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

by

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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.^(1,2) A valuable analytical technique for calculating such incidents was developed by Bethe and Tait,⁽³⁾ and since modified by Jankus.^(1,2) 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,⁽⁴⁾ 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 ($= \frac{k_{ex}}{\ell}$) 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, Δt , 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 Δt) 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
 ρ = density
 θ = 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 Δt 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 Δt 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 α too rapidly or modifying the density of a mass point radically. When the power variation in a hydrocycle, or the change in α 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 = μsec

unit of temperature = kev

Then, it follows that

the unit of velocity = $\text{cm}/\mu\text{sec}$

the unit of acceleration = $\text{cm}/\mu\text{sec}^2$

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

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

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

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

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 α '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)	$K_{\text{eff},i}$		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	α	$\mu \text{ sec}^{-1}$	Inverse of reactor period = $\frac{K_{\text{ex}}}{\ell}$
ALPHAO	α_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	α'	$\mu \text{ sec}^{-1}$	The alpha resulting from the previous converged S_n calculation
AM(1) ... AM(5)	$M(1)$... $M(5)$		S_n constants
AMBAR (1) ... AMBAR (5)	$\overline{M}(1)$... $\overline{M}(5)$		S_n constants

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
AMBART	$\overline{M}_T$		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 num- ber of neutrons emitted per fission
B(1)	B(1)		
...	...		S_n constants
B(5)	B(5)		
BCV(M)	$B_{CV}(M)$	$\frac{cm^2}{\mu sec^2 kev^2}$	Constant in equation $C_V = A_{CV} + B_{CV} \theta$
BETA(M)	$\beta (M)$	$\frac{g}{cm \mu sec^2 kev}$	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	ΔE	$\frac{10^{12} \text{ ergs}}{\text{g}}$	Increment in specific internal energy during hydrocycle.
DELQ	ΔQ	$\frac{10^{12} \text{ ergs}}{\text{g}}$	Energy per gram added to mass point I during hydrocycle.
DELR	ΔR	cm	$= R(I) - R(I-1)$, outer radius of mass point I less inner radius. Is negative in event of radii crossing.
DELT	ΔT	μsec	Time increment between hydrocycles in successive stages in the calculation
DELTA(I)	$\Delta(I)$	cm	$\bar{R}(I) - R(I-1)$
DELTP	$\Delta t'$	μsec	The time interval appropriate to calculations of changes in velocity or power (See Appendix B). Equals Δt except when Δt is halved or doubled.
DELV	ΔV	cm^3/g	$= \frac{1}{\rho_{\text{Hyd}}^T} - \frac{1}{\rho_{\text{Hyd}}^{(I)}}$, the change in specific volume during hydrocycle
DTMAX	Δt_{max}	μsec	Largest Δt 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	ϵ		Internal parameter set equal to EPSA, EPSR, or EPSK in accordance with current calculations.
EPSI	ϵ_1	megabars	Largest negligible pres- sure, needed in test for convergence of hydrody- namic pressure when pressure is small.
EPSA	ϵ_A	μsec^{-1}	Convergence criterion on calculation of alpha.
EPSK	ϵ_K		Convergence criterion on K_{eff} calculation.
EPSR	ϵ_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 inter- nal energy at the various mass points computed in two different ways. (See Appendix D)
ETA 1	η_1		Convergence criterion for iteration on hydrodynamic pressure in equation of state calculation.
ETA 2	η_2		1/4 the maximum value for $\alpha \Delta T$ which is tolerated with- out halving ΔT .

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
ETA 3	η_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	$\overline{F}$		$= \sum_I T(I) F(I), \text{ total fissions in system.}^*$
FE BAR	$\overline{FE}$		$= \sum_I WN(I) \cdot E(I), \text{ the elastic collisions for new } S_n \text{ calculation, weighted with the new flux.}^*$
FE BAR P	$\overline{FE}'$		The elastic collisions for the previous S_n calculation, weighted with the new flux.*
FEN BAR	$\overline{FN}$		$= \sum_I WN(I) \cdot \sum_{g=1}^G \frac{n_g(I)}{V_g},$ average inverse velocity weighted with the new flux.*
F FAKE			Internal parameter in convergence test for S_n (= 0 if converged).
FF BAR	$\overline{FF}$		$= \sum_I WN(I) \cdot F(I), \text{ the fissions for new } S_n \text{ calculation, weighted with the new flux.}^*$
FF BAR P	$\overline{FF}'$		The fissions for the previous S_n calculation, weighted with the new flux.*

*These quantities lack a factor of 4π .

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
FLAG 1			If α 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 NS ₄ 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)	$\frac{10^{12} \text{ ergs}}{\text{gram}}$	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	$\overline{P}_H$	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	α -control		Input controlling α to be used (=01 if radii are to be scaled to fit the input α =00 if α is to be calculated from the given configuration)

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
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_{eff} .
KCNTRL			Input parameter for re- questing calculation of k_{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 on-line 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 ΔT = total time elapsed. When ΔT 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			$NL_{\max}$ - NL is the number of hydrocycles since ΔT was doubled.
NLMAX	$NL_{\max}$		Minimum number of hydrocycles between doubling of ΔT (= 64).
NMAX	$N_{\max}$		Number of substances for which cross sections are to be read in.
NP	N_p		Number of hydrodynamic cycles between detailed print-outs on-line.
NPOFF	$N_p, \text{ off}$		Number of hydrodynamic cycles between detailed-outs off-line.
NPOFFP	$N_p', \text{ off}$		Number of hydrodynamic cycles between detailed prints off-line after VJ-OK test on relative change in α due to pressure build-up is passed.
NS 4	NS_4		Number of hydrodynamics cycles between S_n cycles.
NS4R	NS_{4R}		Number of hydrodynamics cycles since last S_n cycle.
OK1			Test parameter used in VJ-OK test. If OK-1 is exceeded, NS_4 is halved.
OK 2			Test parameter used in VJ-OK test. If OK-2 is exceeded, $NS_4 \rightarrow 1$.
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 ³	$= \sum_I P_H(I) \cdot T(I)$ is $\frac{1}{4\pi} \times$ volume integral of pressure.
POWER		$\frac{10^{12} \text{ ergs}}{\mu \text{ sec}}$	Total energy generated in the reactor per μsec .
POWGL		$\frac{10^{12} \text{ ergs}}{\mu \text{ sec}}$	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} 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 _P	10^{12} ergs	Total energy at end of previous hydrocycle.
QPRIME	Q'	10^{12} 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)	$\rho_{\text{neut}}(I)$	$\frac{10^{24} \text{ atoms}}{\text{cm}^3}$	Atom density of the region between R(I) and R(I - 1).
RHOT	$\rho_{\text{Hyd}}^{\text{T}}$	g/cm^3	Density of mass point I at end of new hydrocycle
RIE	Running E_{Internal}	$\frac{10^{12} \text{ ergs}}{\text{gram}}$	Specific internal energy of mass point I computed in alternate fashion for comparison with $E_{\text{internal}}(I)$. (See Appendix D)
RKE	Running E_{kinetic}	$\frac{10^{12} \text{ ergs}}{\text{gram}}$	Kinetic energy per gram for mass point I
RL(I)	$R_L(I)$		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)	$RO_{\text{sn}}(I)$	g/cm^3	Density of mass point I during S_n calculation
S(I)		$\frac{\Delta R(I)}{R(I)}$	
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)	$S_o(I)$		$= 4 \Delta(I) \left(\nu_g F(I) + \rho_{\text{neut}}(I) \sum_h N_h(I) \sigma_{g \leftarrow h} \right),$ <p>the term in S_n calculation proportional to neutron source.</p>

<u>Fortran Symbol</u>	<u>Physical or Mathematical Symbol</u>	<u>Units</u>	<u>Definition</u>
S4R	S_{4R}		Floating point notation for N_{S4}
SUM(IH)	Σ_h		SUM has no unique definition.
SUM 1	Σ_1		SUM is used to provide storage space for various numbers in the neutron flux calculations.
SUM 2	Σ_2		
T(I)		cm^3	$\frac{1}{3} [R(I)^3 - R(I-1)^3] = \frac{1}{4\pi} \times$ 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	θ	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)	$U(I)$	$\frac{\text{cm}}{\mu \text{sec}}$	Velocity of i'th boundary
V(IG)	V_g	$\frac{\text{cm}}{\mu \text{sec}}$	Velocity of neutrons in g'th energy group
VJ		$\frac{1}{g \text{ cm}^2}$	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 4π .

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 Δt , the time interval, as follows.

Thus, if $\alpha \Delta t$, the fractional change in power per hydrocycle, is too great in the original specification, Δt 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 η_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 Δt 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, Δt 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 α 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 α 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 Δt is appropriate. If W , the stability function, is larger than 0.3, Δt is halved (9285, 9290). If the fractional change of power per cycle, $\alpha \Delta t$, exceeds $4\eta_2$, Δt is halved, assuming the stability test has not already done so (9284, 9290). If the problem has gone through NL_{MAX} hydrocycles since the last doubling of Δt , and if W and $\alpha \Delta t$ are sufficiently small, Δt 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 α 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 α - control) is zero, the program proceeds to the usual calculation of alpha, first setting α_3 slightly different from α_4 to prevent premature convergence on the first S_n calculation. If ICNTRL is unity, the guessed outer radius goes to α_4 ; as the calculation progresses, the successively adjusted values of R (IMAX) are compared for the test of convergence, and a special convergence criterion, ϵ_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 $PM_{,1}, PM_{,2}, \dots, PM_{,i_M}$ (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 S₄ 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, $\rho_{\text{Hyd}}(I)$, g/cc.

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

ROLAB M is a conversion factor between the two previous quantities ($\rho_{\text{Hyd}} = \rho_{\text{lab}} \cdot \rho_{\text{neut}}$), 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 k_{eff} 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 k_{eff} .

