides the relation

$$\begin{aligned} \ddot{\rho} &= \frac{-5}{2.54} \frac{\sqrt{q}}{b} \int \ddot{u} \left( \frac{d\phi}{dr} \right)^2 r dr \\ &= + \frac{5}{2.54} \frac{\sqrt{q}}{b} \int \left( \frac{1}{s} \frac{\partial p}{\partial r} \right) \left( -\frac{2qr}{b^2} \right)^2 r dr \\ &= \frac{5}{2.54} \frac{1}{s} \left( \frac{\sqrt{q}}{b} \right)^5 [pr^3 - p \cdot 3r^2 dr]^\infty_0 \\ &= - \frac{20}{2.54} \frac{3}{s} \left( \frac{\sqrt{q}}{b} \right)^5 \frac{1}{4\pi} \int p r^2 dr \cdot 4\pi \\ &= \frac{-60}{10.16\pi} \frac{1}{s} \left( \frac{\sqrt{q}}{b} \right)^5 \int pdV . \end{aligned}$$

where

$\phi$  is the flux,  
 $u$  is the displacement,  
 $r$  is the radial position  
 $p$  is the pressure, and  
 $b, q$ , and  $s$  are defined below.

Then

$$\frac{\frac{1}{2} \dot{\rho} (\Delta t)^2}{\rho_{\text{initial}}} = \frac{(N_{S_4})^2 (\Delta t)^2}{\rho_{\text{initial}}} \cdot \frac{30}{10.16\pi} \left(\frac{\sqrt{q}}{b}\right)^5 \frac{1}{s} \int p dV < OK_1 .$$

Thus this ratio is proportional to a constant which is a function of the particular reactor, multiplied by the integral of the pressure over the reactor volume. This relation was derived by V. Jankus and has been previously reported in slightly different form in reference 2. (See equation #23.)

The last equation may be rewritten in the form

$$VJ \cdot (\Delta t)^2 \cdot (N_{S_4})^2 \int p dv < OK_1$$

where

$$\begin{aligned} VJ &= \left(\frac{\sqrt{q}}{b}\right)^5 \times \frac{1}{\rho_{\text{max}} s} \\ &= \left(\frac{\sqrt{q}}{b}\right)^5 \times \frac{1}{\alpha_{\text{max}} \cdot \ell \cdot s} \end{aligned}$$

and

$1-q$  = ratio of flux at core edge to center  
 $b$  = core radius, cm  
 $\alpha_{\text{max}}$  = maximum alpha anticipated,  $\delta k/\mu$  sec  
 $s$  = core density, grams/cm<sup>3</sup>  
 $\ell$  = prompt neutron lifetime,  $\mu$  sec

Generally  $OK-1$  has been set equal to .01. If the fractional change in reactivity in time  $N_{S_4} \cdot \Delta t$  exceeds this amount, steps are taken to reduce  $N_{S_4}$ . To improve the efficiency of the over-all program, the test is not imposed until the local pressure at some point exceeds PTEST, an adjustable parameter.

