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ASPRIN - A COMPUTER CODE
FOR PREDICTING REACTOR VESSEL RESPONSE
TO HYPOTHETICAL MAXIMUM ACCIDENTS
ON FAST REACTORS

December 1969

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ASPRIN - A COMPUTER CODE FOR PREDICTING
REACTOR VESSEL RESPONSE TO
HYPOTHETICAL MAXIMUM ACCIDENTS ON FAST REACTORS

By

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FFTF Division

December 1969

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ABSTRACT

Current nuclear reactor design procedure postulates a maximum reactor excursion in order to test containment. The maximum cover loadings are assumed to result from a coolant slug propelled against the cover by blast pressure in the core region. This report describes a method for predicting these head loadings.

The analytical method utilizes combinations of 1 dimensional Newtonian models in radial and axial directions to simulate the reactor, cover, and holddown structure. Wave phenomena are not considered and deformations are assumed to occur from quasi-steady pressures. The equations have been programmed and output information consists of gross vessel and cover displacements, velocities, stresses, strains, and the blast energy distribution.

The report includes an example case and demonstrates the effect of vessel parameters on the cover loading problem.

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1.0 INTRODUCTION

Fast reactor safety analysis practice currently requires the postulation of nuclear excursions terminating in disassembly of the reactor core. The particular hypothetical accident generating the maximum energy release, identified in this analysis as the "Design Basis Accident" (DBA), provides the basis for the plant containment design. The first barrier for containment of such an energy burst is the reactor vessel.

The purpose of this report, therefore, is to present a simplified method for calculating the vessel response to a DBA and a basis for determining loadings on the vessel cover and subsequent containment barriers. Programmed under the computer code name of ASPRIN (A Simulated Propellant Reaction Incident), the method serves as a short running time design tool for investigating effects of reactor design changes and requirements. Details of code operation and code listings are contained in the Appendices.

2.0 SUMMARY AND CONCLUSIONS

The ASPRIN computer code has been described in its present state of development. While the present code does not represent a final version, it provides an adequate means to show overall reactor vessel response and cover response to coolant slug impact. The code will be used for reactor safety analysis to verify the containment system.

Calculated parameters which are useful for reactor design are velocity and displacement as a function of time, for the coolant slug, upper and lower vessel walls, stresses, strains,

and strain rates for the vessel walls and cover holddown bolts. Use of these results in establishing a preferential mode of failure would assist in solving the overall containment problem.

The conservatism of the model was verified by showing the model overpredicts the head loadings that occurred during the SL-1 reactor accident.

The utility of the program was demonstrated by describing the results for a particular reactor design and then showing the effect of varying a single parameter. For example, the energy deposited into the cover was found to increase with larger vessel wall thickness and to decrease with larger cover mass.

3.0 GENERAL BACKGROUND

The energy production is normally predicted according to a modified Bethe-Tait analysis in which the maximum available work energy is obtained by expanding sodium and fuel vapor products to a pressure of 1 atm.^{(1)*} Because of the hypothetical nature of the DBA, energy release rates cannot be well characterized. However, the driving mechanisms responsible for material damage may be conveniently represented by upper and lower limits. The upper limit may be represented by a TNT explosion with an equivalent energy. Although very high pressures and high local deformations can be produced during very short time durations, the impulses are usually too transient to move such massive objects as the vessel cover. The lower limit may be represented by a propellant type of energy release. The medium pressures and medium deformations thus produced and sustained over a longer time duration can be quite effective for moving massive objects.

* Number refers to reference at end of report.

The TNT type explosion, for example, is more likely to rupture the vessel walls, while propellant type explosion will direct the energy into the coolant over the core and drive a coolant slug up against the cover. The coolant slug energy, sufficient to distort the upper vessel region and heavily pressure-load the cover, must be accorded design consideration. Therefore, to find the maximum energies dissipated in the upper vessel region for DBA purposes, a propellant type reaction allowing substantial gas gaps between the top of the coolant and the vessel cover should be considered. This approach would permit a large fraction of the DBA energy transferred to the accelerated coolant slug to be distributed during the impact period.

4.0 ASSUMPTIONS AND FEATURES IN MODEL

The analytical model consists of a gaseous bubble in the core region acting upon and moving the surrounding structures and the coolant slug. Their movement is considered primarily by Newtonian type mechanisms rather than by compressible wave action. A schematic representation of the model and features is shown in Figure 1. Application of the model thus is limited to time periods greater than several wave reflections and pressure regimes where the coolant compresses less than 2 or 3%. Material laws are considered in the structures resistance to motion.

4.1 GAS BUBBLE MODEL

The gas bubble provides the driving force for all the damage mechanisms. At present, the bubble is defined by specifying the peak pressure and the expansion work energy. The computer calculates the required initial volume to satisfy these conditions as follows:

FIGURE 1. ASPRIN Analytical Mode2

$$V_m = \frac{\text{Work}}{P_m \ln P_m / P_o}$$

where V_m = Reference volume of gas bubble

Work = DBA work energy when expanded to pressure of 1 atm

P_m = Maximum pressure level of DBA

P_o = 1 atm (Reference expansion limit).

As the reactor vessel deforms and the coolant slug moves, the gas bubble expands isothermally (Figure 2).

$$P = \frac{P_m V_m}{V_m + \Delta V + A(X1 - Y3)}$$

where P = Gas bubble pressure

ΔV = Increase in volume from vessel expansion

A = Slug cross section area

$X1$ = Position coordinates of slug

$Y3$ = Position coordinates of lower vessel.

This technique originated from J. F. Proctor⁽²⁾ who found the height attained by the vessel cover after a TNT explosion to be predicted by an isothermal expansion of the TNT products. This expansion was also found by the author to reasonably approximate the expansion of a mixture of sodium and molten fuel while in complete thermal equilibrium. The error appeared to be less than 10% during acceleration of the coolant slug.

The isothermal gas bubble model, while adequate for DBA purposes, does require calculation of the available work energy prior to using the computer code. This model will be replaced at some later time by a molten fuel coolant mixing model capable of calculating the work energy based on the quantity of molten fuel available.

FIGURE 2. SL-1 Vessel Deformation Pattern

4.2 DYNAMIC MOTIONS

The gas bubble pressure acts over the core region to deform the vessel walls radially, and to accelerate the coolant slug upward and the vessel downward. A more thorough description of these motions is now presented:

A pressure delay time restraining the gas bubble pressure from acting on the vessel walls until the delay time is exceeded may be specified. This action allows the slug to be accelerated first and simulates a very rigid core structure serving to shield the wall from the pressure waves. The effective inertia of the wall, coolant, and radial shielding may be lumped together in a structure responding to the pressure in an assumed parabolic shape: (3)

$$\frac{d^2_{FB}}{dt^2} = \frac{K}{R_o^2 \gamma} \left[P'(t) - P'_S(FB) \right] (FB + 1/4)$$

where FB = Lower vessel inside radius/initial radius

t = Time

K = Strain hardening coefficient

Stress = K (Strain) ^{N}

γ = Effective material density

$$P'(t) = \frac{P(t) R_o}{K H_o} \text{ (Dimensionless)}$$

$$P'_S(FB) = \frac{P_S(R) R_o}{K H_o}$$

R_o = Initial vessel radius

R_1 = Maximum vessel radius

P = Pressure retaining ability of wall

H_o = Wall thickness,

In addition to the inertial effect, the wall motion is retarded by the tangential wall stresses which increase through

an exponential strain hardening law. If the wall strain exceeds 25%, the vessel is assumed to rupture and the gas bubble pressure is thus reduced to zero. Actually, stress concentrations caused by discontinuities in the vessel wall such as nozzles, together with the reduced ductility from neutron fluence, will cause failure before 25% strain. However, to maximize the cover loading and avoid the associated uncertainties, the strain limit as precedingly defined was used.

The downward acceleration of the reactor vessel by the gas bubble pressure may be expressed as

$$\frac{d^2 Y_3}{dt^2} = (-P A + R_3 A - M_2 G) / M_2$$

where $R_3 A$ = Force from longitudinal stress in vessel wall

G = Gravity

M_2 = Lower vessel mass.