The S₄ calculation itself is conventional^(5,6,7) 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, $WN(I) = T(I) \cdot \left(\sum_{g=1}^6 N_g(I) \right)$ (Order No. 8301) rather than merely a volume term T(I). (See Order No. 301, for example, defining $\overline{FE'}$.) The procedure used for calculating the next α is identical to that in reference 6. For the convergence on radius or k_{eff} , 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 k_{eff} 1,2,3,4 are arranged to insure a minimum of four iterations before convergence of the k_{eff} 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, ρ_{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) ϵ_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 Δt and $\Delta t'$ when the time interval is halved or doubled are discussed in Appendix B.

next page

PRINT ON TAPE 6 $t, Q_p, \text{POWER}, \alpha, \Delta t, W$
 "TOTAL ENERGY, KINETIC ENERGY, CHECK, ERROR LOCAL"
 $Q_p, E_{\text{kinetic}}, \text{CHECK, ERRLEL}$
 "DENSITY, RADIUS, VELOCITY, PRESSURE, INTERNAL ENERGY, TEMPERATURE"
 $\rho_{\text{hyd}}^{(I)}, R(I), U(I), P_h(I), E_{\text{int}}(I), \theta(I)$ for $I = 2, 3, \dots, I_{\text{max}}$
 PROBLEM NAME & DATE
 "TIME, Q_p , 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), HEO(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 (10H0F, EN(IG))
9981 FORMAT (1P9E13.5)
9982 FORMAT (60H0      TOTAL ENERGY      KINETIC ENERGY      CHECK      ERROR
      1LOCAL)
9983 FORMAT (90H0      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(IRCNBR) 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

```

```

      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 217 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 = RT*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(ABS(F(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(KCNTRL) 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(ABS(F(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-RL(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)
      QPRIME = -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 ALPHA0 = MAX1F(ABSF(ALPHA), ALPHA0)
      IF(ALPHA) 9018, 9018, 9017
9017 FLAG1 = 1.0
9018 Z = ARSF(ALPHAP-ALPHA)/(ALPHA0 + 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*DELT*P
      POWER=EXPF(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 QPRIME = 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(HPBAR-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, ERRCL
      WRITE OUTPUT TAPE 6, 9983
      WRITE OUTPUT TAPE 6, 9911, (RO(I),R(I),U(I),HP(I),HE(I),THETA(I),I
      1=2,IMAX)
      WRITE OUTPUT TAPE 6, 9900
      WRITE OUTPUT TAPE 6, 9986
9255 IF(SENSE LIGHT 3) 9283, 9256
9256 IF(NDUMP) 9257, 9257, 9258
9257 IRCNBR = IRCNBR + 1
      NDUMP = NDUMP + 1
      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, ALPHA DELT 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
H 32165 76645	HP 32647 77607	HMASS 31869 76175	HE 32606 77536	HEO 31909 76245
F 32405 77225	E 32365 77155	EN 31785 76051	ENN 31505 75421	ENNN 31949 76315
DELTA 32285 77035	B 31954 76322	BETA 32069 76505	BCV 32045 76455	A 31968 76340
ANUSIG 31305 75111	ANU 32022 76426	AM 31964 76334	AMBAR 31959 76327	ALPH 32077 76515
AK 31829 76125	ACV 32053 76465	KP 32037 76445	K 32485 77345	MN 31129 74631
P 31193 74731	RBAR 32325 77105	RHO 32445 77275	RL 32526 77416	ROLAB 32085 76525
RO 32767 77777	ROSN 31825 76121	R 32727 77727	SIGMA 31057 74521	SIG 31249 75021
SO 32125 76575	S 32245 76765	SUM 32015 76417	TAU 32061 76475	THETA 32566 77466
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
IS 30665 73711	I 30664 73710	IRCNBR 30663 73707	IMAX 30662 73706	ILOOP 30661 73705
II 30660 73704	IG 30659 73703	IGMAX 30658 73702	ICNTRL 30657 73701	HPT 30656 73700
HPBAR 30655 73677	FLAG1 30654 73676	FFBAR 30653 73675	FFBARP 30652 73674	FFAKE 30651 73673
FENBAR 30650 73672	FEBAR 30649 73671	FEBARP 30648 73670	FBAR 30647 73667	ETA3 30646 73666
ETA2 30645 73665	ETA1 30644 73664	ERRLCL 30643 73663	EPS 30642 73662	EPSR 30641 73661
EPSK 30640 73660	EPSA 30639 73657	EPS1 30638 73656	DTMAX 30637 73655	DELV 30636 73654
DELT 30635 73653	DELTP 30634 73652	DELR 30633 73651	DELQ 30632 73650	DELE 30631 73647
CVP 30630 73646	CSC 30629 73645	CONST 30628 73644	CHECK 30627 73643	BT 30626 73642
BS 30625 73641	AMT 30624 73640	AMBART 30623 73637	ALPHA 30622 73636	ALPHAP 30621 73635
ALPHA0 30620 73634	AKEFF 30619 73633	AITCT 30618 73632	JK 30617 73631	JMAX 30616 73630
J 30615 73627	KCALC 30614 73626	KCNTRL 30613 73625	LDONT 30612 73624	L 30611 73623
MA 30610 73622	MMAX 30609 73621	M 30608 73620	NDMAX 30607 73617	NDUMP 30606 73616
NH 30605 73615	NITMAX 30604 73614	NIT 30603 73613	NLMAX 30602 73612	NL 30601 73611
NMAX 30600 73610	NPOFFP 30599 73607	NPOFF 30598 73606	NP 30597 73605	N 30596 73604
NS4R 30595 73603	NS4 30594 73602	OK1 30593 73601	OK2 30592 73600	PBAR 30591 73577
POWER 30590 73576	POWNG1 30589 73575	PSTAR 30588 73574	PTEST 30587 73573	QBAR 30586 73572
QPRIME 30585 73571	QP 30584 73570	Q 30583 73567	RHOT 30582 73566	RIE 30581 73565
RKF 30580 73564	S4R 30579 73563	SUM1 30578 73562	SUM2 30577 73561	THET 30576 73560
TIME 30575 73557	TOTIEN 30574 73556	TOTKE 30573 73555	VJ 30572 73554	VP 30571 73553
WR 30570 73552	W 30569 73551	Z 30568 73550		

EXTERNAL FORMULA NUMBERS WITH CORRESPONDING INTERNAL FORMULA NUMBERS AND OCTAL LOCATIONS

EFN IFN LOC	EFN IFN LOC	EFN IFN LOC	EFN IFN LOC	EFN IFN LOC
9900 2 00000	9910 3 00000	9911 4 00000	9915 5 00000	9920 6 00000
9921 7 00000	9922 8 00000	9930 9 00000	9931 10 00000	9940 11 00000
9941 12 00000	9942 13 00000	9943 14 00000	9944 15 00000	9980 16 00000
9981 17 00000	9982 18 00000	9983 19 00000	9984 20 00000	9985 21 00000
9986 22 00000	9987 23 00000	7000 24 00000	7000 25 00007	7005 26 00011
7005 28 00023	7010 30 00031	7015 35 00046	7020 37 00050	7020 39 00062
7025 49 00132	7030 52 00141	7030 54 00157	7040 68 00242	7045 75 00266
7045 80 00304	7050 81 00311	7050 89 00341	7060 90 00343	7070 92 00403
7070 98 00425	7080 99 00444	7090 105 00475	7100 109 00511	7110 110 00517
7110 115 00537	7120 116 00544	7130 126 00624	7130 128 00641	7135 129 00643
7135 131 00662	7140 136 00677	7150 138 00704	7155 157 00762	7155 159 00774

7160	170	01045	7160	172	01063	7168	186	01146	7170	193	01172	7170	198	01210
7172	199	01216	7172	207	01246	7180	210	01310	7180	216	01332	7190	219	01360
7190	224	01400	9000	240	01521	9002	252	01550	9003	253	01551	208	255	01555
209	256	01557	210	259	01621	211	265	01666	207	268	01706	212	269	01723
213	270	01737	214	272	01764	215	274	01774	8009	275	02013	8010	278	02024
9	279	02033	13	283	02050	8000	284	02070	2	285	02077	5	288	02134
8	290	02150	7	291	02157	14	292	02162	15	294	02165	6	295	02167
40	296	02174	4	297	02214	10	299	02232	3	301	02253	11	302	02270
30	304	02301	101	305	02306	120	309	02324	102	310	02330	104	312	02342
899	315	02361	900	316	02364	103	317	02370	105	321	02413	107	324	02426
106	325	02437	902	327	02457	901	328	02463	108	329	02467	109	330	02520
1000	332	02532	1001	333	02537	110	334	02542	79	335	02553	905	339	02572
80	340	02577	81	341	02602	84	343	02614	91	344	02621	911	345	02627
300	346	02632	8300	353	02656	8301	354	02670	301	357	02706	307	358	02714
303	364	03001	302	366	03016	310	373	03050	913	374	03056	305	375	03063
311	376	03067	312	377	03070	315	383	03120	313	384	03122	8999	386	03130
8999	387	03137	314	390	03152	314	392	03164	306	393	03166	306	395	03200
319	399	03207	325	400	03210	8015	402	03220	8020	406	03236	8021	409	03252
321	411	03264	338	415	03301	330	416	03305	339	418	03311	915	419	03315
331	420	03317	331	421	03326	501	425	03357	501	431	03400	503	432	03407
502	433	03411	502	434	03420	9010	445	03465	9011	447	03472	6800	449	03503
6801	451	03512	6803	458	03527	6803	459	03536	6802	462	03553	6810	464	03560
6820	466	03615	6822	467	03626	2004	468	03640	6830	474	03654	6833	479	03671
6835	481	03724	6837	483	03753	6840	485	03772	6990	498	04051	6990	500	04063
9014	510	04126	9017	512	04142	9018	513	04144	9015	515	04161	9016	516	04164
9020	518	04170	9022	519	04175	9023	520	04201	9024	522	04205	9025	523	04211
9027	525	04213	9030	526	04215	9040	527	04222	9045	528	04227	9050	529	04231
9051	530	04233	9052	531	04234	9054	533	04242	9056	540	04307	9060	544	04325
9061	546	04340	9062	547	04343	9065	548	04347	9066	549	04351	9068	556	04456
9069	558	04461	2003	565	00020	9070	571	04537	9080	575	04557	9082	577	04561
9120	579	04570	9122	580	04606	9123	581	04612	9124	582	04615	9130	586	04626
9140	589	04703	9150	590	04721	9151	591	04741	9160	593	04750	9170	595	04753
9180	596	04754	9190	599	04763	9200	601	05023	9201	603	05033	9202	604	05040
9203	605	05044	9204	607	05051	9205	609	05065	9206	611	05072	9213	616	05134
9207	617	05136	9208	618	05143	9209	620	05146	9211	621	05153	9212	623	05163
9210	624	05171	9220	626	05176	9230	627	05200	9240	628	05203	9241	629	05212
9242	630	05220	5999	632	05223	6000	633	05225	6010	638	05242	6020	639	05275
6030	640	05306	6040	642	05324	6050	647	05351	6050	649	05370	9250	657	05433
9250	662	05460	6055	667	05504	6055	669	05523	9255	687	05637	9256	688	05642
9257	689	05645	9258	692	05653	9262	693	05656	9264	694	05660	9265	695	05663
9263	696	05664	9266	697	05665	9266	699	05677	9267	703	05715	9268	704	05721
9269	705	05731	9270	706	05735	9272	707	05740	9274	708	05743	9278	709	05750
9280	710	05755	9281	711	05764	9282	716	00140	2000	722	00010	9283	723	06033
9283	724	06042	2001	728	00010	9284	729	06056	9284	730	06065	2002	734	00010
9285	735	06101	9285	736	06110	9290	739	06123	9310	743	06136	9320	744	06140
9330	746	06150	9331	748	06154	9332	750	06156	9333	751	06161	9334	752	06166
9335	753	06173	9336	754	06177	2005	756	00010	9337	762	06230			