## APPENDIX B

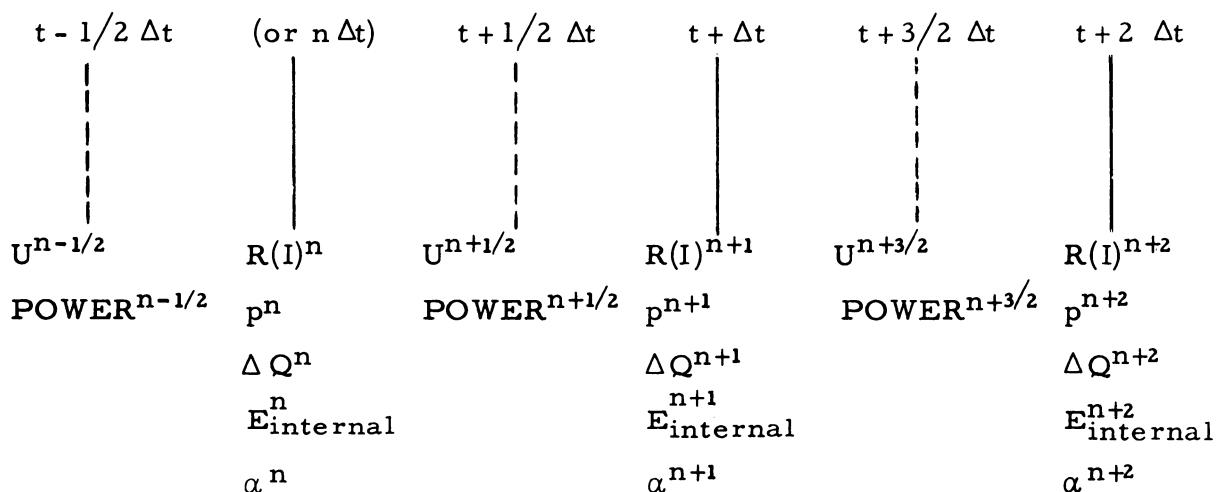
### THE TIME SCALE

The continuous time variable of the burst is approximated by a series of small, finite steps,  $\Delta t$ . From any point  $t$  in the course of the solution, the time is given by  $t + n\Delta t$ , assuming constant time increments. A superscript notation is used herein to label other parameters which vary with time. Thus, the radius for mass point I may be written as  $R(I)^n$ ,  $R(I)^{n+1}$ , etc.

When the problem begins, the radii are specified at time  $t = 0$ . Alpha is calculated for this configuration, so that alpha is known at  $t = 0$ . The acceleration is calculated at this time, requiring a knowledge of the pressure (and hence the energy) at  $t = 0$ . To find the radii at  $t + \Delta t$ ,  $(R^{n+1})$  the average velocity during the interval of  $U^{n+1/2}$  is needed. This may be calculated, provided that  $U^{n-1/2}$  and the average acceleration during the time interval between  $t + 1/2 \Delta t$  are known.

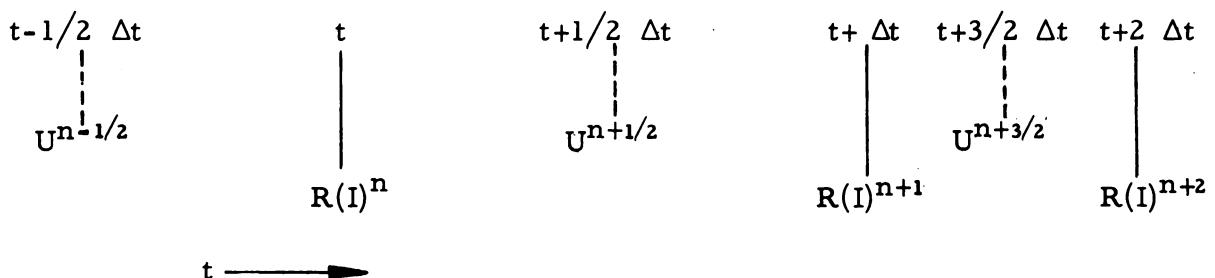
To find the internal energy (and thus the pressure) at  $t + \Delta t$  requires the internal energy at  $t$ , plus the average power during  $\Delta t$ , or  $POWER^{n+1/2}$ . The latter may be calculated from the power at  $t - 1/2 \Delta t$ , and the average rate of rise during the period  $t - \frac{\Delta t}{2}$  to  $t + \frac{\Delta t}{2}$ ,  $ALPHA^n$ .

The positions in time at which the various variables must be computed are summarized in the following time chart.



The time chart helps to explain the steps taken when  $\Delta t$  is halved or doubled. When, as per order 9290,  $\frac{\Delta t}{2} \rightarrow \Delta t$ , one notes  $\frac{3}{4} \Delta t' \rightarrow \Delta t'$ . In the solution parameters specified on the half interval station change in accordance with  $\Delta t'$ , while the others vary with  $\Delta t$ . Except during a change in time interval,  $\Delta t' = \Delta t$ . At a time interval change, the variables U and POWER

should be maintained at their half interval position. Thus, if at time  $t + \Delta t$ , the time interval is halved, the time chart for  $R(I)$  and  $U$  would look as follows.



Thus the time interval between  $R(I)^{n+1}$  and  $R(I)^{n+2}$  is half the old  $\Delta t$ , while the time interval between  $U^{n+1/2}$  and  $U^{n+3/2}$  is  $3/4$  the old  $\Delta t$ . On the other hand, on a doubling of  $\Delta t$ ,  $\Delta t'$  increases only by a factor of 1.5. This arbitrary procedure maintains the velocities and radii in the proper relative positions. A small error in computation is produced in that during a halving of  $\Delta t$ , the increment in  $U$  is computed using as average acceleration the value at  $2/3$  the interval instead of midway.