The motion is restrained by the elastic-plastic deformation of the vessel walls with linear strain hardening and an elastic return. The upper vessel flange may be assumed to be connected rigidly to the building foundation or to the cover by bolts stronger than the vessel wall. This assumption allows for the possibility that the whole vessel may be lifted when the slug impacts the cover.

The coolant slug continues to be accelerated by a decreasing gas bubble pressure until it impacts with the vessel cover.

$$\frac{d^2 X_1}{dt^2} = \frac{P A}{M_3} - G$$

where M_3 = Mass of coolant in slug. At this point, the slug may have received a considerable portion of the gas bubble energy, and this energy must be conserved during the collision process. Elastic rebound of the slug is not allowed in the

model because (1) the energy would be included in recurring subsequent collisions, and (2) rebound implies movement of a pressure wave from the cover-coolant interface to the gas bubble and back, a process requiring several milliseconds. Analytical models indicate the pressure energy would be dissipated by this time.

A critical part of the analytical model is the slug impact period when kinetic energy of the slug is transferred to the cover and walls. While failure to consider wave motion during this period is particularly questionable, results may be checked by applying the code to the SL-1 accident (to be presented later) and by using a two-dimensional hydrodynamic code.⁽⁴⁾ The purpose of producing a conservative design code with fast running times was considered to warrant the use of approximate techniques. Further refinements in this area are expected in the future.

The impact pressure during the energy transfer process is not easily defined. The water hammer equations are not applicable since the vessel wall does not reach an equilibrium position during the times considered here. Therefore, an independent approach was tried.

The impact pressure was first assumed to be dependent on any increase in coolant density occurring during impact. The upper vessel was considered a fixed region where a coolant mass balance is performed. The mass flow into the region depends on the maximum slug velocity as shown in the following:

$$\frac{dM}{dt} = U_m A \rho_o$$

where $\frac{dM}{dt}$ = Mass flow into region

U_m = Maximum slug velocity

ρ_o = Initial coolant density.

The mass flow-out depends on upward cover movement and radial wall movement. It can be written as

$$\frac{dM}{dt} = \rho_o \frac{d(Vol)}{dt} + Vol \frac{d\rho}{dt}$$

where $\rho_o \frac{d(Vol)}{dt}$ = Mass out flow from region

$Vol \frac{d\rho}{dt}$ = Mass increase in region

ρ = Region density

Vol = Region volume.

Rearranging:

$$\frac{d\rho}{dt} = \frac{U_m A \rho_o}{Vol} - \frac{\rho_o}{Vol} \frac{d(Vol)}{dt}.$$

The rate of mass increase then determines the rate of impact pressure buildup which is integrated to obtain the value of impact pressure.

$$\frac{dP_I}{dt} = C^2 \frac{d\rho}{dt} \text{ and } Vol = A(TBDL)$$

$$\frac{dP_I}{dt} = C^2 \rho_o \left(\frac{U_m}{TBDL} - 2 FT \frac{d FT}{dt} - \frac{1}{TBDL} \frac{dX_3}{dt} \right)$$

where TBDL = Length of control region

X_3 = Position coordinate of vessel cover

FT = Upper vessel inside radius/initial radius

C = Coolant speed of sound

P_I = Impact pressure.

Definition of a pressure-time relationship for the impact makes it possible to determine the upper vessel wall response.

$$\frac{d^2 FT}{dt^2} = (P_I + P - PW) \frac{2\pi FT}{TM}$$

where PW = Pressure retaining ability of upper wall

TM = Effective mass of vessel walls and coolant.

The inertia of the system was composed of the upper cylinder structure and, for conservatism, all of the coolant in the upper region. The quantity of coolant may be conveniently modified by use of an input constant, FF1, as the effective coolant fraction. Experience with two-dimensional hydrodynamic codes may justify a coolant fraction different from the one now in use. The upper vessel radial expansion is resisted by the strength of the wall, which increases in accordance with a linear strain hardening law. Vessel radial strain in excess of 25% is considered to rupture the wall and reduce the gas bubble pressure to zero.

The time length of impact depends on dissipation of the available kinetic energy in the slug. The energy balance considers the kinetic energy of the vessel walls, reactor cover, and coolant slug after impact, as well as the plastic deformation of the vessel walls and holddown bolts. The impact period is assumed completed and the impact pressure reduced to zero when all kinetic energy in the coolant slug is expended just before the time of impact.

The reactor cover is accelerated by the impact pressure and restrained by holddown bolts attached to the building foundation.

$$\frac{d^2 X_3}{dt^2} = [(P_I + P) A - R_3 - M_1 G] / M_1$$

where R_3 = Cover restraining force from holddown bolts and vessel walls

M_1 = Slug and cover mass.

The kinetic energy transferred to the cover and the added work energy from gas bubble expansion will be dissipated by plastic deformation in the bolts. Bolt strain in excess of an input value will rupture the bolts and release the cover. A description of the elastic-plastic equations for the bolts is included in Appendix A.

5.0 DEMONSTRATION OF PROGRAM USE

ASPRIN was applied to a "base case", Parameter No. 1 for liquid metal reactor design, and the selected parameters were then varied.

The reactor used for the "base case" was 17 ft in diameter with a 2 in. wall thickness. A 3-in. thermal shield, because of its inertia, was included to reduce the energy dissipated in wall deformation. A distance of 20 ft was assumed from the top of the core to the vessel cover. However, the use of only about a 12-ft height of sodium simulates the possibility of reducing the sodium level down to the outlet nozzles during a pre-DBA condition. The DBA work energy was 1500 MW-sec, with a peak pressure of 616 atm. A delay period of 3 msec was assumed to ensue before the gas bubble pressure would act on the vessel walls. A detailed listing of input variables for the base case and selected portions of the computer output are shown in Appendix C.

Only the highlights of the base case can be conveniently described here because of the magnitude and variety of output. The slug is accelerated by the gas bubble to a velocity of 310 ft/sec before impact occurs. The lower vessel walls have expanded 24% and do not surpass the rupture criteria of 25%. About 26% of the DBA energy is contained in the coolant slug mass of 3460 slugs. Upon impact, pressures of 31,000 psi generated in the head region accelerate the cover and upper vessel walls. The cover mass of 17,100 slugs is accelerated to a velocity of 64 ft/sec in a few milliseconds and the upper vessel walls rupture about 5 msec later. The stainless steel holddown bolts with a total area of 700 in.² and a length of 10 ft begin to decelerate and then stop the cover after undergoing about an 18% plastic strain.

The cover velocity of 64 ft/sec is noted to compare very closely with a velocity of 69 ft/sec from a completely inelastic collision. Therefore, for approximate purposes, an inelastic collision is a reasonable assumption for wall thicknesses of a few inches.

The results of thirteen parameter runs are shown in Figures 3 through 7. Only one parameter has been varied from the "base case" conditions for each run. The kinetic energy in the coolant slug and the vessel cover has been chosen as the parameter most representative of the holddown problem. The total plastic strain produced in the holddown bolts is also included. A listing of the parameter variations is also shown in Appendix B.

Figure 3 shows that, with increasing wall thickness, a larger portion of the DBA energy is transmitted to the cover. The thicker walls not only provide more strength and inertia in the core region, indicated as a larger slug kinetic energy before impact, but also prevent the upper vessel from rapidly distorting and absorbing energy. The steep line signifying the energy decrease during the impact period is drawn only to connect before and after energy values.

Figure 4 shows the effect of increasing the gas gap between the cover and coolant slug. As the gas gap increases, the consequent increase in sodium slug acceleration distances serves to increase the slug kinetic energy. However, with larger gas gap, the slug mass becomes smaller and the energy transfer to the cover becomes less efficient. Therefore, a gas gap transferring a maximum amount of energy can be reached. This gap, however, has not been attained in the Figure 4 representations.

Figure 5 shows a larger cover mass to be a very effective parameter for directing the slug kinetic energy into the vessel

FIGURE 3. Effect of Vessel Wall Thickness for DBA

FIGURE 4. *Effect of Variable Gas Gap Between Core and Cover for DBA*

FIGURE 5. Effect of Cover Mass for DBA

FIGURE 6. Effect of DBA Energy

FIGURE 7. Effect of Maximum Gas Bubble Pressure

walls and not into the cover. The inertia of the cover prevents it from rapidly absorbing energy.