SUBROUTINES OBTAINED FROM LIBRARY

(DBC)	DEC	OCT	(CSH)	DEC	OCT	(BDC)	DEC	OCT	(FIL)	DEC	OCT	(LEV)	DEC	OCT
(RTN)	3513	06671	(SPH)	4030	07676	(STH)	4111	10017	LOG	4141	10055	EXP	4154	10072
CUBERT	4181	10125		4661	11065		4757	11225		4765	11235		4807	11307
	4870	11406												

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, α , 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, α , Δt , etc. is provided, independent of whether $NH = 0 \pmod{N_p}$. This light is lit at Order No. 9290 where Δt is halved.

Sense Light No. 2

At Order No. 9281, if the course of the problem permits a doubling of Δt , 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 Δt 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	Pause 7010	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	Pause 111	Optional pause (Sense Switch No. 1) to allow modification of memory or any other steps when beginning problem from a dump.
9002	Pause 11111	Optional pause (Sense Switch No. 2) following print-out of input data.
14	Pause 14	If H(I) should be negative, this pause results. When problem is continued, H(I) is set equal to zero.
900	Stop 13571	The problem is stopped if $I < 0$ results somehow.
901	Stop 12345	The problem is stopped if $J = 0$, falling outside the proper range 1-5.
9051	Pause 66666	This is an optional pause (Sense Switch No. 6) at the beginning of the hydrocycle.
9068	Pause 50	This pause occurs after continuing from Pause 60, or if excessive change occurs in $\rho_{\text{Hyd}}^T \Delta V $, both serious troubles. Continuing the problem leads to dummy pause 9069.
9069	Dummy Pause	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 Δt halved.
9080	Pause 60	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 $N_{dump} > 0$.
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 170₈ punched in row 12L of the fourth card instead of the usual 140₈ - 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 170₈ - 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:

- 51₈ 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.

- 52₈ 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, EPSA, and EPSK are the convergence criteria for the various types of S_n calculations. Running time will be particularly sensitive to EPSA, 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 Δt . Unless conditions dictate otherwise, it is reasonable to choose the largest initial Δt which satisfies the ETA 2 test.

Δt_{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. = 5×10^{-5} kev.

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

Initial power = 10^{12} ergs/ μsec .

Use 1 group cross sections

$V_g = 1.695 \times 10^2$ cm/ μsec .

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	$3 \times 10^{-6} \text{ cm}$	
EPSA	$5 \times 10^{-5} \mu\text{sec}^{-1}$	
EPS1	$10^{-4} \text{ gm/cm } \mu\text{sec}^2$	
ETA1	10^{-3}	
ETA2	1.5×10^{-2}	
ETA3	3×10^{-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.)
Δt	2 μsec	
Δt_{Max}	16 μsec	
NP	100	
NPOFF	15	
NPOFFP	3	
KCNTRL	01	
VJ	6.6×10^{-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	5×10^{-6}	
POWNGL	1	

2. Formal Presentation of Specifications

INPUT SHEETS - Ax IProblem Name and Date Geneve 10 Rerun March 20, 1959Record Number { 00 if beginning new problem
(choose one) { > 0 if restarting from tape, omit rest of form 00 α Control { 00 to find α for given configuration. A guess is required for α .
(choose one) { 01 to scale radii given α below 01 α (μsec^{-1}) 1.3084×10^{-2} Power (10^{12} ergs/ μsec) 1 $I_{\text{Max}} = \text{Total Number of Zones} + 1$
($I_{\text{Max}} \leq 40$) 40**ZONE DATA**The following must be filled out for each i ($2 \leq i \leq I_{\text{Max}}$)

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

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

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:

$$\begin{array}{cccccccccccccccccccccccc} \frac{4}{2} & \frac{4}{3} & \frac{4}{4} & \frac{4}{5} & \frac{4}{6} & \frac{4}{7} & \frac{4}{8} & \frac{4}{9} & \frac{4}{10} & \frac{4}{11} & \frac{4}{12} & \frac{4}{13} & \frac{4}{14} & \frac{4}{15} & \frac{4}{16} & \frac{4}{17} & \frac{4}{18} & \frac{4}{19} & \frac{4}{20} \\ \frac{4}{21} & \frac{4}{22} & \frac{4}{23} & \frac{4}{24} & \frac{4}{25} & \frac{4}{26} & \frac{3}{27} & \frac{3}{28} & \frac{3}{29} & \frac{3}{30} & \frac{3}{31} & \frac{3}{32} & \frac{3}{33} & \frac{3}{34} & \frac{3}{35} & \frac{3}{36} & \frac{3}{37} & \frac{3}{38} & \frac{3}{39} & \frac{3}{40} \end{array}$$

G Max = number of energy groups (≤ 7) 1

N Max 3 M Max 1

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

M Max = number of mixtures (≤ 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:	<u>.36</u>	<u>.64</u>							
Substance Label:	<u>1</u>	<u>2</u>							<u>4</u> Mixture Label
Proportions:									
Substance Label:									<u> </u> Mixture Label
Proportions:									
Substance Label:									<u> </u> Mixture Label

Proportions:	_____	_____	_____	_____	_____	_____	_____	_____
Substance Label:	_____	_____	_____	_____	_____	_____	_____	_____
								Mixture Label
Proportions:	_____	_____	_____	_____	_____	_____	_____	_____
Substance Label:	_____	_____	_____	_____	_____	_____	_____	_____
								Mixture Label
Proportions:	_____	_____	_____	_____	_____	_____	_____	_____
Substance Label:	_____	_____	_____	_____	_____	_____	_____	_____
								Mixture Label

NEUTRON CONSTANTS

Average Neutron Velocity (cm/ μ sec)							Relative Fission Spectrum ν_g ($\sum \nu_g = 1$)						
$\nu_g > \nu_{g-1}$ ↓							↓						
169.5							1						
$g = 1$	$g = 2$	$g = 3$	$g = 4$	$g = 5$	$g = 6$	$g = 7$	$g = 1$	$g = 2$	$g = 3$	$g = 4$	$g = 5$	$g = 6$	$g = 7$

Cross Sections (barns)

Note: ν = average number of neutrons emitted per fission

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

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

	$(\nu\sigma_f)_g$	$(\sigma_{tr})_g$	$(\sigma_{scat})_{g \leftarrow 1}$	$(\sigma_{scat})_{g \leftarrow 2}$	$(\sigma_{scat})_{g \leftarrow 3}$	$(\sigma_{scat})_{g \leftarrow 4}$	$(\sigma_{scat})_{g \leftarrow 5}$	$(\sigma_{scat})_{g \leftarrow 6}$	$(\sigma_{scat})_{g \leftarrow 7}$
$g = 1$	0.25	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:

	P_{Lab} (10^{-24} g/atom)	$\alpha(\text{cm}^2/\mu\text{sec}^2)$	$\beta(\text{g/cm}\mu\text{sec}^2\text{kev})$	$\tau(\text{g/cm}\mu\text{sec}^2)$	$A_{\text{cv}}(\text{cm}^2/\mu\text{sec}^2\text{kev})$	$B_{\text{cv}}(\text{cm}^2/\mu\text{sec}^2\text{kev}^2)$
Innermost Material	396	.02873	278.46	- .3946	12.163	5780
Next New Material	396	.02873	278.46	- .4687189	12.163	5780

ACCURACY CRITERIA

Definitions:

- EPSR Tolerance for outer radius when α -control $\neq 0$
- EPSA Tolerance in α 's found by S_4
- 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 $\alpha \Delta t$
- ETA3 Tolerance for the change in α between successive S_4 cycles

	EPSR (cm)	EPSA (μsec^{-1})	EPS1 ($\text{g/cm}\mu\text{sec}^2$)	ETA1	ETA2	ETA3
	3×10^{-6}	5×10^{-5}	10^{-4}	10^{-3}	1.5×10^{-2}	3×10^{-2}
C_{vp} Viscous pressure coefficient _____ 2	Courant stability constant _____ 3					
for shock smearing	equals high estimate for $\gamma(\gamma-1)$					
Δt (μsec) _____ 2	Δt max (μsec) _____ 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_{eff} is desired
00 if calculation of k_{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

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

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

b = core radius, cm

ℓ = neutron lifetime

ρ = density, g/cm³

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>6.6×10^{-7}</u>	<u>10^{-2}</u>	<u>4×10^{-2}</u>	<u>10^{-4}</u>	<u>5×10^{-6}</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

[illegible]

704 INPUT DATA
FORM II

PROBLEM GENEVE 10 RERUN ORIGINATOR

DATA I.D.

DATE MARCH 20, 1959 PAGE 2 OF 4

[illegible]

704 INPUT DATA
FORM II

DATE MARCH 20, 1959 PAGE 3 OF 4

DATA I.D.