## APPENDIX C

### DISCUSSION OF HYDRODYNAMIC STABILITY CRITERIA AND SHOCK WAVE TREATMENT

If  $c$  is the velocity of sound in the material, then for stability of the finite-difference scheme  $c\Delta t < \Delta R$  must hold. (See Ch. II, Sections 2 and 3 of reference (10); also, see Ch. X, Section 11, p. 221 of (9).)

Let  $p = p(\rho, s)$  be the caloric equation of state, where  $p$  is pressure,  $\rho$  is density, and  $s$  is specific entropy. Then  $c^2 = \frac{\partial p}{\partial \rho}$ . (See (11), Ch. III, Section 35; or (12) p. 111, Section 6.10.) The material is treated as a polytropic gas, so that  $p = f(s)\rho^\gamma$  and  $\frac{\partial p}{\partial \rho} = \gamma \frac{p}{\rho}$ , where  $\gamma$  is the adiabatic exponent. But  $\frac{p}{\rho} = (\gamma - 1)E$ , where  $E$  is the specific internal energy (see p. 7 of (11)), so that the stability criterion becomes  $\left(\frac{\Delta R}{\Delta t}\right)^2 > \gamma(\gamma - 1)E$ . Then, if one defines a "Courant stability constant" by  $C_{sc} = \gamma(\gamma - 1)$ ,  $C_{sc}E \frac{(\Delta t)^2}{(\Delta R)^2} < 1$  must hold.

Actually, the stronger criterion

$$C_{sc}E \frac{(\Delta t)^2}{(\Delta R)^2} + 4 C_{vp} \frac{|\Delta V|}{V} < .3$$

is imposed. (When it fails,  $\Delta t$  is halved.) The second term (due to George N. White, Jr.) will ordinarily dominate only in the vicinity of a shock.  $C_{vp}$  is the "shock-width constant," and is usually taken to be between 1.5 and 2. It is related to the number of mesh-widths by which the shock is artificially broadened in the von Neumann-Richtmyer method for the numerical calculation of hydrodynamic shocks. (See Ref. 8, also Ref. 9, Chap. 10.) They add a fictitious "pseudo-viscosity pressure"  $P_v = C_{vp}\rho^3 \left( \Delta R \frac{\partial V}{\partial t} \right)^2$  to the real physical pressure in all dynamical equations. This imitates the shock-smearing effect of ordinary physical viscosity, and the differential equations need not be interrupted by troublesome boundary conditions (given by the Rankine-Hugoniot equations) at moving surfaces of internal discontinuity.

$P_v$  is quadratic in  $\frac{\partial V}{\partial t}$  so that the transition layer will have width independent of shock strength. (In the case of physical viscosity, the term is linear and the width goes to zero with increasing strength.) For further discussion of this method, see Ch. X, Sections 8-12, of (9).

## APPENDIX D

### THERMODYNAMIC CONSIDERATIONS

The equation of state has been taken as

$$p = \alpha\rho + \beta\theta + \tau$$

with the accompanying relation

$$\left(\frac{\partial E}{\partial \theta}\right)_V = c_V = A_{cv} + B_{cv} \theta$$

The first law of thermodynamics provides the relation

$$dE = dQ - pdv = \left(\frac{\partial E}{\partial \theta}\right)_V d\theta + \left(\frac{\partial E}{\partial v}\right)_\theta dv .$$

Further thermodynamic considerations (Ref. 12, See Chap. XIII) lead to the additional relation,

$$\left(\frac{\partial E}{\partial v}\right)_\theta = \theta \left(\frac{\partial p}{\partial \theta}\right)_V - p .$$

Hence

$$\begin{aligned} d\theta &= \frac{\left\{ dE - \left(\frac{\partial E}{\partial v}\right)_\theta dv \right\}}{\left(\frac{\partial E}{\partial \theta}\right)_V} \\ &= \frac{\left\{ dE - \left[ \theta \left(\frac{\partial p}{\partial \theta}\right)_V - p \right] dv \right\}}{\left(\frac{\partial E}{\partial \theta}\right)_V} \\ &= \frac{dE + (\alpha\rho + \tau)dv}{A_{cv} + B_{cv} \theta} . \end{aligned}$$