Figure 6 shows that a smaller DBA directs a larger percentage of the energy into the coolant slug. The walls more easily resist the gas bubble expansion since the pressure decreases more rapidly. However, an energy of 2000 MW-sec causes an early vessel rupture and an accompanying reduction in the cover loadings.

Figure 7 shows the effect of varying the maximum pressure used to characterize the DBA. The slug kinetic energy is rather insensitive to the initial pressure used.

6.0 VERIFICATION OF MODEL

The analytical model was developed with conservatism wherever required. The propellant type of explosion, by producing a minimum of vessel deformation about the core region, conserves more potentially available work energy in the gas bubble. The large gas volume between the coolant and cover in the present DBA model undergoes a large expansion before slug impact, and a significant fraction of the DBA energy is directed into the coolant slug. The distribution of the coolant slug energy provides a basis for establishing the reactor vessel cover design.

In order to verify the conservatism of the analytical model, the predicted results are compared with data available from the SL-1 accident. Estimates obtained from Reference (1) indicate that the 50-60 MW-sec of heat energy promptly released to the coolant by the reactor excursion served to generate a vapor bubble that accelerated the coolant located above the core. The slug appears to have been accelerated to 159 ft/sec where it impacted the cover and transmitted enough energy to lift the vessel 11.4 ft. The resulting vessel deformations are

shown in Figure 2. The radial strains occurring from the core gas bubble and slug impact are shown to be in different locations along the vessel.

The accident was then simulated using ASPRIN with the proper geometry and mass conditions. The input data to ASPRIN is listed in Appendix C. A DBA work energy of 8.26 MW-sec was used as the value obtained from Reference (1) for the TNT products expanded to 1 atm. A maximum pressure of 200 atm, obtained by putting 55 MW-sec of heat energy into the available coolant and finding the saturation pressure from a Mollier chart, was used. In addition to the wall inertia in the core region, the effective core constraint inertia was assumed to be that of a 3-in. wall. The predicted deformation pattern of the vessel is also shown in Figure 2. A comparison of SL-1 conditions with predictions by RSPRIN is shown in Table 1.

TABLE 1. *Comparison of SL-1 Conditions with Predictions by ASPRIN*

Parameter	SL-1 Conditions	ASPRIN Predictions for 8.26 MW-Sec Work Energy at 200 atm Maximum Pressure
Energy absorbed in lower vessel, ft-lb	1.85×10^6	1.63×10^6
Energy absorbed in upper vessel, ft-lb	2.67×10^6	1.48×10^6
Maximum slug velocity, ft/sec	159	145
Impact pressure, psi	10,000	6,000
Vessel velocity, ft/sec	29	31
Vessel rise, ft	11.4	15

The degree of correlation is not the most important factor in Figure 2 and Table 1. A better correlation could be obtained by adjusting the work energy and varying wall inertia parameters.

This approach, however, would be just a matter of "data fitting", and misleading as well. The important factors are that ASPRIN, as it is conventionally used, underpredicts the vessel radial deformations and overpredicts the kinetic energy remaining in the coolant slug and cover system. This disclosure substantiates the statement that the analytical model overpredicts the cover loadings which might occur as the result of a DBA.

Additional verification of the methods predicting energy transfer from the coolant slug to the vessel cover are underway. A two-dimensional hydrodynamic code⁽²⁾ which handles shock waves and reflections is being applied for information during the impact period. Also, model experiments are being considered to verify the analytical assumptions made herein.

7.0 ACKNOWLEDGEMENTS

The development of ASPRIN was helped greatly by discussions with many personnel of the FFTF Division. Noteworthy contributors were L. M. Finch and D. P. Schivley in Reactor and Plant Engineering. A. Padilla provided information about molten fuel and sodium interaction. F. E. Bard supplied help with equations for elastic-plastic material deformation, and the FORTRAN programming was performed by D. Dutt.

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APPENDIX A

ELASTIC-PLASTIC MODELING FOR HOLDDOWN BOLTS AND LONGITUDINAL VESSEL WALL STRAIN

APPENDIX A
ELASTIC-PLASTIC MODELING FOR HOLDDOWN BOLTS
AND LONGITUDINAL VESSEL WALL STRAIN*

The following stress and strain rate equations were developed for a linear strain hardening material.

$$\dot{\epsilon} \cdot T = \dot{\epsilon} \cdot E + \dot{\epsilon} \cdot P \quad (1)$$

where $\dot{\epsilon} \cdot T$ = total strain rate
 $\dot{\epsilon} \cdot E$ = elastic strain rate
 $\dot{\epsilon} \cdot P$ = plastic strain rate

$$\dot{\epsilon} \cdot E = \frac{\dot{\sigma}}{E} \approx \frac{EPP}{\sigma_y} \dot{\sigma} \quad (2)$$

where σ = stress rate
 E = Youngs Modulus
 EPP = yield strain
 σ_y = yield point stress
 f = yield condition = $\frac{1}{2} (\sigma^2 - Y^2)$

$$\dot{\epsilon} \cdot P = (1 - g) \gamma \sigma \quad (3)$$

Elastic

$$g = 1 \text{ if } \sigma^2 < Y^2 \text{ or if } \dot{\sigma} \geq 0 \\ \text{and } \sigma < 0$$

Plastic

$$g = 0 \text{ if } \sigma^2 = Y^2 \text{ and } \dot{\sigma} \geq 0$$

* B. A. Boley and J. H. Weiner. "Theory of Thermal Stress," pp. 466-473, Third Printing, 1966, John Wiley & Sons, Inc.

where Y = the linear strain hardening yield function

$$Y = \frac{\sigma}{YY'}$$

Applying these equations

$$Y = \frac{\sigma_u - \sigma_y}{EPR - EPP} \epsilon^P + \sigma_y \quad (4)$$

$$Y' = \frac{\partial Y}{\partial \epsilon^P} = \frac{\sigma_u - \sigma_y}{EPR - EPP} = KPC \quad (5)$$

where σ_u = ultimate stress

EPR = ultimate strain

$$\epsilon \cdot T = \frac{\frac{dX_3}{dt} - \frac{dY_3}{dt}}{X_0} = \frac{EPP}{\sigma_y} \dot{\sigma} + (1 - g) \frac{\dot{\sigma} \sigma}{YY'} \quad (6)$$

Rearranging

$$\dot{\sigma} = \frac{(dX_3/dt - dY_3/dt)}{X_0 \frac{EPP}{\sigma_y} + (1 - g) \frac{\sigma}{YY'}} \quad (7)$$

where X_0 = initial longitudinal length

Integrating Equations (3) and (7) produce the plastic strain and stress.

APPENDIX B

ASPRIN PARAMETER RUNS

APPENDIX B

ASPRIN PARAMETER RUNSBASE CASE CONDITIONS

PMAX	=	6.1600+02	DBWAK	=	1.5000+03	SYA	=	2.4000+04
SYB	=	2.4000+04	SUB	=	6.6000+04	EPPB	=	2.0000-03
CRHO	=	5.2300+01	SOS	=	7.1600+03	FSTRK	=	1.2500+00
K	=	1.2600+05	N	=	3.8000-01	FF1	=	1.0000+00
AREAA	=	1.2700+03	XA	=	2.0000+01	AREAB	=	7.0000+02
ORAD	=	8.5000+00	WIHK	=	2.0000+00			
GBDL	=	1.7000+01	MCU	=	3.4600+03	MH	=	1.7100+04
TBDL	=	5.0000+00	VRHOT	=	1.2200+03	VRHOB	=	1.7100+03
SUA	=	6.6000+04	EPPA	=	2.0000-03	EPRA	=	2.0000-01
EPRB	=	4.0000-01						
M2	=	2.0000+04						
XB	=	1.0000+01						
VGG	=	1.7680+03						
CONECT	=	F	DELAYT	=	3.0000-03			

SELECTED PORTIONS OF COMPUTER OUTPUT FOR BASE CASE

Detailed printouts following these comments are included for each time point.

<u>Time, sec</u>	<u>Comments</u>
0	Initial values of program variables. Note the bottom of the cover (X3) is reference position and coolant slug (XC3) and lower vessel (Y3) start with negative values. The maximum coolant slug velocity (UC3) has a small value to prevent division by zero in program.
0.00904	Coolant slug has accelerated to 337 ft/sec and lower vessel has expanded radially 11%.(FB)
0.0248	Before coolant slug impact.
0.0249	After coolant slug impact. Lower vessel wall has stopped radial expansion (DFB). Impact pressure values (PAI3) occur. Upper vessel expansion (DFT) occurs.