PROBLEM GENEVE 10 RERUN ORIGINATOR

[illegible]

704 INPUT DATA FORM II

PROBLEM GENEVE 10 RERUN ORIGINATOR

DATA I.D.

DATE MARCH 20, 1959 PAGE 4 OF 4

[illegible]

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, Δt 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 ($NH \equiv 0 \pmod{N_p}$) 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

1.000000E 00

40

9.500000E-01	7.920000E 00	1.000000E 00	0.	10.000000E-05
1.900000E 00	7.920000E 00	1.000000E 00	0.	10.000000E-05
2.850000E 00	7.920000E 00	9.900000E-01	0.	10.000000E-05
3.800000E 00	7.920000E 00	9.800000E-01	0.	10.000000E-05
4.750000E 00	7.920000E 00	9.700000E-01	0.	10.000000E-05
5.700000E 00	7.920000E 00	9.500000E-01	0.	10.000000E-05
6.650000E 00	7.920000E 00	9.300000E-01	0.	10.000000E-05
7.600000E 00	7.920000E 00	9.100000E-01	0.	10.000000E-05
8.550000E 00	7.920000E 00	8.900000E-01	0.	10.000000E-05
9.500000E 00	7.920000E 00	8.700000E-01	0.	10.000000E-05
1.045000E 01	7.920000E 00	8.500000E-01	0.	10.000000E-05
1.140000E 01	7.920000E 00	8.200000E-01	0.	10.000000E-05
1.235000E 01	7.920000E 00	7.900000E-01	0.	10.000000E-05
1.330000E 01	7.920000E 00	7.600000E-01	0.	10.000000E-05
1.425000E 01	7.920000E 00	7.300000E-01	0.	10.000000E-05
1.520000E 01	7.920000E 00	7.000000E-01	0.	10.000000E-05
1.615000E 01	7.920000E 00	6.700000E-01	0.	10.000000E-05
1.710000E 01	7.920000E 00	6.400000E-01	0.	10.000000E-05
1.805000E 01	7.920000E 00	6.100000E-01	0.	10.000000E-05
1.900000E 01	7.920000E 00	5.800000E-01	0.	10.000000E-05
1.995000E 01	7.920000E 00	5.500000E-01	0.	10.000000E-05
2.090000E 01	7.920000E 00	5.200000E-01	0.	10.000000E-05
2.185000E 01	7.920000E 00	4.800000E-01	0.	10.000000E-05
2.280000E 01	7.920000E 00	4.400000E-01	0.	10.000000E-05
2.375000E 01	7.920000E 00	4.000000E-01	0.	10.000000E-05
2.470000E 01	1.583000E 01	0.	0.	5.000000E-05
2.565000E 01	1.583000E 01	0.	0.	5.000000E-05
2.660000E 01	1.583000E 01	0.	0.	5.000000E-05
2.755000E 01	1.583000E 01	0.	0.	5.000000E-05
2.850000E 01	1.583000E 01	0.	0.	5.000000E-05
3.030000E 01	1.583000E 01	0.	0.	5.000000E-05
3.210000E 01	1.583000E 01	0.	0.	5.000000E-05
3.390000E 01	1.583000E 01	0.	0.	5.000000E-05
3.570000E 01	1.583000E 01	0.	0.	5.000000E-05
3.750000E 01	1.583000E 01	0.	0.	5.000000E-05
3.930000E 01	1.583000E 01	0.	0.	5.000000E-05
4.110000E 01	1.583000E 01	0.	0.	5.000000E-05
4.290000E 01	1.583000E 01	0.	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	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																			
0.3600000	0.6400000	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.
1	2	4	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0
1.695000E 02	1.000000E 00																		
3.750000E 00	7.000000E 00	5.300000E 00																	
2.500000E-01	7.000000E 00	6.700000E 00																	
0.	7.000000E 00	6.800000E 00																	
3.960000E 02	2.873000E-02	2.784600E 02	-3.946000E-01	1.216300E 01	5.780000E 03														
3.960000E 02	2.873000E-02	2.784600E 02	-4.687189E-01	1.216300E 01	5.780000E 03														
3.000000E-06	5.000000E-05	10.000000E-05	10.000000E-04	1.500000E-02	3.000000E-02														
2.000000E 00	3.000000E 00																		
2.000000E 00	1.600000E 01																		
100 15	3 1																		
6.600000E-07	10.000000E-03	4.000000E-02	10.000000E-05	5.000000E-06	1.000000E 00														

GENEVE 10 RERUN MARCH 20 1959

K EFFECTIVE = 1.003243E 00

TOTAL KINETIC ENERGY = 0.

TOTAL INTERNAL ENERGY = 3.484515E 03

INITIAL MAXIMUM RADIUS = 4.400910E 01

TIME	QP	POWER	ALPHA	DELT	W
0.	3.484515E 03	1.000000E 00	1.308400E-02	2.000000E 00	0.
2.000000E 00	3.486570E 03	1.026513E 00	1.306381E-02	2.000000E 00	1.717759E-02
6.000000E 00	3.490840E 03	1.081580E 00	1.306669E-02	2.000000E 00	1.737788E-02
1.200000E 01	3.497678E 03	1.169789E 00	1.306910E-02	2.000000E 00	1.769934E-02
2.000000E 01	3.507671E 03	1.298716E 00	1.307150E-02	2.000000E 00	1.816912E-02
3.000000E 01	3.521725E 03	1.480072E 00	1.307318E-02	2.000000E 00	1.882985E-02
4.200000E 01	3.541205E 03	1.731467E 00	1.307486E-02	2.000000E 00	1.974568E-02
5.600000E 01	3.568153E 03	2.079270E 00	1.307654E-02	2.000000E 00	2.101261E-02
7.200000E 01	3.605640E 03	2.563162E 00	1.307702E-02	2.000000E 00	2.277511E-02
9.000000E 01	3.658339E 03	3.243418E 00	1.307847E-02	2.000000E 00	2.525282E-02
1.100000E 02	3.733451E 03	4.213092E 00	1.307943E-02	2.000000E 00	2.878439E-02

DUMP 1

1.320000E 02	3.842258E 03	5.617822E 00	1.307967E-02	2.000000E 00	3.390018E-02
1.560000E 02	4.002723E 03	7.689500E 00	1.308039E-02	2.000000E 00	4.144491E-02
1.820000E 02	4.243975E 03	1.080431E 01	1.308087E-02	2.000000E 00	5.278815E-02
2.000000E 02	4.466130E 03	1.367270E 01	1.308087E-02	2.000000E 00	6.323373E-02

TOTAL ENERGY	KINETIC ENERGY	CHECK	ERROR LOCAL
4.466130E 03	0.	-1.378316E-04	2.656016E-06

DENSITY	RADIUS	VELOCITY	PRESSURE	INTERNAL ENERGY	TEMPERATURE
7.920000E 00	9.353166E-01	-0.	0.	4.609830E-03	3.500994E-04
7.919999E 00	1.870633E 00	-0.	0.	4.603765E-03	3.496712E-04
7.919999E 00	2.805949E 00	-0.	0.	4.591511E-03	3.488057E-04
7.920000E 00	3.741266E 00	-0.	0.	4.573052E-03	3.475017E-04
7.919999E 00	4.676582E 00	-0.	0.	4.548420E-03	3.457605E-04
7.919999E 00	5.611899E 00	-0.	0.	4.517679E-03	3.435855E-04
7.919999E 00	6.547217E 00	-0.	0.	4.480917E-03	3.409822E-04
7.919999E 00	7.482533E 00	-0.	0.	4.438245E-03	3.379570E-04
7.919999E 00	8.417846E 00	-0.	0.	4.389797E-03	3.345174E-04
7.919998E 00	9.353163E 00	-0.	0.	4.335721E-03	3.306729E-04
7.919998E 00	1.028848E 01	-0.	0.	4.276185E-03	3.264334E-04
7.919999E 00	1.122380E 01	-0.	0.	4.211373E-03	3.218098E-04
7.919998E 00	1.215911E 01	-0.	0.	4.141483E-03	3.168140E-04
7.919997E 00	1.309443E 01	-0.	0.	4.066724E-03	3.114589E-04
7.919998E 00	1.402975E 01	-0.	0.	3.987319E-03	3.057583E-04
7.919998E 00	1.496507E 01	-0.	0.	3.903497E-03	2.997261E-04
7.919998E 00	1.590038E 01	-0.	0.	3.815498E-03	2.933772E-04

7.919998E 00	1.683569E 01	-0.	0.	3.723564E-03	2.867267E-04
7.919997E 00	1.777101E 01	-0.	0.	3.627943E-03	2.797899E-04
7.919997E 00	1.870633E 01	-0.	0.	3.528882E-03	2.725825E-04
7.919997E 00	1.964164E 01	-0.	0.	3.426623E-03	2.651197E-04
7.919996E 00	2.057696E 01	-0.	0.	3.321385E-03	2.574151E-04
7.919997E 00	2.151228E 01	-0.	0.	3.213252E-03	2.494729E-04
7.919995E 00	2.244760E 01	-0.	0.	3.101458E-03	2.412334E-04
7.919998E 00	2.338291E 01	-0.	0.	2.980167E-03	2.322627E-04
1.583000E 01	2.431823E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	2.525355E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	2.618887E 01	-0.	0.	6.153750E-04	4.999999E-05
1.583000E 01	2.712418E 01	-0.	0.	6.153750E-04	4.999999E-05
1.583000E 01	2.805950E 01	-0.	0.	6.153750E-04	4.999999E-05
1.583000E 01	2.983168E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	3.160386E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	3.337602E 01	-0.	0.	6.153750E-04	4.999998E-05
1.582999E 01	3.514820E 01	-0.	0.	6.153750E-04	4.999997E-05
1.582999E 01	3.692038E 01	-0.	0.	6.153750E-04	4.999997E-05
1.583000E 01	3.869256E 01	-0.	0.	6.153750E-04	4.999999E-05
1.582999E 01	4.046474E 01	-0.	0.	6.153750E-04	4.999998E-05
1.582999E 01	4.223692E 01	-0.	0.	6.153750E-04	4.999997E-05
1.582999E 01	4.400910E 01	0.	0.	6.153750E-04	4.999997E-05