This leads to the formula under Order #9130, which in effect reads

$$\Delta\theta = \frac{\left\{ \Delta E + \left( \frac{\alpha}{2} [\rho^n + \rho^{n+1}] + \tau \right) \Delta v \right\}}{A_{cv} + \frac{B_{cv}}{2} (\theta^n + \theta^{n+1})}$$

For the alternate computation of energy a similar starting point is taken, namely,

$$\left(\frac{\partial E}{\partial v}\right)_\theta = \theta \left(\frac{\partial p}{\partial \theta}\right) - p$$

$$= -\frac{\alpha}{v} - \tau \quad \text{for the assumed equation of state.}$$

Integrating, one gets

$$\begin{aligned} E &= -\alpha \ln v - \tau v + f(\theta) \\ &= \alpha \ln \rho - \frac{\tau}{\rho} + f(\theta) \end{aligned}$$

Since  $\left(\frac{\partial E}{\partial \theta}\right)_v = C_v = \frac{\partial f(\theta)}{\partial \theta}$ , integration of the specific heat equation, yields

the result

$$f(\theta) = A_{cv} \theta + \frac{1}{2} B_{cv} \theta^2 + E_0 ,$$

and thus

$$E = \alpha \ln \rho - \frac{\tau}{\rho} + A_{cv} \theta + \frac{1}{2} B_{cv} \theta^2 + E_0 = \text{Running } E_{\text{internal}}.$$

If

$$E \Big|_{t=0} = A_{cv} \theta + \frac{1}{2} B_{cv} \theta^2 \Big|_{t=0} ,$$

then

$$E_0 = \frac{\tau}{\rho} - \alpha \ln \rho \Big|_{t=0} .$$

The so-called error local is obtained by comparing the running  $E_{\text{internal}}$ , computed as above for each mass point with the value obtained at Order #9180, which represents the sum of the initial energy and all the succeeding  $\Delta E$  values resulting from the corresponding iterative solutions for pressure.

The second energy balance or "check" involves summing the kinetic and internal energies for all mass points and comparing it with the total energy  $Q$ , as determined directly from the integral of power over time.

## APPENDIX E

## POSSIBLE VARIATIONS IN THE PROGRAM - Ax-1'

For Ax-1, a simple form of the equation of state was chosen, with the explicit intent of making modifications therein simple to accomplish. For example, another simple equation of state would be that employed by Bethe and Tait,<sup>(3)</sup>  $p = (\gamma-1)\rho E_{int}$ , wherein a direct calculation of temperature is bypassed, and a different dependence of pressure on density results. Considerably more elaborate equations might also be utilized. Work is continuing in this area to determine that form which might be most satisfactory for problems in fast reactor safety.

One modification of Ax-1 has already been made. It has been customary in previous analytical calculations to make a pair of partially compensating assumptions, for simplicity of analysis.<sup>(3)</sup> First, during the burst alpha was held constant up till the time sufficient reactivity had been inserted by the shut off mechanism to balance the input reactivity exactly. This procedure kept the power rising too fast. Secondly, the energy developed in the burst was computed up to this point of reactivity balance, neglecting that portion generated while the power fell from its peak during the time of negative alpha. To check the effect of these assumptions, Ax-1 was modified so that it followed the course of the explosion in the above manner. The power distribution at zero time was used as that valid for computing the distribution of energy. The  $S_n$  section was allowed to go on computing new alphas, but they were used only to terminate the calculation when  $\alpha < 0$ . The recomputed fluxes and alphas did not enter the hydrodynamic calculation. The computation was accomplished by the following list of modifications:

- (1) Insert "FOD(40)" in dimension statements.
- (2) Omit "POWNGL" from (7135) and from print statement.
- (3) Insert "FBAR" = 0 after (7135)  
"FALPHA = 0"
- (4) In (9010) omit "FBAR = 0", and move up to insert the order  
"IF(NH)6800, 6800, 9014," now after (9011), in its place - keeping the number (9010) for the moved order.