0.0260 Before slug impact period has ended.
 0.0264 End of slug impact period.

0.0312 Before upper vessel rupture.
 0.0316 After upper vessel rupture.
 FT is greater than 1.25, therefore
 gas bubble pressure (PA3) is zero.

0.0463 Cover is still being decelerated.

0.0776 Cover has stopped and is rebounding
 elastically. Plastic strain rates
 of bolts (DEP3B) is zero.

PARAMETER RUN DESCRIPTION

<u>Parameter Run Number</u>	<u>Parameter Variable</u>	<u>Variables Changed</u>	<u>Value</u>
1	Base Case	-	-
2	Wall Thickness	WTHIK VRHOT VRHOB AREAA	4. 857. 1,110. 2,520.
3	Wall Thickness	WTHIK VRHOT VRHOB AREAA	8. 678. 807. 4,940.
4	Gas Gap, 2 f t	VGG MCU	436. 5,200.
5	Gas Gap, 4 f t	VGG MCU	872. 4,620.
6	Gas Gap, 10 f t	VGG MCU	2,180. 2,890.
7	Cover Mass	MH	10,000.
8	Cover Mass	MH	25,000.
9	DBA Energy	DBWAK	2,000.
10	DBA Energy	DBWAK	1,000.
11	DBA Energy	DBWAK	500.
12	DBA Max Pressure	IMAX	1,000.
13	DBA Max Pressure	PMAX	800.

APPENDIX C

ASPRIN VARIABLES FOR SL-1 SIMULATORS

APPENDIX C

ASPRIN VARIABLES FOR SL-1 SIMULATORS

The values used in ASPRIN to simulate the SL-1 accident are listed below:

PMAX	=	2.0000+02	DBWAK	=	8.2600+00	SYA	=	4.7100+04
SYB	=	4.7100+04	SUB	=	7.0600+04	EPPB	=	2.0000-03
CRHO	=	6.2400+01	SOS	=	5.0000+03	FSTRK	=	1.2500+00
K	=	8.2600+04	N	=	1.2000-01	FF1	=	5.0000-01
AREAA	=	1.5600+02	XA	=	6.0000+00	AREAB	=	0.0000
ORAD	=	4.5000+00	WTHIK	=	9.3800-01			
GBDL	=	6.0000+00	MCU	=	2.0000+02	MH	=	4.5000+02
TBDL	=	3.0000+00	VRHOT	=	5.0000+02	VRHOB	=	2.1600+03
SUA	=	7.0600+04	EPPA	=	2.0000-03	EPRA	=	2.6000-01
EPRB	=	2.6000-01						
M2	=	4.5000+02						
XB	=	1.0000+00						
VGG	=	4.0740+01						
CONECT	=	T	DELAYT	=	0.0000			

APPENDIX D

ASPRIN PROGRAM DESCRIPTION

APPENDIX D

ASPRIN PROGRAM DESCRIPTION

Appendix D contains the following information necessary for code operation:

- Input and output variable definitions
- Code flow diagram
- Program subroutine listing
- Integration subroutine listing

The program input used a Format (6G12.0,I3) for all data cards. Therefore data may contain a decimal point, an exponent or both. The ordering of the input data is shown below in Table D-1.

TABLE D-1. *Input Cards*

<u>Col.1</u> 1 12	<u>Col.2</u> 13 24	<u>Col.3</u> 25 36	<u>Col.4</u> 37 48	<u>Col.5</u> 49 60	<u>Col.6</u> 61 72	<u>Col.7</u> 72 75
TIME	DTIME	IOT	TMIN	OUTM		1
PMAX	DBWAK	SYA	SUA	EPPA	EPRA	2
CONECT	MCU	SYB	SUB	EPPB	EPRB	3
CRHO	SOS	FSTRK	M2			4
FF1	K	N	VGG			5
AREAA	XA	AREAB	XB	ORAD	WTHIK	6
GBDL	VRHOB	TBDL	VRHOT	MH	DELAYT	7
						8

The value for TIME should be set equal to zero since this is the time reference. DTIME is the initial time increment although the program will pick successively smaller values until the error is negligible. We have been starting with 0.001.

We have been using a value of 24 for IOT, 0.00001 for TMIN, and 0.1 for OUTM. The other input values are listed in Appendix C.

Parameter runs are performed by submitting only the card with data changes. Card 1 and Card 8 are always required for each parameter run.

ASPRIN INPUT VARIABLES

IMAX	= Maximum pressure of DBA gas bubble atm
DBWAK	= DBA work energy, when expanded to pressure of 1 atm, MW-sec
SYA	= Vessel yield stress, psi
SUA	= Vessel ultimate stress, psi
EPPA	= Vessel elastic strain limit, in./in.
EPRA	= Vessel plastic strain limit, (rupture) in./in.
SYB	= Bolt yield stress, psi
SUB	= Bolt elastic strain limit, in./in.
EPRB	= Bolt plastic strain limit, (rupture) in./in.
CRHO	= Coolant density, lb/ft ³
SOS	= Coolant speed of sound, ft/sec
FSTRK	= Value of FT or FB for vessel rupture
M2	= Mass of lower vessel and coolant, slugs
TIME	= Initial time, sec
OUTM	= Time for end of run, sec
IOT	= Number of integrations between printouts
DTIME	= Initial time increment, sec
TMIN	= Minimum time increment, sec
K	= Strain hardening coefficient, stress = $K(\text{strain})^N$, psi
N	= Strain hardening coefficient, stress = $K(\text{strain})^N$, psi
FF1	= Effective coolant slug fraction that influences the radial expansion during slug impact.
AREAA	= Area which resists vessel downward motion (wall area), in. ²
XA	= Effective length of wall undergoing strain longitudinally, ft

AREAB = Area which resists cover motion (bolt area), in.⁴
 XB = Effective length of holddown bolts, ft
 ORAD = Vessel outside radius, ft
 WITHK = Vessel wall thickness, in.
 GBDL = Length of vessel deformed radially by the gas bubble, ft
 MCU = Coolant mass above the core, slugs
 MH = Vessel cover mass, slugs
 VGG = Volume in gas gap above coolant, ft
 TBDL = Length of upper vessel deformed radially by impact of coolant slug, ft
 VRHOT = Effective density of upper vessel wall, lb/ft³
 VRHOB = Effective density of lower coolant wall, lb/ft³
 CONECT = Variable which defines connection from vessel flange to vessel cover. Any number greater than or equal to zero indicates that flange is connected to cover. Negative number specifies no connection.
 DELAYT = Length of time gas bubble pressure is prevented from acting on vessel walls.

ASPRIN OUTPUT VARIABLES

• Output Once Only

PO = Maximum gas bubble pressure, lb/ft²
 VO = Reference gas bubble volume, ft³
 KPCA = Slope of vessel wall yield function, psi/(in./in.)
 KPCB = Slope of holddown bolt yield function, psi/(in./in.)
 XCM = Gas gap distance between cover and coolant, ft
 TM = Total mass of upper vessel region, slugs (walls plus coolant)
 AREA = Slug cross section area, ft²
 IRAD = Inside radius of vessel, ft
 RCA = Compressibility parameter
 (CRHO * SOS * AREA/G)

● Output Each Time Step

TIME = Time, sec
 DXC3 = Coolant slug velocity, ft/sec
 XC3 = Coolant slug position coordinate, ft
 DX3 = Cover velocity, ft/sec
 X3 = Cover position coordinate, ft
 SW3 = Logical variable, true before slug impact
 DY3 = Lower vessel longitudinal velocity, ft/sec
 Y3 = Lower vessel position coordinate, ft
 MC3 = Effective vessel head mass, slugs
 = MH before and during impact
 = MH + MCU after impact
 PA3 = Gas bubble pressure, lb/ft²
 R3 = Cover holddown force, lb
 FC3 = Impact force on cover, lb
 STR3A = Total longitudinal strain in vessel, in./in.
 STR3B = Total longitudinal strain in holddown bolts, in./in.
 DEP3A = Plastic longitudinal strain rate in vessel, in./in.-sec
 DEP3B = Plastic strain rate in bolts, in./in.-sec
 EP3B = Plastic strain in bolts, in./in.
 DSG3A = Longitudinal stress rate in vessel, psi/sec
 DSG3B = Bolt stress rate, psi/sec
 SIG3A = Longitudinal stress in vessel, psi
 SIG3B = Bolt stress, psi
 DELAYP = Pressure acting on vessel wall, psi
 = 0 before DELAYT
 = PA3 after DELAYT
 YF3A = Longitudinal yield stress of vessel, psi
 YF3B = Bolt yield stress, psi
 RPT3A = Logical variable
 False if vessel has not ruptured longitudinally
 RPT3B = Logical variable
 False if bolts have not ruptured
 PAI3 = Impact pressure, lb/ft²