GENEVE 10 RERUN MARCH 20 1959

TIME	QP	POWER	ALPHA	DELT	W
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-02	8.218011E-04
7.493912E 00	1.905539E 00	1.461096E-03	4.980521E-02	1.319808E-02	8.227578E-04
7.493629E 00	2.858224E 00	2.419077E-03	4.903755E-02	1.315292E-02	8.200302E-04
7.504321E 00	3.809892E 00	2.837079E-03	4.895018E-02	1.309500E-02	8.186132E-04
7.515374E 00	4.760746E 00	3.736507E-03	4.849854E-02	1.301343E-02	8.158509E-04
7.528976E 00	5.710589E 00	4.365463E-03	4.791449E-02	1.291162E-02	8.123501E-04
7.549754E 00	6.658724E 00	5.095267E-03	4.764249E-02	1.279374E-02	8.092295E-04
7.567464E 00	7.605683E 00	5.717149E-03	4.669176E-02	1.265076E-02	8.039881E-04
7.592811E 00	8.550646E 00	6.363582E-03	4.609189E-02	1.249247E-02	7.992186E-04
7.617350E 00	9.493879E 00	6.965566E-03	4.503848E-02	1.231175E-02	7.929039E-04
7.648377E 00	1.043473E 01	7.512518E-03	4.420762E-02	1.211524E-02	7.867189E-04
7.680144E 00	1.137329E 01	8.007845E-03	4.308627E-02	1.189895E-02	7.794144E-04
7.716881E 00	1.230911E 01	8.478864E-03	4.204543E-02	1.166610E-02	7.718863E-04
7.752517E 00	1.324249E 01	8.894262E-03	4.054883E-02	1.141318E-02	7.628349E-04
7.791894E 00	1.417309E 01	9.367871E-03	3.903099E-02	1.114415E-02	7.533214E-04
7.833664E 00	1.510078E 01	9.557108E-03	3.738020E-02	1.085900E-02	7.430835E-04
7.881988E 00	1.602497E 01	9.646610E-03	3.593785E-02	1.055997E-02	7.329179E-04
7.926625E 00	1.694623E 01	9.939646E-03	3.384898E-02	1.024234E-02	7.208111E-04
7.970825E 00	1.786472E 01	9.889098E-03	3.142713E-02	9.909864E-03	7.075534E-04
8.023799E 00	1.877955E 01	9.526138E-03	2.938053E-02	9.565789E-03	6.947382E-04

8.058807E 00	1.969283E 01	9.354209E-03	2.562169E-02	9.201159E-03	6.776275E-04
8.126535E 00	2.060099E 01	8.658014E-03	2.413655E-02	8.836209E-03	6.653063E-04
8.100561E 00	2.151433E 01	2.032907E-03	1.578500E-02	8.429936E-03	6.357862E-04
7.936677E 00	2.244760E 01	2.877922E-10	6.016498E-05	8.004120E-03	5.819281E-04
7.919998E 00	2.338291E 01	-0.	0.	7.562369E-03	5.503850E-04
1.583000E 01	2.431823E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	2.525355E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	2.618887E 01	-0.	0.	6.153750E-04	4.999999E-05
1.583000E 01	2.712418E 01	-0.	0.	6.153750E-04	4.999999E-05
1.583000E 01	2.805950E 01	-0.	0.	6.153750E-04	4.999999E-05
1.583000E 01	2.983168E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	3.160386E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	3.337602E 01	-0.	0.	6.153750E-04	4.999998E-05
1.582999E 01	3.514820E 01	-0.	0.	6.153750E-04	4.999997E-05
1.582999E 01	3.692038E 01	-0.	0.	6.153750E-04	4.999997E-05
1.583000E 01	3.869256E 01	-0.	0.	6.153750E-04	4.999999E-05
1.582999E 01	4.046474E 01	-0.	0.	6.153750E-04	4.999998E-05
1.582999E 01	4.223692E 01	-0.	0.	6.153750E-04	4.999997E-05
1.582999E 01	4.400910E 01	0.	0.	6.153750E-04	4.999997E-05

GENEVE 10 RERUN MARCH 20 1959

TIME	QP	POWER	ALPHA	DELT	W
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	TEMPERATURE
7.481986E 00	9.532235E-01	1.832310E-04	5.029360E-02	1.328717E-02	8.257421E-04
7.483834E 00	1.906310E 00	1.541746E-03	5.007831E-02	1.326452E-02	8.247782E-04
7.483896E 00	2.859438E 00	2.428255E-03	4.934222E-02	1.321954E-02	8.221285E-04
7.496565E 00	3.811334E 00	2.884498E-03	4.944069E-02	1.316300E-02	8.211750E-04
7.505908E 00	4.762645E 00	3.797786E-03	4.882175E-02	1.307953E-02	8.179883E-04
7.520732E 00	5.712786E 00	4.393979E-03	4.834875E-02	1.297824E-02	8.147601E-04
7.540719E 00	6.661322E 00	5.194831E-03	4.799533E-02	1.285901E-02	8.114288E-04
7.559311E 00	7.608573E 00	5.779899E-03	4.712015E-02	1.271605E-02	8.063677E-04
7.584273E 00	8.553883E 00	6.473626E-03	4.647534E-02	1.255657E-02	8.014766E-04
7.609310E 00	9.497405E 00	7.052238E-03	4.545819E-02	1.237529E-02	7.952406E-04
7.640404E 00	1.043855E 01	7.629301E-03	4.462197E-02	1.217775E-02	7.890296E-04
7.672613E 00	1.137735E 01	8.116051E-03	4.352798E-02	1.196060E-02	7.817777E-04
7.709292E 00	1.231343E 01	8.634149E-03	4.246773E-02	1.172641E-02	7.741857E-04
7.745423E 00	1.324701E 01	9.051432E-03	4.099948E-02	1.147246E-02	7.651852E-04
7.784577E 00	1.417786E 01	9.538440E-03	3.944508E-02	1.120181E-02	7.555634E-04
7.827812E 00	1.510563E 01	9.705800E-03	3.790197E-02	1.091598E-02	7.455610E-04
7.876376E 00	1.602990E 01	9.861428E-03	3.645849E-02	1.061536E-02	7.353667E-04
7.920403E 00	1.695132E 01	1.018808E-02	3.429620E-02	1.029561E-02	7.230590E-04
7.966570E 00	1.786977E 01	1.009850E-02	3.201226E-02	9.962271E-03	7.100937E-04
8.020249E 00	1.878451E 01	9.909690E-03	2.999489E-02	9.616482E-03	6.973107E-04
8.056527E 00	1.969758E 01	9.505358E-03	2.630742E-02	9.250290E-03	6.803254E-04
8.122704E 00	2.060574E 01	9.505549E-03	2.466803E-02	8.882461E-03	6.676102E-04
8.124196E 00	2.151614E 01	3.625286E-03	1.822741E-02	8.481242E-03	6.426800E-04
7.951445E 00	2.244760E 01	6.091743E-06	1.910850E-04	8.046777E-03	5.871777E-04
7.920021E 00	2.338291E 01	-0.	4.681418E-10	7.602204E-03	5.529851E-04
1.583000E 01	2.431823E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	2.525355E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	2.618887E 01	-0.	0.	6.153750E-04	4.999999E-05
1.583000E 01	2.712418E 01	-0.	0.	6.153750E-04	4.999999E-05
1.583000E 01	2.805950E 01	-0.	0.	6.153750E-04	4.999999E-05
1.583000E 01	2.983168E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	3.160386E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	3.337602E 01	-0.	0.	6.153750E-04	4.999998E-05

1.582999E 01	3.514820E 01	-0.	0.	6.153750E-04	4.999997E-05
1.582999E 01	3.692038E 01	-0.	0.	6.153750E-04	4.999997E-05
1.583000E 01	3.869256E 01	-0.	0.	6.153750E-04	4.999999E-05
1.582999E 01	4.046474E 01	-0.	0.	6.153750E-04	4.999998E-05
1.582999E 01	4.223692E 01	-0.	0.	6.153750E-04	4.999997E-05
1.582999E 01	4.400910E 01	0.	0.	6.153750E-04	4.999997E-05

GENEVE 10 RERUN MARCH 20 1959

TIME	QP	POWER	ALPHA	DELT	W
2.955000E 02	7.079975E 03	4.484325E 01	3.829388E-03	5.000000E-01	3.101643E-02
2.960000E 02	7.102438E 03	4.492919E 01	3.373051E-03	5.000000E-01	2.742106E-02
2.965000E 02	7.124940E 03	4.500503E 01	2.902788E-03	5.000000E-01	3.258085E-02
2.970000E 02	7.147474E 03	4.507040E 01	2.416258E-03	5.000000E-01	3.735047E-02
2.975000E 02	7.170036E 03	4.512488E 01	1.913964E-03	5.000000E-01	4.068206E-02
2.980000E 02	7.192619E 03	4.516808E 01	1.394506E-03	5.000000E-01	4.232702E-02
2.985000E 02	7.215218E 03	4.519958E 01	8.567256E-04	5.000000E-01	4.214406E-02
2.990000E 02	7.237827E 03	4.521895E 01	3.018303E-04	5.000000E-01	4.009234E-02
2.995000E 02	7.260439E 03	4.522577E 01	-2.711039E-04	5.000000E-01	3.624670E-02
3.000000E 02	7.283048E 03	4.521964E 01	-2.711039E-04	5.000000E-01	3.206001E-02