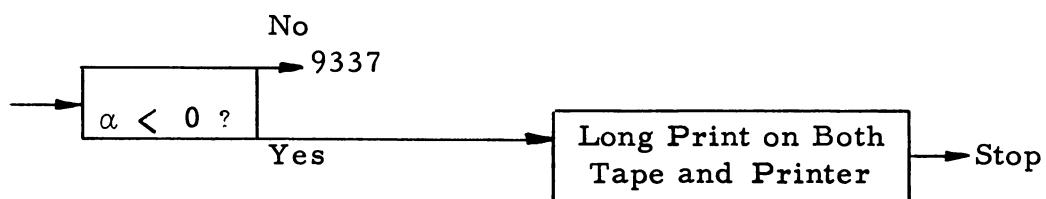
Move the two orders

```
"DO 9011 I = 2, I MAX"
"9011 FBAR = FBAR + T(I)* F(I)"
```

down to just beyond 6800. Then insert "FALPHA = ALPHA"

- (5) Just beyond (6835), insert  $FOD(I) = F(I)/RO(I)$
- (6) In (9070), replace formula for DELQ by "DELQ = FOD(I)\*QBAR"

- (7) Omit (9060) + 1 through (9065).
- (8) Omit "Z = ALPHA \* DELTP"  
Insert "Z = FALPHA \* DELTP" from just before (9060).
- (9) Between (9330) and (9337), take everything out and replace it by



## APPENDIX F.1

## Ax-1 TAPE DUMP AND RECALL ROUTINE

A periodic dumping of the memory from 10000<sub>8</sub> through 17777<sub>8</sub> onto tape #5 has been provided. In case of machine failure, lack of sufficient machine time to complete a problem, a desire to change control parameters, or a desire to continue past the original termination point, a previous dump can be selected and the problem continued from that point. The Tape Dump and Recall Routine occupies positions 140<sub>8</sub> through 165<sub>8</sub> in memory and is loaded by the FORTRAN loader. It was necessary to arrange transfers at appropriate addresses in the main body of the Ax-1 code to the above routine. This was accomplished by inserting at the addresses of formulas 7010 and 9069 a transfer to the tape recall portion of the routine and at the address of formula 9263 a transfer to the tape dump portion of the routine.

## Listing of Ax-1 Tape Dump and Recall Routine

	00140	ORG 96	
00140	0 77200 0 00205	REW 5	
00141	-0 73400 1 00000	PDX 0, 1	(IRCNBR IS IN DEC.
00142	0 76200 0 00225	RTB 5	OF ACCUMULATOR)
00143	2 00001 1 00142	TIX 98, 1, 1	
00144	0 02000 0 00147	TRA 103	
00145	0 10000 0 00000	TZE 0, 0, 0	
00146	0 76600 0 00225	WTB 5	
00147	-0 53400 1 00145	LXD 101, 1	
00150	-0 75400 0 00000	PXD 0, 0	
00151	-0 70000 1 00000	CAD 0, 1	
00152	2 00001 1 00151	TIX 105, 1, 1	
00153	0 60200 0 00165	SLW 117	
00154	0 50000 0 00165	CLA 117	
00155	0 70000 0 00165	CPY 117	
00156	0 40200 0 00165	SUB 117	
00157	0 10000 4 00001	TZE 1, 4	
00160	0 42000 0 00051	HPR 41	
00161	0 76400 0 00205	BST 5	
00162	0 42000 0 00052	HPR 42	
00163	0 76200 0 00225	RTB 5	
00164	0 02000 0 00147	TRA 103	
	00000	END	

## APPENDIX F.2

### Ax-1 DUMP-TAPE CONSOLIDATION ROUTINE

If many Ax-1 dump tapes are saved in anticipation of restarts, the accumulation of tapes can present problems. In order to have the dumps available and yet avoid keeping a large number of tapes, a routine to combine several tapes into one was written. This routine copies the dumps from individual problems onto one master dump tape, checking both the tape reading and writing processes. Cards for this routine are not included in the Ax-1 deck.

#### A. Operating Instructions:

**Reader:** 72 x 72 board.

**Punch:** Not used.

**Printer:** Not used.

**Tapes:** #5-dump tape which is to be added to the consolidated tape.

#3-consolidated tape.