LOGICAL CONTROL VARIABLES

The following group of logical control variables describe whether material deformation is elastic or plastic. $i = A$ or B , depending on application to vessel wall or holddown bolts

SET13i = False if $(\text{SIG3i}^2 - \text{YF3i}^2) \geq 0$

SET23i = False if $(\text{SIG3i} * \text{DSG3i}) \geq 0$

SET33i = Not SETi3i and SET23i

SET438 = True for elastic deformation

SET53i = True for plastic deformation

SET63i = True for elastic deformation and no rupture

SET73i = True for plastic deformation and no rupture

LSTRK3 = Logical variable
True if wall has not ruptured

FOR3 = Logical variable
True when slug impact period is over

BUMB = Logical variable
True during impact period

ELSVES = Kinetic energy change of lower vessel after impact occurs

ESPVES = Energy dissipated by impact pressure in upper vessel radial expansion.

DFT = Radial strain rate of upper vessel, 1/sec

FT = Upper vessel inside radius/initial inside radius

DELV3T = Volume expansion of upper vessel, ft^3

PW = Pressure retaining ability of upper vessel wall, lb/ft^2

MOMTUM = Impulse delivered to vessel cover/momentum removed from coolant slug

DFB = Radial strain rate of lower vessel, 1/sec

FB = Lower vessel inside radius/initial inside radius

DELV3B = Volumetric expansion of lower vessel, ft^3

PDB = Dimensionless pressure causing lower vessel radial expansion

PSB = Dimensionless pressure retaining ability of lower vessel wall

VHM3 = Maximum cover velocity after slug impact, ft/sec
(elastic impact)

V3 = $V_0 + \text{DELV3T} + \text{DELV3B}$, ft³

UC3 = Maximum coolant slug velocity, ft/sec

CONNECT = Logical variable
True if cover is connected to vessel

ET = Total DBA energy, ft-lb

ESLUG = Maximum coolant slug kinetic energy fraction

EADDEN = Added energy fraction from longitudinal vessel
expansion

EUPVES = Total energy fraction dissipated in upper vessel
deformation

EVESLG = Energy fraction dissipated in straining vessel
longitudinally

EHDBTS = Energy fraction dissipated in straining head bolts

ELWVES = Kinetic energy fraction in lower vessel

ESGCL = Kinetic energy fraction in coolant slug and cover

EGBDL = Energy fraction dissipated in lower vessel deformation

EREMAN = Energy fraction remaining in gas bubble

ASPRIN FLOW DIAGRAM

MORAT

MORAT

ENERGY

STSTC

INTEGRATION SUBROUTINES

The numerical solution of the differential equations in ASPRIN uses the subroutines DES, DEI, DED, AND DEDIS from the Univac 1107 BEEF MATH ROUTINES.* The differential equations are of the form:

$$\begin{aligned} \dot{Y}_1 &= f_1(t, Y_1, \dots, Y_n) \\ &\vdots \\ \dot{Y}_i &= f_i(t, Y_1, \dots, Y_n) \\ &\vdots \\ \dot{Y}_n &= f_n(t, Y_1, \dots, Y_n). \end{aligned}$$

DES is used once at the beginning to set up the routines for integration. DEI is linked to the required number of integration points to integrate all $\dot{Y}_i$ from time initial to time final. DED is used to test whether the integration step is sufficiently accurate.

The Math Routines allow three options for the method of solution. They are: Runge Kutta, Adams-Moulton fixed step, and Adams-Moulton variable step. We have selected the Adams-Moulton variable step, predictor corrector method. The first four-time points are integrated using the Runge-Kutta classical fourth order method. Then the prediction and correction equations can be applied. For example, let $Y_{ij} = Y_i(t_j)$ and suppose that we know at least four past-time points, that is we know $Y_{ij}, Y_{ij-1}, Y_{ij-2}, Y_{ij-3}$. Then the prediction equation is

$$Y_{ij+1}^{(P)} = Y_{ij} + \frac{\Delta t}{24} (55f_{ij} - 59f_{ij-1} + 37f_{ij-2} - 9f_{ij-3})$$

* Further information on the BEEF ROUTINES can be found in Share write-up RWDE2F, Section D2.

From this result we can obtain a better value of the dependent variable using the corrective equation:

$$Y_{ij+1}^C = Y_{ij} + \frac{\Delta t}{24} \left(9f_{ij+1}^{(P)} + 19f_{ij} - 5f_{ij-1} + f_{ij-2} \right)$$

These two values are then tested against an allowable error. If the difference between the values is too large, the time step is reduced and four points are calculated using Runge-Kutta and integration proceeds as before. If the test is satisfied, the derivatives Y_{ij+1} are calculated from the differential equations and a new time point is selected.

```

F 5 DEW,DEW
SUBROUTINE DEW(NARG,I)
100
CALL DEWIS(NUM,IND,NTEST,I)
NARG=0
IF (1.67.3)NARG=1
RETURN
END
DENIS009
DENIS010
DENIS011
DENIS012
DENIS013
DENIS014
DENIS015

F 5 VES,DES
SUBROUTINE VES (NUM,IND,NTEST)
CALL DEWIS (0,IND,NTEST,1)
RETURN
DENIS001
DENIS002
DENIS003
DENIS004

F 5 DEI,DEI
SUBROUTINE DEI (NUM,IND,NTEST)
CALL DEWIS (NUM,IND,NTEST,2)
RETURN
DENIS005
DENIS006
DENIS007
DENIS008

11 F 5 DEUS,DEUS
SUBROUTINE DEUS (NUM,IND,NTEST,IFORN)
DOUBLE PRECISION DP
INTEGER ALPHA,IP,ISXOC5,TOT027
LOGICAL SWIS,W2,DECRH,INCRH
EQUIVALENCE (DP,D(1)),(TEMP,IADD,K(1),IT(1)),(TEMP2,KTEMP)
DIMENSION T(1),D(2),RKA(7,4),IT(1)
DATA ((RKA(I,J),I=1,7),J=1,4) 0.,0.2,-1.,1.3,-.5,1. 0.,0.,2.,-1.5,-1. DENIS016
1.,5,-.33333333,0.,-.5,1.,0.,-1.0.,1.,0.,2.,6.,1.13,-.5,-3.,0./ DENIS022
DATA ERRN1,ERRN2,ERRHE,ERRE,ERR1/30,PN=0 N FLT H=0 E=0 IN DENIS024
10 / DENIS025
GO TO (10002,100300) , IPRWM DENIS026
S.1=.TRUE. DENIS027
S.2=.TRUE. DENIS028
TOT027=2**27 DENIS029
IADD=LOC (NM)-LOC (IADD) +65537 DENIS030
IND=LOC (NTEST)-LOC (IADD)+65537 DENIS031
IND = LOC (A)-LOC (IADD)+65537 DENIS032
IND = IT(116) DENIS033
N=NUM DENIS034
N1=IADD+N DENIS035
N2=N1+N DENIS036
N3=N2+N DENIS037
N4=N3+N DENIS038
N5=N4+N DENIS039
N6=N5+N DENIS040
N7=N6+N DENIS041
N8=N7+N DENIS042
N9=N8+N DENIS043