TOTAL ENERGY	KINETIC ENERGY	CHECK	ERROR LOCAL
7.283048E 03	2.097754E 01	-4.672505E-04	9.519164E-06

DENSITY	RADIUS	VELOCITY	PRESSURE	INTERNAL ENERGY	TEMPERATURE
7.401031E 00	9.566864E-01	1.424552E-03	5.353012E-02	1.389095E-02	8.457175E-04
7.393915E 00	1.913910E 00	1.696909E-03	5.248137E-02	1.386256E-02	8.426854E-04
7.404357E 00	2.869995E 00	2.315887E-03	5.273834E-02	1.382527E-02	8.425310E-04
7.412364E 00	3.825582E 00	3.379210E-03	5.234674E-02	1.376084E-02	8.402985E-04
7.425086E 00	4.780163E 00	3.948628E-03	5.203104E-02	1.367740E-02	8.378522E-04
7.441152E 00	5.733496E 00	4.823062E-03	5.162633E-02	1.357202E-02	8.347411E-04
7.457356E 00	6.685685E 00	5.528755E-03	5.086122E-02	1.344403E-02	8.303217E-04
7.481923E 00	7.635847E 00	6.323115E-03	5.048868E-02	1.329935E-02	8.264491E-04
7.504809E 00	8.584374E 00	6.975247E-03	4.957673E-02	1.313071E-02	8.208129E-04
7.534809E 00	9.530544E 00	7.631582E-03	4.893916E-02	1.294487E-02	8.154280E-04
7.565585E 00	1.047445E 01	8.233802E-03	4.797767E-02	1.273753E-02	8.087998E-04
7.600967E 00	1.141568E 01	8.869514E-03	4.706591E-02	1.251226E-02	8.018751E-04
7.636243E 00	1.235442E 01	9.463822E-03	4.575969E-02	1.226570E-02	7.935446E-04
7.676543E 00	1.329021E 01	1.002161E-02	4.453489E-02	1.200253E-02	7.849881E-04
7.720246E 00	1.422281E 01	1.030141E-02	4.324137E-02	1.172205E-02	7.758339E-04
7.769700E 00	1.515174E 01	1.072612E-02	4.207328E-02	1.142572E-02	7.665367E-04
7.814853E 00	1.607768E 01	1.120278E-02	4.015730E-02	1.110779E-02	7.549974E-04
7.865319E 00	1.700015E 01	1.130235E-02	3.835686E-02	1.077639E-02	7.433248E-04
7.922419E 00	1.791856E 01	1.149764E-02	3.676734E-02	1.043189E-02	7.317254E-04
7.973327E 00	1.883378E 01	1.156862E-02	3.429114E-02	1.006687E-02	7.175805E-04
8.037897E 00	1.974442E 01	1.140977E-02	3.262382E-02	9.695081E-03	7.049308E-04
8.077105E 00	2.065343E 01	1.096143E-02	2.858021E-02	9.296469E-03	6.863642E-04
8.148068E 00	2.155735E 01	1.197423E-02	2.671503E-02	8.896784E-03	6.723445E-04
8.215868E 00	2.245678E 01	6.082644E-03	2.466825E-02	8.480696E-03	6.564321E-04
7.995130E 00	2.338293E 01	2.579092E-05	5.399298E-04	7.963973E-03	5.891142E-04
1.583035E 01	2.431823E 01	1.911376E-07	1.040176E-05	6.153750E-04	5.000154E-05

1.583000E 01	2.525355E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	2.618887E 01	-0.	0.	6.153750E-04	4.999999E-05
1.583000E 01	2.712418E 01	-0.	0.	6.153750E-04	4.999999E-05
1.583000E 01	2.805950E 01	-0.	0.	6.153750E-04	4.999999E-05
1.583000E 01	2.983168E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	3.160386E 01	-0.	0.	6.153750E-04	4.999998E-05
1.583000E 01	3.337602E 01	-0.	0.	6.153750E-04	4.999998E-05
1.582999E 01	3.514820E 01	-0.	0.	6.153750E-04	4.999997E-05
1.582999E 01	3.692038E 01	-0.	0.	6.153750E-04	4.999997E-05
1.583000E 01	3.869256E 01	-0.	0.	6.153750E-04	4.999999E-05
1.582999E 01	4.046474E 01	-0.	0.	6.153750E-04	4.999998E-05
1.582999E 01	4.223692E 01	-0.	0.	6.153750E-04	4.999997E-05
1.582999E 01	4.400910E 01	0.	0.	6.153750E-04	4.999997E-05

GENEVE 10 RERUN MARCH 20 1959

TIME	QP	POWER	ALPHA	DELT	W
3.000000E 02	7.283048E 03	4.521964E 01	-8.627618E-04	5.000000E-01	3.206001E-02
3.005000E 02	7.305648E 03	4.520014E 01	-1.472876E-03	5.000000E-01	3.893714E-02
3.010000E 02	7.328230E 03	4.516687E 01	-2.102314E-03	5.000000E-01	4.515666E-02
3.015000E 02	7.350790E 03	4.511941E 01	-2.750493E-03	5.000000E-01	4.991508E-02
3.020000E 02	7.373317E 03	4.505741E 01	-3.418249E-03	5.000000E-01	5.291061E-02
3.025000E 02	7.395807E 03	4.498046E 01	-4.103592E-03	5.000000E-01	5.394539E-02
3.030000E 02	7.418250E 03	4.488827E 01	-4.807859E-03	5.000000E-01	5.293765E-02
3.035000E 02	7.440639E 03	4.478049E 01	-5.530758E-03	5.000000E-01	4.991733E-02
3.040000E 02	7.462967E 03	4.465683E 01	-6.271793E-03	5.000000E-01	4.506278E-02
3.045000E 02	7.485225E 03	4.451701E 01	-7.031903E-03	5.000000E-01	3.865892E-02
3.050000E 02	7.507404E 03	4.436076E 01	-7.807106E-03	5.000000E-01	3.107027E-02
3.055000E 02	7.529497E 03	4.418793E 01	-8.601431E-03	5.000000E-01	3.322387E-02
3.060000E 02	7.551496E 03	4.399830E 01	-9.411856E-03	5.000000E-01	3.717559E-02
3.065000E 02	7.573391E 03	4.379174E 01	-1.023865E-02	5.000000E-01	4.049618E-02
3.070000E 02	7.595174E 03	4.356812E 01	-1.108231E-02	5.000000E-01	4.301705E-02
3.075000E 02	7.616837E 03	4.332737E 01	-1.194028E-02	5.000000E-01	4.459131E-02
3.080000E 02	7.638371E 03	4.306947E 01	-1.281443E-02	5.000000E-01	4.512015E-02
3.085000E 02	7.659767E 03	4.279440E 01	-1.370453E-02	5.000000E-01	4.455614E-02
3.090000E 02	7.681017E 03	4.250217E 01	-1.461057E-02	5.000000E-01	4.290867E-02
3.095000E 02	7.702113E 03	4.219281E 01	-1.553092E-02	5.000000E-01	4.024723E-02
3.100000E 02	7.723045E 03	4.186643E 01	-1.646695E-02	5.000000E-01	3.667578E-02
3.105000E 02	7.743806E 03	4.152314E 01	-1.741867E-02	5.000000E-01	3.235808E-02
3.110000E 02	7.764387E 03	4.116307E 01	-1.838352E-02	5.000000E-01	3.244738E-02
3.115000E 02	7.784779E 03	4.078644E 01	-1.936288E-02	5.000000E-01	3.186726E-02
3.120000E 02	7.804976E 03	4.039348E 01	-2.035465E-02	5.000000E-01	3.182550E-02
3.125000E 02	7.824967E 03	3.998446E 01	-2.136045E-02	5.000000E-01	3.300821E-02
3.130000E 02	7.844746E 03	3.955969E 01	-2.238026E-02	5.000000E-01	3.374180E-02
3.135000E 02	7.864305E 03	3.911948E 01	-2.341171E-02	5.000000E-01	3.399938E-02
3.140000E 02	7.883636E 03	3.866423E 01	-2.445683E-02	5.000000E-01	3.377077E-02
3.145000E 02	7.902733E 03	3.819430E 01	-2.551348E-02	5.000000E-01	3.305616E-02
3.150000E 02	7.921587E 03	3.771016E 01	-2.658201E-02	5.000000E-01	3.185945E-02
3.155000E 02	7.940192E 03	3.721227E 01	-2.766188E-02	5.000000E-01	3.021179E-02
3.160000E 02	7.958542E 03	3.670113E 01	-2.875345E-02	5.000000E-01	2.814415E-02
3.165000E 02	7.976630E 03	3.617727E 01	-2.985618E-02	5.000000E-01	2.663193E-02
3.170000E 02	7.994450E 03	3.564122E 01	-3.096927E-02	5.000000E-01	2.630324E-02
3.175000E 02	8.011996E 03	3.509358E 01	-3.209406E-02	5.000000E-01	2.788240E-02
3.180000E 02	8.029263E 03	3.453493E 01	-3.322723E-02	5.000000E-01	2.865106E-02
3.185000E 02	8.046245E 03	3.396592E 01	-3.437060E-02	5.000000E-01	2.894692E-02
3.190000E 02	8.062937E 03	3.338719E 01	-3.552483E-02	5.000000E-01	2.985070E-02
DUMP 3					
3.195000E 02	8.079336E 03	3.279939E 01	-3.668805E-02	5.000000E-01	3.176535E-02