**Sense Switches:** Not used.

**Running Procedure:**

1. Ready UA CSB1 Binary Card Loader (3 cards) followed by the Consolidation Routine Deck (4 cards) in the card reader.
2. Mount and ready tapes #5 and #3.
3. Clear and load cards.
4. At stop 266<sub>8</sub>:
  - a. Enter into the decrement of the MQ the total number (in octal) of records (dumps) on tape #5 to be saved.
  - b. Enter into the address of the MQ the total number (in octal) of records (dumps) already on tape #3.
  - c. Press start.
5. At stop 270<sub>8</sub>, tape #5 has been completely copied onto tape #3. If another tape is to be copied onto tape #3, mount and set it at #5 and follow instructions under 4, omitting step B.

**Error Stops:**

- 245<sub>8</sub>** CKS error in reading tape #5. Press start to try again.
- 250<sub>8</sub>** CKS error in writing or reading tape #3. Press start to try reading tape #3 again. If stop 250<sub>8</sub> reoccurs, the error was in writing, not reading tape #3. Press start again to recopy tape #5 onto tape #3.
- 261<sub>8</sub>** CKS error in writing tape #3. Press start to try again.

**B. Comments on Dump Numbering:**

For a new problem, the dumps are numbered consecutively starting at one. The number of dumps on tape #5 at the time the problem is terminated is equal to the last dump number printed in the on-line output.

For a problem restarted from dump number M, (but not from the consolidated tape), additional dumps are made on tape #5 following dump M and numbered consecutively starting at M + 1. Therefore, the total number of dumps on tape #5 at the time the problem is terminated is still equal to the last dump number printed in the on-line output.

For a problem restarted from the consolidated tape the dump number (IRCNBR) specified must be the number of the desired record on the consolidated tape, which is usually not the dump number of the specific problem. Therefore great care must be taken in keeping track of the location and the number of records on the consolidated tape. Reading in the dump replaces IRCNBR with the dump number of the specified problem. After the dump is completely read in from the consolidated tape, another blank tape should be set at 5 and the consolidated tape removed to avoid destroying dumps from other problems when getting new dumps from the problem being run. Also, it would be wise to manually set IRCNBR = 0 at this time so that the dump numbers from the restarted problem will equal the record numbers on the new tape #5. Depressing S.S. #1 at the start of the problem will cause pause 111 which will enable these changes to be made.

### C. Listing of Ax-1 Dump-Tape Consolidation Routine

00200	00200	ORG 128
00201	0 76300 0 00043	LLS 35
00202	0 73400 1 00000	PAX 0, 1
00203	-2 00000 1 00205	TNX 133, 1, 0
00204	0 76200 0 00223	No. of Records on Tape 3 goes to A-Reg.
00205	2 00001 1 00203	RTB 3
00206	-0 73400 1 00000	TIX 131, 1, 1
00207	0 76200 0 00225	PDX 0, 1
00208	-0 53400 2 00265	No. of Records on Tape 5 goes to A-Reg.
00209	0 75400 0 00000	LXD 181, 2
00210	-0 70000 2 00000	PXD 0
00211	0 60200 0 00244	CAD 0, 2
00212	2 00001 2 00211	TIX 137, 2, 1
00213	0 50000 0 00244	SLW 164
00214	0 70000 0 00244	CLA 164
00215	0 40200 0 00244	CPY 164
00216	0 60200 0 00244	SUB 164
00217	-0 10000 0 00245	TNZ 165
00218	0 76600 0 00223	WTB 3
00219	-0 53400 2 00265	LXD 181, 2
00220	0 75400 0 00000	PXD 0, 0
00221	-0 70000 2 00000	CAD 0, 2
00222	2 00001 2 00223	TIX 147, 2, 1
00223	0 60200 0 00244	SLW 164
00224	0 70000 0 00244	CPY 164
00225	0 76400 0 00203	BST 3
00226	0 76200 0 00223	RTB 3
00227	-0 53400 2 00265	LXD 181, 2
00228	0 75400 0 00000	PXD 0, 0
00229	-0 70000 2 00000	CAD 0, 2
00230	2 00001 2 00233	TIX 155, 2, 1
00231	0 60200 0 00244	SLW 164
00232	0 50000 0 00244	CLA 164
00233	0 70000 0 00244	CPY 164
00234	0 40200 0 00244	SUB 164
00235	0 60200 0 00250	TNZ 168
00236	-0 10000 0 00250	TIX 134, 1, 1
00237	2 00001 1 00206	TRA 184
00238	0 02000 0 00270	HTR 0
00239	0 00000 0 00000	HPR 0
00240	0 76400 0 00205	Tape 5 read fail - try again
00241	0 02000 0 00206	BST 5
00242	0 42000 0 00000	TRA 134
00243	0 76000 0 00141	HPR 0
00244	-0 02000 0 00254	Tape 3 read or write fail - try again
00245	0 02000 0 00256	SLT 1
00246	0 76000 0 00141	TRA 172
00247	0 02000 0 00227	TRA 174
00248	0 76000 0 00141	SLN 1
00249	0 02000 0 00227	TRA 151
00250	0 76000 0 00141	SLN 1
00251	-0 02000 0 00142	SLT 2
00252	0 76000 0 00142	TRA 178
00253	0 02000 0 00262	HPR 0
00254	0 42000 0 00000	2nd Tape 3 write fail
00255	0 76000 0 00142	SLN 2
00256	0 02000 0 00262	BST 3
00257	0 42000 0 00000	TRA 166
00258	0 76000 0 00142	TZE 0
00259	0 02000 0 00262	HPR 0
00260	0 42000 0 00000	TRA 128
00261	0 76000 0 00142	HPR 0
00262	0 02000 0 00262	TRA 128
00263	0 42000 0 00000	END
00264	0 76400 0 00203	END 182
00265	0 02000 0 00246	
00266	0 10000 0 00000	
00267	0 42000 0 00000	
00268	0 02000 0 00200	
00269	0 42000 0 00000	
00270	0 02000 0 00200	
00271	0 02000 0 00200	