```


	N10=N9+N	DEBIS044
	N11=N10+N	DEBIS045
	N12=N11+N	DEBIS046
C	TEST IF N = 0	DEBIS047
	IF (N.EQ.0) GO TO 32	DEBIS048
C	TEST IF N IS REAL	DEBIS049
	IF (N.GT.4096) GO TO 33	DEBIS050
C	TEST IF H=0	DEBIS051
	IF (ABS(T(N12)).LT.1.E-35) GO TO 34	DEBIS052
C	ASSURE IND=0, 1, OR 2	DEBIS053
	IF (((ABS(IND).NE.0).AND.(IND.NE.1)).AND.(IND.NE.2)) GO TO 36	DEBIS054
C	IND IS 0, 1, OR 2	DEBIS055
	IF(IND.NE.0)GO TO 27	DEBIS056
C	TEST IF E=0	DEBIS057
	IF (ABS(T(N12+3)).LT.1.E-35) GO TO 35	DEBIS058
27	IF (IND=1) 21,20,19	DEBIS059
19	SW2=.FALSE.	DEBIS060
	GO TO 677	DEBIS061
20	SW1=.FALSE.	DEBIS062
	GO TO 677	DEBIS063
21	IF (T(N12+3)) 9001,9000,9001	DEBIS064
9000	BETA=.5	DEBIS065
	GO TO 9002	DEBIS066
9001	BETA=T(N12+3)	DEBIS067
9002	EBAR=14.*T(N12+8)	DEBIS068
	IF (T(N12+7)) 9004,9003,9004	DEBIS069
9003	EBARUM=EBAR/100.	DEBIS070
	GO TO 9005	DEBIS071
9004	EBARUM=EBAR/T(N12+7)	DEBIS072
9005	IF (T(N12+6)) 9007,9006,9007	DEBIS073
9006	A=1.	DEBIS074
	GO TO 9008	DEBIS075
9007	A=T(N12+6)	DEBIS076
9008	IF (T(N12+5)) 9010,9009,9010	DEBIS077
9009	INCRH=.FALSE.	DEBIS078
	GO TO 1019	DEBIS079
9010	INCRH=.TRUE.	DEBIS080
	HMAXTB=T(N12+5)*BETA	DEBIS081
1019	IF (T(N12+4)) 9012,9011,9012	DEBIS082
9011	DECRH=.FALSE.	DEBIS083
	GO TO 677	DEBIS084
9012	DECRH=.TRUE.	DEBIS085
	HMINUB=T(N12+4)/BETA	DEBIS086
677	TSXJC5=1	DEBIS087
	GO TO 999	DEBIS088

D-20

BNWL-1166

	DO 2011 I=1,N	DE0IS089
	DP=T(N12-I)+(N10-I)/3	DE0IS090
	T(N12-I)=D(1)	DE0IS091
	DO 2011 I=1,N	DE0IS092
	T(N10-I)=D(2)	DE0IS093
	DO 998 I=1,N	DE0IS094
	T(N8-I)=T(N12-I)	DE0IS095
	T(N1-I)=T(N11-I)	DE0IS096
	T(N7-I)=T(N10-I)	DE0IS097
	DO 2002 I=1,N	DE0IS098
	D(1)=T(N12-I)	DE0IS099
	D(2)=T(N10-I)	DE0IS100
	TEMP=T(N12)*(T(N1-I)*(55./24.)-(50./24.)*T(N2-I)+(37./24.)*T(N3-I)	DE0IS101
	+ (3./8.)*T(N4-I))	DE0IS102
	T(N9-I)=UP+TEMP	DE0IS103
	T(N12-I)=T(N9-I)	DE0IS104
	T(N12+1)=T(N12+1)+T(N12)	DE0IS105
	TSXJC5=2	DE0IS106
	GO TO 999	DE0IS107
	IF (ALPHA=1) GO TO 902	DE0IS108
	DO 905 I=1,N	DE0IS109
	T(N2-I)=T(N11-I)	DE0IS110
	GO TO 2212	DE0IS111
	DO 904 I=1,N	DE0IS112
	T(N3-I)=T(N1-I)	DE0IS113
	GO TO 2212	DE0IS114
	DO 903 I=1,N	DE0IS115
	T(N4-I)=T(N11-I)	DE0IS116
	T(N6-I)=T(N12-I)	DE0IS117
	T(N5-I)=T(N10-I)	DE0IS118
	ALPHA=ALPHA+1	DE0IS119
	RKA(7,1)=T(N12)/2	DE0IS120
	RKA(7,3)=RKA(7,1)	DE0IS121
	NPASS=1	DE0IS122
	GO TO 7023	DE0IS123
	GO TO (26,3,24,4008,6), TSXJC5	DE0IS124
	DO 3026 I=1,N	DE0IS125
	T(N10-I)=0.	DE0IS126
	ALPHA=0	DE0IS127
	R=0	DE0IS128
	IF (INT(WST)=1	DE0IS129
	RETURN	DE0IS130
	ENP1=0	DE0IS131
	DO 300 I=1,N	DE0IS132
		DE0IS133
		DE0IS134

```

      D(1)=T(N8-I)                                DENIS135
      D(2)=T(N10-I)                                DENIS136
      TEMP=T(N12)*(1./24.)*T(N3-I)-(5./24.)*T(N2-I)+(19./24.)*T(N1-I)+(DENIS137
13./8.)*T(N11-I))                                DENIS138
      DP=DP+TEMP                                    DENIS139
      T(N10-I)=D(2)                                WENIS140
      T(N12-I)=D(1)                                WENIS141
3003 ENP1=AMAX1(ENP1,(ABS(T(N9-I)-T(N12-I))/AMAX1(A,ABS(T(N12-I)))) WENIS142
4      IF (.NOT.SW2)      GO TO 5                    WENIS143
      IF (EBAR-ENP1)      9017,9017,9013            WENIS144
9017 IF (.NOT.DECRH)      GO TO 7                    WENIS145
      IF (ABS(T(N12)).LT.HMINDB)      GO TO 14        DENIS146
7      TEMP=T(N12)                                    DENIS147
      T(N12)=T(N12)*ETA                                DENIS148
      IF (ALPHA.EQ.3)      GO TO 8                    DENIS149
      T(N12+1)=T(N12+1)-TEMP                                DENIS150
      DO 3008 I=1,N                                    DENIS151
      T(N11-I)=T(N1-I)                                DENIS152
      T(N12-I)=T(N8-I)                                DENIS153
3008 T(N10-I)=T(N7-I)                                DENIS154
4008 DO 5008 I=1,N                                    DENIS155
5008 T(N10-I)=3.*T(N10-I)                                DENIS156
6008 ALPHA=0                                            DENIS157
      K=0                                            DENIS158
C      IF P-C MODE CHECK IF INTEGRATION IS GOOD POINT DENIS159
6      IF (1ABS(JND).NE.0) GO TO 31                DENIS160
C      INW=0 P-C MODE                                DENIS161
      IF (ALPHA.NE.0) GO TO 30                        DENIS162
C      ALPHA = 0                                      DENIS163
      IF (ABS(T(N12)).GT.HINT) GO TO 31                DENIS164
C      H DECREASED                                    DENIS165
      GO TO 900                                        DENIS166
C      ALPHA NOT 0                                    DENIS167
                                                    DENIS168
                                                    DENIS169
                                                    DENIS170
                                                    DENIS171
                                                    DENIS172
                                                    DENIS173
30 IF (ALPHA.LE.3) GO TO 2000                        DENIS174
C      SUCCESS FROM D.E. ALPHA GREATER THAN 3 FOR P-C MODE DENIS175
31 IFROM = 4                                          DENIS176
      RETURN                                          DENIS177
9013 IF (EBARDM-ENP1) 14,14 8010                    DENIS178
9018 IF (.NOT.INCRH)      GO TO 15                    DENIS179
9      IF (ABS(T(N12)).GT.HMAXIB)      GO TO 5        DENIS180
15      K=K+1                                          DENIS181