3.200000E 02	8.095437E 03	3.220320E 01	-3.786118E-02	5.000000E-01	3.297700E-02
3.205000E 02	8.111236E 03	3.159931E 01	-3.904422E-02	5.000000E-01	3.336086E-02
3.210000E 02	8.126729E 03	3.098841E 01	-4.023603E-02	5.000000E-01	3.287899E-02
3.220000E 02	8.156796E 03	2.976631E 01	-4.264045E-02	5.000000E-01	2.962761E-02
3.230000E 02	8.185626E 03	2.852374E 01	-4.508476E-02	5.000000E-01	2.618562E-02
3.240000E 02	8.213201E 03	2.726631E 01	-4.756128E-02	5.000000E-01	2.910206E-02
3.250000E 02	8.239512E 03	2.599985E 01	-5.006933E-02	5.000000E-01	3.343638E-02
3.260000E 02	8.264554E 03	2.473011E 01	-5.260200E-02	5.000000E-01	3.227879E-02
3.270000E 02	8.288328E 03	2.346287E 01	-5.515871E-02	5.000000E-01	2.701019E-02
3.280000E 02	8.310841E 03	2.220374E 01	-5.773410E-02	5.000000E-01	3.003798E-02
3.290000E 02	8.332104E 03	2.095813E 01	-6.032818E-02	5.000000E-01	3.424720E-02
3.300000E 02	8.352136E 03	1.973115E 01	-6.293555E-02	5.000000E-01	3.321113E-02
3.310000E 02	8.370958E 03	1.852762E 01	-6.555734E-02	5.000000E-01	3.166332E-02
3.320000E 02	8.388597E 03	1.735196E 01	-6.818837E-02	5.000000E-01	3.170859E-02
3.330000E 02	8.405085E 03	1.620820E 01	-7.082857E-02	5.000000E-01	3.451502E-02
3.340000E 02	8.420455E 03	1.509991E 01	-7.347678E-02	5.000000E-01	3.247912E-02
3.350000E 02	8.434747E 03	1.403019E 01	-7.612848E-02	5.000000E-01	2.951676E-02
3.360000E 02	8.447999E 03	1.300174E 01	-7.878513E-02	5.000000E-01	3.324070E-02
3.370000E 02	8.460255E 03	1.201671E 01	-8.144062E-02	5.000000E-01	3.413450E-02
3.380000E 02	8.471561E 03	1.107685E 01	-8.409400E-02	5.000000E-01	3.229823E-02
3.390000E 02	8.481961E 03	1.018345E 01	-8.674214E-02	5.000000E-01	3.322019E-02
3.400000E 02	8.491504E 03	9.337340E 00	-8.938380E-02	5.000000E-01	3.429283E-02
3.415000E 02	8.504318E 03	8.165727E 00	-9.332411E-02	5.000000E-01	3.088998E-02
3.430000E 02	8.515481E 03	7.099040E 00	-9.723935E-02	5.000000E-01	3.361961E-02
3.445000E 02	8.525148E 03	6.135555E 00	-1.011212E-01	5.000000E-01	3.313833E-02
3.460000E 02	8.533471E 03	5.272048E 00	-1.049645E-01	5.000000E-01	3.209773E-02
3.475000E 02	8.540595E 03	4.504028E 00	-1.087615E-01	5.000000E-01	3.437118E-02
3.490000E 02	8.546659E 03	3.826038E 00	-1.125067E-01	5.000000E-01	3.621689E-02
3.500000E 02	8.550175E 03	3.418915E 00	-1.125067E-01	5.000000E-01	3.528061E-02

TOTAL ENERGY	KINETIC ENERGY	CHECK	ERROR LOCAL
8.550175E 03	1.368729E 02	-5.476842E-04	9.557465E-06

DENSITY	RADIUS	VELOCITY	PRESSURE	INTERNAL ENERGY	TEMPERATURE
6.314549E 00	1.008679E 00	1.903546E-03	2.256632E-04	1.716892E-02	7.663890E-04
6.331030E 00	2.015825E 00	2.738945E-03	1.769532E-03	1.714454E-02	7.702328E-04
6.332251E 00	3.023369E 00	3.405926E-03	1.072511E-03	1.709448E-02	7.676037E-04
6.348160E 00	4.029092E 00	4.107742E-03	1.676030E-03	1.701922E-02	7.681297E-04
6.367569E 00	5.032946E 00	5.150840E-03	2.247181E-03	1.691839E-02	7.681782E-04
6.378636E 00	6.036252E 00	6.556652E-03	1.397774E-03	1.679133E-02	7.639860E-04
6.405681E 00	7.036680E 00	7.342406E-03	1.987394E-03	1.664034E-02	7.633132E-04
6.442238E 00	8.033304E 00	7.712783E-03	3.203344E-03	1.646434E-02	7.639081E-04
6.491994E 00	9.024756E 00	7.854918E-03	5.464867E-03	1.626532E-02	7.668960E-04

6.555941E 00	1.000969E 01	7.335353E-03	8.817092E-03	1.604428E-02	7.723368E-04
6.632662E 00	1.098707E 01	7.141673E-03	1.304636E-02	1.580372E-02	7.796092E-04
6.689918E 00	1.196023E 01	8.478125E-03	1.456976E-02	1.553414E-02	7.791726E-04
6.724833E 00	1.293225E 01	1.074075E-02	1.315776E-02	1.523308E-02	7.704995E-04
6.754738E 00	1.390344E 01	1.233564E-02	1.077600E-02	1.490775E-02	7.588608E-04
6.836493E 00	1.486659E 01	1.103045E-02	1.342873E-02	1.457292E-02	7.599522E-04
6.960171E 00	1.581698E 01	1.056044E-02	1.981119E-02	1.423097E-02	7.701123E-04
7.001918E 00	1.676634E 01	1.437733E-02	1.717220E-02	1.383640E-02	7.563279E-04
7.028634E 00	1.771623E 01	1.493643E-02	1.264631E-02	1.341849E-02	7.373183E-04
7.193249E 00	1.864888E 01	1.161766E-02	2.124285E-02	1.302402E-02	7.510082E-04
7.318319E 00	1.957093E 01	1.377292E-02	2.504398E-02	1.259762E-02	7.519524E-04
7.349396E 00	2.049433E 01	1.548974E-02	1.951535E-02	1.211210E-02	7.288918E-04
7.500106E 00	2.140441E 01	1.371949E-02	2.449901E-02	1.165500E-02	7.312261E-04
7.624422E 00	2.230530E 01	1.469176E-02	2.631066E-02	1.116626E-02	7.249193E-04
7.757402E 00	2.319662E 01	1.397264E-02	2.808407E-02	1.065590E-02	7.175677E-04
7.906766E 00	2.407719E 01	1.453332E-02	2.986557E-02	1.009694E-02	7.085549E-04
1.686310E 01	2.490974E 01	1.439552E-02	3.116328E-02	6.840935E-04	5.532360E-05
1.702260E 01	2.574283E 01	1.413444E-02	3.583450E-02	6.980878E-04	5.564177E-05
1.693770E 01	2.658759E 01	1.493270E-02	3.326008E-02	6.863924E-04	5.515595E-05
1.696021E 01	2.743772E 01	1.574984E-02	3.391666E-02	6.882650E-04	5.519161E-05
1.683841E 01	2.829966E 01	1.295722E-02	3.039186E-02	6.744950E-04	5.466222E-05
1.703349E 01	2.992774E 01	1.119276E-02	3.618852E-02	7.004454E-04	5.576919E-05
1.647310E 01	3.162433E 01	3.870941E-03	2.070090E-02	6.408979E-04	5.299972E-05
1.598175E 01	3.337844E 01	6.223858E-04	4.838512E-03	6.168054E-04	5.068078E-05
1.584885E 01	3.514838E 01	5.822392E-05	5.738734E-04	6.153963E-04	5.008409E-05
1.583147E 01	3.692039E 01	3.547075E-06	4.418609E-05	6.153751E-04	5.000656E-05
1.583004E 01	3.869256E 01	3.465208E-08	1.259382E-06	6.153750E-04	5.000019E-05
1.582999E 01	4.046474E 01	-0.	0.	6.153750E-04	4.999998E-05
1.582999E 01	4.223692E 01	-0.	0.	6.153750E-04	4.999997E-05
1.582999E 01	4.400910E 01	0.	0.	6.153750E-04	4.999997E-05

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TIME	QP	POWER	ALPHA	DELT	W
3.505000E 02	8.551790E 03	3.231899E 00	-1.161970E-01	5.000000E-01	3.434920E-02
DUMP 4					
3.520000E 02	8.556109E 03	2.714952E 00	-1.198263E-01	5.000000E-01	3.335743E-02
3.535000E 02	8.559723E 03	2.268310E 00	-1.233918E-01	5.000000E-01	3.362587E-02
3.555000E 02	8.563617E 03	1.772253E 00	-1.280392E-01	5.000000E-01	3.309837E-02
3.575000E 02	8.566642E 03	1.371868E 00	-1.325590E-01	5.000000E-01	3.361232E-02
3.595000E 02	8.568970E 03	1.052381E 00	-1.369468E-01	5.000000E-01	3.279974E-02
POWER SMALL NS4 UP					
3.615000E 02	8.570745E 03	8.002442E-01	-1.412027E-01	5.000000E-01	3.265014E-02
3.660000E 02	8.573310E 03	4.239031E-01	-1.503135E-01	5.000000E-01	3.405175E-02
3.710000E 02	8.574737E 03	1.999240E-01	-1.597197E-01	5.000000E-01	3.279529E-02
3.765000E 02	8.575432E 03	8.305300E-02	-1.691910E-01	5.000000E-01	3.154983E-02
3.825000E 02	8.575722E 03	3.009422E-02	-1.784988E-01	5.000000E-01	3.112533E-02
DUMP 5					
3.890000E 02	8.575824E 03	9.431836E-03	-1.876245E-01	5.000000E-01	3.067695E-02
3.960000E 02	8.575850E 03	2.536333E-03	-1.967015E-01	5.000000E-01	3.020719E-02
4.000000E 02	8.575852E 03	1.154784E-03	-1.967015E-01	5.000000E-01	2.994476E-02

TOTAL ENERGY	KINETIC ENERGY	CHECK	ERROR LOCAL
8.575852E 03	1.414158E 02	-5.208532E-04	2.470845E-05

DENSITY	RADIUS	VELOCITY	PRESSURE	INTERNAL ENERGY	TEMPERATURE
4.917073E 00	1.096389E 00	1.753956E-03	0.	1.725101E-02	4.417189E-05
5.205647E 00	2.156736E 00	2.818523E-03	0.	1.722617E-02	2.572979E-04
5.499321E 00	3.188685E 00	3.305828E-03	0.	1.717615E-02	4.281693E-04
5.537857E 00	4.230596E 00	4.029824E-03	0.	1.710035E-02	4.433258E-04
5.419751E 00	5.297382E 00	5.289495E-03	0.	1.699883E-02	3.721420E-04
5.439850E 00	6.358381E 00	6.441835E-03	0.	1.687154E-02	3.745921E-04
6.025999E 00	7.328801E 00	5.509934E-03	0.	1.671965E-02	6.370937E-04
6.094808E 00	8.307465E 00	5.501657E-03	0.	1.654206E-02	6.518982E-04
6.331326E 00	9.265503E 00	4.705751E-03	0.	1.633964E-02	7.214578E-04
5.812325E 00	1.031525E 01	6.145067E-03	0.	1.611205E-02	5.094094E-04
5.605493E 00	1.139668E 01	8.310706E-03	0.	1.586059E-02	3.934048E-04
6.437482E 00	1.234178E 01	7.164884E-03	0.	1.558564E-02	7.089424E-04
6.060120E 00	1.335402E 01	8.256142E-03	0.	1.528728E-02	5.586441E-04
6.334372E 00	1.432737E 01	7.440804E-03	0.	1.496597E-02	6.371157E-04
6.329760E 00	1.530778E 01	8.697620E-03	0.	1.462263E-02	6.138243E-04
6.527848E 00	1.626487E 01	7.460192E-03	8.721617E-07	1.425737E-02	6.543277E-04
6.711025E 00	1.720369E 01	6.942592E-03	0.	1.387102E-02	6.834968E-04
6.821918E 00	1.813551E 01	6.589408E-03	0.	1.346437E-02	6.883366E-04
6.773332E 00	1.908118E 01	8.033070E-03	0.	1.303804E-02	6.486851E-04