## REFERENCES

1. Koch, L. J., Monson, H. O., Okrent, D., Levenson, M. Simmons, W. R., Humphreys, J. R., Haugsnes, J., Jankus, V. Z., and Loewenstein, W. B., Hazard Summary Report, EBR-II, ANL-5719.
2. McCarthy, W. J. Jr., Nicholson, R. B., Okrent, D., and Jankus, V. Z., Studies of Nuclear Accidents in Fast Power Reactors, Paper P/2165, Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy. (Geneva, 1958)
3. Bethe, H. A., and Tait, J. H., An Estimate of the Order of Magnitude of the Explosion When the Core of a Fast Reactor Collapses, UKAEA RHM(56)/113.
4. Stratton, W. R., Colvin, T. H., and Lazarus, R. B., Analysis of Prompt Excursions in Simple Systems and Idealized Fast Reactors, Paper P/431, Proceedings of the Peaceful Uses of Atomic Energy. (Geneva, 1958)
5. Carlson, B. G., Solution of the Transport Equation by S<sub>n</sub> Approximations, LA-1891.
6. Carlson, B. G., The S<sub>n</sub> Method and the SNG and SNK Codes, T-1-159 (LASL document, unpublished).
7. Carlson, B. G., and Bell, G. I., Solution of the Transport Equation by the S<sub>n</sub> Method, Paper P/2386, Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy. (Geneva, 1958).
8. von Neumann, J., and Richtmyer, R. D., J. App. Phys., 21, 232 (1950).
9. Richtmyer, R. D., Difference Methods for Initial-Value Problems, Interscience Publishers, Inc., New York, 1957.
10. Courant, R., Friedrichs, K. O., and Lewy, H., Math. Ann., 100, 32 (1928).
11. Courant, R., and Friedrichs, K. O., Supersonic Flow and Shock Waves, Interscience Publishers, Inc., New York, 1948.
12. Zemansky, M. W., Heat and Thermodynamics (2nd Ed.), McGraw-Hill Book Co., Inc., New York, 1943.

#### ACKNOWLEDGEMENTS

This program has been constructed upon a foundation of experience gained through the efforts of many individuals at LASL. The present authors have modified the method to suit it better to the purposes in mind.

Janet Heestand assisted in preparing the report, in particular by writing Appendix F on Tape Dump, Recall and Consolidation Routines. L. Miller assisted in proof-reading and expediting the printing of the report. V. Z. Jankus contributed part of the ideas leading to the VJ-OK1 test described in Appendix A, for control of the number of hydrodynamic iterations between neutronics calculations.



UNIVERSITY OF MICHIGAN



3 9015 07850 9448