```

```

      IF (K.LT.3)      GO TO 5
10    T(N12)=T(N12)/BETA
      TSXJCS=4
      GO TO 999
14    R=0
5     DO 3005 I=1,N
      T(N4-I)=T(N3-I)
      T(N3-I)=T(N2-I)
3005  T(N2-I)=T(N1-I)
      ALPHA=ALPHA+1
      TSXJCS=5
999   IT(INTEST)=0
      RETURN
24    IF (NPASS.EQ.4)      GO TO 6
      NPASS=NPASS+1
7023  DO 4023 I=1,N
      T(N9-I)=RKA(1,NPASS)*T(N9-I)+T(N12-I)*(N1-I)
      TEMP=T(N9-I)/RKA(2,NPASS)+RKA(3,NPASS)*(N10-I)
      IF (TEMP) 9014,3023,9014
9014  JTEMP=IADD/TOTOT27
      IF (T(N12-I)) 9015,3023,9015
9015  TEMP2=ABS(T(N12-I))
      JTEMP=(KTEMP/TOTOT27)-IABS(JTEMP)
      IF (JTEMP) 3023,3023,9016
9016  IF (JTEMP-27) 9019, 9019, 9020
9020  TEMP = 0.
      GO TO 3023
9019  JTEMP = 2**JTEMP
      IADD=IADD/JTEMP
      IADD=JTEMP*IADD
3023  T(N12-I)=T(N12-I)+TEMP
4023  T(N10-I)=T(N10-I)*RKA(6,NPASS)+TEMP*RKA(4,NPASS)+T(N9-I)*RKA(5,NPASS)
      ISS)
      T(N12+1)=T(N12+1)+RKA(7,NPASS)
      TSXJCS=3
      GO TO 999
8     T(N12+1)=T(N12+1)-4.*TEMP
      DO 1008 I=1,N
      T(N11-I)=T(N4-I)
      T(N12-I)=T(N6-I)
1008  T(N10-I)=T(N5-I)
      GO TO 6008
32    ERROR = ERRN1
      GO TO 37
33    ERROR = ERRN2
      GO TO 37

```

```

DENIS182
DENIS183
DENIS184
DENIS185
DENIS186
DENIS187
DENIS188
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DENIS224
DENIS225
DENIS226
DENIS227

```

34	ERROR = ERKHB	DEFIS228
	GO TO 37	DEFIS229
35	ERROR = ERRE	DEFIS230
	GO TO 37	DEFIS231
36	ERROR = ERKI	DEFIS232
37	WRITE(6,8000) ERROR	DEFIS233
	CALL EXIT	DEFIS234
8000	FORMAT(51H0DIFFERENTIAL EQUATION SUBROUTINE DES INPUT ERROR A6	DEFIS235
	END	DEFIS236

WIL PDP COM.COM

RCP* FCOPY

```
COMMON /REDC/ PMAX,DEWAK,SYA,SUA,FPH,EPRA,SYB,SUB,EPPB,FPRB,  
1CRHO,SOS,FF1,FSTRK,M2,K,N,AREAA,XA,AXEAB,XB,ORAD,  
2WTHIK,GBDL,MCU,MH,VGG,THDL,VKROT,VKHC,CONNECT,DELAYT,  
3IOT,INTM,OUTM,TIME,DTIME,TMIN  
LOGICAL CONNECT  
REAL K,M2,N,MCU,MH  
END
```

XCP* FCOPY

```
COMMON /CONC/ HC3,G,IRAD,AREA,XCM,RCA,VO,FBMAX,PO,GAMT,  
1GAMB,TM1,TM,DN,RUG,KPCA,KPCB,SLB,ET  
REAL IRAD,KPCB,KPCA  
END
```

PCP* FCOPY

```
COMMON /PVCOM/ PA3,V3,PA13,PA31,DELV3T,DELV3B,DELV3  
END
```

TCP* FCOPY

```
COMMON /TBLKC/ T(273),UC3  
EQUIVALENCE (T(1),NUM1),(T(266),T1),(T(265),DTI),(T(264),Y3),  
1(T(263),X3),(T(262),XC3),(T(261),FT),(T(260),FB),(T(259),SIG3A),  
2(T(258),SIG3B),(T(257),EP3A),(T(256),EP3B),(T(255),EADGEN),  
3(T(254),EUPVES),(T(253),ESPVES),(T(252),EVESLG),(T(251),EHDBTS)  
4,(T(250),EGBDL),(T(249),MOMTM),(T(248),  
5DELP),(T(247),DY3), (T(246),DX3), (T(245),DXC3),  
6,(T(244),DFT), (T(243),DFB), (T(237),DSG3A),(T(236),  
7DSG3B),(T(235),DEP3A),(T(234),DEP3B),(T(233),DEADEN),(T(232),  
8DEUPVS),(T(231),DESPVS),(T(230),DEVSLG),(T(229),DEHBTIS),(T(228),  
9DEGBDL),(T(227),MOMTM),(T(226),DEELP),(T(225),DDY3)  
1,(T(224),DUX3),(T(223),DUXC3),(T(222),DFT),(T(221),UDFB)  
END
```

LCP* FCOPY

```
COMMON/LOC/BUM3,LSTRK3,SW3,KP13A,PPT3B,SET13A,SET13B,SET23A,SET23B,  
1,SET133A,SET133B,SET43A,SET43B,SET53A,SET53B,SET63A,SET73A,SET73B,  
2FOR3,SET63B  
LOGICAL BUM3,LSTRK3,SW3,KP13A,PPT3B,SET13A,SET13B,SET23A,SET23B,  
1SET133A,SET133B,SET43A,SET43B,SET53A,SET53B,SET63A,SET73A,SET73B,  
2FOR3,SET63B  
END
```

SCP* FCOPY

```
COMMON/ENC/ESLG,ELSVES,ESGCL,YF3A,YF3B,STR3A,STR3B,UV3,LV  
END
```

UCP* FCOPY

```
COMMON /OPTC/ PW,MOMTUM,R3,ELWVES,EREMAN,PDR,PSR,DELAYP,FC3  
1,MC3,FSW3,VHM3,EVGSLG  
REAL MC3,MOMTUM  
END
```

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```

SUBROUTINE IPT
  INCLUDE RCP,LIST
  DIMENSION DUM(6)
22 READ (5,11) DUM,KARD
31 FORMAT (6G12.0,I3)
  GO TO (1,2,3,4,5,6,7,10),KARD
C THIS CARD MUST BE READ IN FOR EVERY NEW CASE
1 TIME=DUM(1)          0 INITIAL TIME
  DTIME=DUM(2)          0 INITIAL TIME INCREMENT
  DDT=DUM(3)            0 NO. OF INTEGRATIONS BETWEEN PRINT OUTS
  DMIN=DUM(4)           0 MINIMUM TIME INCREMENT
  DUTM=DUM(5)           0 RUNNING TIME
  GO TO 22
2 PMAX=DUM(1)
  DBWAK=DUM(2)
  SYA=DUM(3)
  SUA=DUM(4)
  EPPA=DUM(5)
  EPRA=DUM(6)
  GO TO 22
3 CONECT=.FALSE.
  IF (DUM(1).GE.0.0) CONECT=.TRUE.
  MCU=DUM(2)
  SYB=DUM(3)
  SUB=DUM(4)
  EPPB=DUM(5)
  EPRB=DUM(6)
  GO TO 22
4 CRHO=DUM(1)          0 COOLANT DENSITY
  SOS=DUM(2)           0 SPEED OF SOUND
  FSTRK=DUM(3)
  M2=DUM(4)
  GO TO 22
5 FF1=DUM(1)
  K=DUM(2)
  N=DUM(3)
  VGG=DUM(4)
  GO TO 22
6 AREAA=DUM(1)
  XA=DUM(2)
  AREAB=DUM(3)
  XB=DUM(4)
  ORAD=DUM(5)
  WTHIK=DUM(6)

  GO TO 22
7 GBDL=DUM(1)          0 BOTTOM VESSEL DEFORMATION LENGHT
  VRHOB=DUM(2)          0 BOTTOM VESSEL DENSITY
  TBDL=DUM(3)          0 TOP BUBBLE DEFORMATION LENGTH-
  VRHOT=DUM(4)          0 TOP VESSEL DENSITY

```