6.977439E 00	2.000584E 01	7.377634E-03	0.	1.259182E-02	6.739882E-04
7.033787E 00	2.093008E 01	4.673943E-03	6.565979E-05	1.212834E-02	6.589158E-04
7.226250E 00	2.183670E 01	7.127221E-03	6.102771E-04	1.164701E-02	6.737058E-04
7.305969E 00	2.274062E 01	5.481286E-03	1.880346E-05	1.114650E-02	6.599739E-04
7.365635E 00	2.364396E 01	6.677044E-03	0.	1.062398E-02	6.399492E-04
7.515942E 00	2.453581E 01	6.270953E-03	0.	1.005223E-02	6.348003E-04
1.574286E 01	2.539423E 01	4.572521E-03	5.531476E-05	6.246356E-04	5.031701E-05
1.593890E 01	2.625012E 01	5.868169E-03	3.378190E-03	6.212036E-04	5.089614E-05
1.586963E 01	2.711704E 01	5.013392E-03	1.277981E-03	6.191517E-04	5.047225E-05
1.597222E 01	2.798483E 01	6.122503E-03	4.330344E-03	6.196177E-04	5.087734E-05
1.598912E 01	2.885760E 01	6.870994E-03	4.837479E-03	6.199504E-04	5.095500E-05
1.619101E 01	3.050550E 01	7.821550E-03	1.095472E-02	6.290912E-04	5.209313E-05
1.637874E 01	3.215221E 01	9.812453E-03	1.652120E-02	6.362296E-04	5.271491E-05
1.654083E 01	3.379871E 01	9.618474E-03	2.135148E-02	6.464864E-04	5.333774E-05
1.660374E 01	3.545305E 01	1.090850E-02	2.322140E-02	6.509714E-04	5.356141E-05
1.681300E 01	3.709948E 01	1.111459E-02	2.947552E-02	6.702914E-04	5.443109E-05
1.668047E 01	3.876998E 01	7.408754E-03	2.577956E-02	6.569390E-04	5.383090E-05
1.628444E 01	4.048833E 01	3.136491E-03	1.409954E-02	6.276976E-04	5.204429E-05
1.598472E 01	4.224215E 01	8.856262E-04	4.775890E-03	6.168221E-04	5.069100E-05
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 $\frac{\ddot{\rho}}{\rho}$ 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

$$\frac{\frac{1}{2} \ddot{\rho} (\Delta t)^2}{\rho_{\text{initial}}} > OK_1$$

N_{S_4} is modified.

Equation 14 from Appendix C of reference 1 provides the relation

$$\begin{aligned} \ddot{\rho} &= \frac{-5}{2.54} \frac{\sqrt{q}}{b} \int \ddot{u} \left(\frac{d\phi}{dr} \right)^2 r dr \\ &= + \frac{5}{2.54} \frac{\sqrt{q}}{b} \int \left(\frac{1}{s} \frac{\partial p}{\partial r} \right) \left(- \frac{2qr}{b^2} \right)^2 r dr \\ &= \frac{5}{2.54} \frac{1}{s} \left(\frac{\sqrt{q}}{b} \right)^5 [pr^3 - p \cdot 3r^2 dr]_0^\infty \\ &= - \frac{20}{2.54} \frac{3}{s} \left(\frac{\sqrt{q}}{b} \right)^5 \frac{1}{4\pi} \int p r^2 dr \cdot 4\pi \\ &= \frac{-60}{10.16\pi} \frac{1}{s} \left(\frac{\sqrt{q}}{b} \right)^5 \int p dV. \end{aligned}$$

where

ϕ 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

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

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
 α_{max} = maximum alpha anticipated, $\delta k/\mu \text{ sec}$
 s = core density, grams/cm^3
 ℓ = prompt neutron lifetime, $\mu \text{ sec}$

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, Δt . 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 Δt , 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.

$t - 1/2 \Delta t$	(or $n \Delta t$)	$t + 1/2 \Delta t$	$t + \Delta t$	$t + 3/2 \Delta t$	$t + 2 \Delta t$
$U^{n-1/2}$	$R(I)^n$	$U^{n+1/2}$	$R(I)^{n+1}$	$U^{n+3/2}$	$R(I)^{n+2}$
$POWER^{n-1/2}$	p^n	$POWER^{n+1/2}$	p^{n+1}	$POWER^{n+3/2}$	p^{n+2}
	ΔQ^n		ΔQ^{n+1}		ΔQ^{n+2}
	E_{internal}^n		$E_{\text{internal}}^{n+1}$		$E_{\text{internal}}^{n+2}$
	α^n		α^{n+1}		α^{n+2}

The time chart helps to explain the steps taken when Δt 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 Δt . 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 Δt , while the time interval between $U^{n+1/2}$ and $U^{n+3/2}$ is $3/4$ the old Δt . On the other hand, on a doubling of Δt , $\Delta t'$ 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 Δt , 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, ρ 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 γ 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, Δt 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

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

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

$$\begin{aligned}\left(\frac{\partial E}{\partial v}\right)_\theta &= \theta \left(\frac{\partial p}{\partial \theta}\right) - p \\ &= -\frac{\alpha}{v} - \tau \quad \text{for the assumed equation of state.}\end{aligned}$$

Integrating, one gets

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

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

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

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

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

then

$$E_0 = \left[\frac{\tau}{\rho} - \alpha \ln \rho \right]_{t=0} \quad .$$

The so-called error local is obtained by comparing the running E_{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 ΔE 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,⁽³⁾ $p = (\gamma - 1)\rho E_{\text{int}}$, 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.⁽³⁾ 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 10000₈ through 17777₈ 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 140₈ through 165₈ 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 266₈:
 - 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 270₈, 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:

- 245₈ CKS error in reading tape #5. Press start to try again.
- 250₈ CKS error in writing or reading tape #3. Press start to try reading tape #3 again. If stop 250₈ reoccurs, the error was in writing, not reading tape #3. Press start again to recopy tape #5 onto tape #3.
- 261₈ 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	ORG 128	
00200	0 76300 0 00043	LLS 35	
00201	0 73400 1 00000	PAX 0, 1	No. of Records on Tape 3
00202	-2 00000 1 00205	TNX 133, 1, 0	goes to A-Reg.
00203	0 76200 0 00223	RTB 3	
00204	2 00001 1 00203	TIX 131, 1, 1	
00205	-0 73400 1 00000	PDX 0, 1	No. of Records on Tape 5
00206	0 76200 0 00225	RTB 5	goes to A-Reg.
00207	-0 53400 2 00265	LXD 181, 2	
00210	-0 75400 0 00000	PXD 0	
00211	-0 70000 2 00000	CAD 0, 2	
00212	2 00001 2 00211	TIX 137, 2, 1	
00213	0 60200 0 00244	SLW 164	
00214	0 50000 0 00244	CLA 164	
00215	0 70000 0 00244	CPY 164	
00216	0 40200 0 00244	SUB 164	
00217	-0 10000 0 00245	TNZ 165	
00220	0 76600 0 00223	WTB 3	
00221	-0 53400 2 00265	LXD 181, 2	
00222	-0 75400 0 00000	PXD 0, 0	
00223	-0 70000 2 00000	CAD 0, 2	
00224	2 00001 2 00223	TIX 147, 2, 1	
00225	0 60200 0 00244	SLW 164	
00226	0 70000 0 00244	CPY 164	
00227	0 76400 0 00203	BST 3	
00230	0 76200 0 00223	RTB 3	Read Tape 3 again
00231	-0 53400 2 00265	LXD 181, 2	to check copying.
00232	-0 75400 0 00000	PXD 0, 0	
00233	-0 70000 2 00000	CAD 0, 2	
00234	2 00001 2 00233	TIX 155, 2, 1	
00235	0 60200 0 00244	SLW 164	
00236	0 50000 0 00244	CLA 164	
00237	0 70000 0 00244	CPY 164	
00240	0 40200 0 00244	SUB 164	
00241	-0 10000 0 00250	TNZ 168	
00242	2 00001 1 00206	TIX 134, 1, 1	
00243	0 02000 0 00270	TRA 184	
00244	0 00000 0 00000	HTR 0	
00245	0 42000 0 00000	HPR 0	Tape 5 read fail -
00246	0 76400 0 00205	BST 5	try again
00247	0 02000 0 00206	TRA 134	
00250	0 42000 0 00000	HPR 0	Tape 3 read or write
00251	-0 76000 0 00141	SLT 1	fail - try again
00252	0 02000 0 00254	TRA 172	
00253	0 02000 0 00256	TRA 174	
00254	0 76000 0 00141	SLN 1	
00255	0 02000 0 00227	TRA 151	
00256	0 76000 0 00141	SLN 1	
00257	-0 76000 0 00142	SLT 2	
00260	0 02000 0 00262	TRA 178	
00261	0 42000 0 00000	HPR 0	2nd Tape 3 write fail
00262	0 76000 0 00142	SLN 2	
00263	0 76400 0 00203	BST 3	
00264	0 02000 0 00246	TRA 166	
00265	0 10000 0 00000	TZE 0	
00266	0 42000 0 00000	HPR 0	
00267	0 02000 0 00200	TRA 128	
00270	0 42000 0 00000	HPR 0	END
00271	0 02000 0 00200	TRA 128	
	00266	END 182	

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_n Approximations, LA-1891.
6. Carlson, B. G., The S_n 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_n 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.

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