```

      MH=DUM(5)
      DELAYT=DUM(6)
      GO TO 22
10  WRITE (6,100)
100 FORMAT (1H1)
      WRITE (6,18) P,AX,DBWAK,SYA,SUA,EPPA,EPRA,SYB,SUB,EPPB,EPRB,
1CRHO,SOS,FSTRK,M2,K,N,FF1
18  FORMAT(' PAX= ',1PE10.4,3X,'DBWAK= ',E10.4,3X,'SYA= ',1PE10.4,
13X,'SUA= ',1PE10.4,3X,'EPPA= ',1PE10.4,3X,'EPRA= ',1PE10.4,/,
2' SYB= ',1PE10.4,3X,'SUB= ',1PE10.4,3X,'EPPB= ',E10.4,3X,
3' EPRB= ',1PE10.4,/, ' CRHO= ',1PE10.4,3X,'SOS= ',1PE10.4,
4' FSTRK= ',1PE10.4,3X,'M2= ',4X,1PE10.4,3X,
5/, ' K= ',5X,1PE10.4,3X,
6' N= ',5X,1PE10.4, ' FF1= ',1PE10.4)
      WRITE (6,19) AREAA,XA,AREAB,XB,ORAD,WTHIK,GBDL,MCU,MH,
1VGG,TBDL,VRHOT,VRHOB,CONECT,DELAYT
19  FORMAT (' AREAA= ',1PE10.4,3X,'XA= ',4X,1PE10.4,3X,'AREAB= ',
11PE10.4,3X,'XB= ',4X,1PE10.4,/,
2' ORAD= ',1PE10.4,3X,'WTHIK= ',1PE10.4,/, ' GBDL= ',
31PE10.4,3X,'MCU= ',1PE10.4,3X,'MH= ',1PE10.4,3X,'VGG= ',
41PE10.4,/, ' TBDL= ',1PE10.4,3X,'VRHOT= ',1PE10.4,
5,3X,'VRHOB= ',1PE10.4,3X,'CONECT= 'L2,11X,'DELAYT= ',1PE10.4,/)
      RETURN
      END

```


RETURN
END

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```

SUBROUTINE CONST
C  CONST EVALUATES THOSE CONSTANTS THAT REMAIN FIXED FOR A PARTICULAR RUN
  INCLUDE RCP,LIST
  INCLUDE XCP,LIST
  PI=3.1416
  G=32.2
  IRAD=ORAD-WTHIK/12.
  AREA=IRAD*IRAD*PI
  XCM=VGG/AREA
  RCA=CRHO*SOS*AREA/G
  GAMT=VRHOT/G
  GAMB=VRHOB/G
C  IMPACT MASS
  TM1=VRHOT*PI*(ORAD-WTHIK/24.)*WTHIK/6.
C  FF1 IS THE EFFECTIVE COOLANT SLUG FRACTION THAT INFLUENCES THE RADIAL
C  EXPANSION DURING SLUG IMPACT
  TM=(TM1+CRHO*PI*IRAD**2*FF1)/6
  DN=(N-1.)/2.
  ROG=CRHO/G
  KPCA=(SUA-SYA)/(EPA-EPPA)
  KPCB=(SUB-SYB)/(EPB-EPPB)
  PO=PMAX*(14.7*144.)
  VO=DBWAK/(PMAX*LOG(PMAX))*348.4372
  FBMAX=.95*(.5+SQRT(.25+.75*(GBDL/(2.*IRAD))**2))
  SLB=GBDL/(2.*IRAD)
  WRITE (6,20) PO,VO,KPCA,KPCB,XCM,TM,AREA,IRAD,RCA
20 FORMAT(' PO=',4X,1PE10.4,3X,' VO=',4X,1PE10.4,3X,' KPCA= ',1PE10.4
1,3X,' KPCB= ',1PE10.4,3X,' XCM= ',1PE10.4,/,
2' TM=',4X,1PE10.4,3X,' AREA= ',1PE10.4,3X,' IRAD= ',1PE10.4,2X,
3' RCA= ',1PE10.4,/,/)
  RETURN
  END

```

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```

SUBROUTINE INTL
  INCLUDE RCP,LIST
  INCLUDE LCP,LIST
  INCLUDE TCP,LIST
  INCLUDE XCP,LIST
  C INITIAL CONDITIONS
  C INITIALIZE THE Y BLOCK TO ZERO
  DO 10 I=221,264
10  T(I)=0.0
    DELP=0.0
    DDFT=0.0
    DDFB=0.0
    FT=1.0
    FB=1.0
    Y3=-XCM
    DY3=0.0
    SIG3A=0.0
    SIG3B=0.0
    XC3=-XCM
    DX3=0.0
    UC3=.1
    DXC3=0.0
    MOMYM=0.0
    SW3=.TRUE.
    SET13A=.TRUE.
    SET13B=.TRUE.
    LSTRK3=.TRUE.
    FOR3=.TRUE.
  C ET IS THE TOTAL ENERGY AVAILABLE
  C ET=PO*VO*LOG(PMAX)
  C THESE ARE INITIAL VALUES FOR PARAMETERS USED IN THE INTEGRATION SUBROUTINE
    NUM1=22
    DTI=DTIME
    TI=TIME
    NUM=NUM1
    NUM12=12*NUM1
    T(NUM12+4)=.5
    T(NUM12+5)=TMIN
    T(NUM12+6)=.1
    T(NUM12+7)=1.
    T(NUM12+8)=1000.
    T(NUM12+9)=1.E-6
    RETURN
  END

```

```

SUBROUTINE DELVOL
  INCLUDE XCP,LIST
  INCLUDE KCP,LIST
  INCLUDE TCH,LIST
  INCLUDE PCP,LIST
  DELVST=AREA*TR*(1+(PT**2-1.))
  DELVSD=1.333*(F1-1.)*(1+1.4*(F1-1.))*AREA*CHDL
  DELV3=DELVST+DELVSD
C  EVALUATE THE VOLUME INCREASE OF THE VESSEL
  V3=V0+DELV3
  RETURN
END

```

```

SUBROUTINE DEPRES
C  DEPRES CALCULATES THE THREE PRESSURES FROM THE VOLUM CHANGE
  INCLUDE LCP,LIST
  INCLUDE RCP,LIST
  INCLUDE XCP,LIST
  INCLUDE TCP,LIST
  INCLUDE PCP,LIST
  INCLUDE OCP,LIST
  REAL MOMTM
  PA3=0.0
  IF(LSTRK3) PA3=PC*V0/(V3+AREA*(XC3-Y3)
  VLIM1=R06*UC3**2
  VLIM2=R06*SOS*(UC3-DX3)
  IF(DELPLT.VLIM1) GO TO 200
  IF(DELPLT.VLIM2) GO TO 201
  PAI3=DELP
  GO TO 202
200 PAI3=VLIM1
  GO TO 202
201 PAI3=VLIM2
C
C
C  PAI3 IS THE 1ST CT PRESSURE
202 IF (.NOT.BUN) PAI3=0.0
  IF (.NOT.BUN) ELP=0.0
  PA31=0.0
  IF(.NOT.SW3)PA31=PA3
  DMOMTM=PAI3*AREA
  MOMTUN=MOMTM/(MC0*(UC3-DX3))
  RETURN
END

```

```

SUBROUTINE MORAT
C- MORAT CALCULATES THE RATES OF THE FOUR MOTIONS
  INCLUDE RCP,LIST
  INCLUDE PCP,LIST
  INCLUDE LCP,LIST
  INCLUDE TCP,LIST
  INCLUDE XCP,LIST
  INCLUDE OCP,LIST
  INCLUDE SCP,LIST
C UC3 IS THE MAX. SLUG VELOCITY AND IS EQUAL TO DXC3 BEFORE IMPACT,
C AFTER IMPACT WE RETAIN IT FOR FURTHER USE
C XC3 IS THE SLUG DISPLACEMENT
C DX3 IS THE COVER VELOCITY
C THESE CHECKS ARE TO INSURE THAT THERE IS NO NEGATIVE VELOCITY
C AND THAT WE REMAIN WITH IN THE PRESCRIBED WALL BOUNDARIES
C THESE TESTS ARE TO INSURE THAT WE NEVER HAVE A NEGATIVE VELOCITY
  IF (DFB.LT.0.0) DFB=0.0
  IF (DFT.LT.0.0) DFT=0.0
  IF (FB.GT.FBMAX) FB=FBMAX
  IF (F1.GT.1.5) F1=1.5
  IF (FB.LT.1.0) FB=1.0
  IF (FT.LT.1.0) FT=1.0
  PDB=DELAYP*IRAT/K*THIK*12.0
  UV=0.0
  IF (CONNECT) UV=X3
  UV3=0.0
  IF (CONNECT) V3=DX3
202 IF (TI=DELAYP) 203,204,205
203 DELAYP=0.0
  GO TO 205
204 DELAYP=PA3
205 BB=.5*SLB*SLH/(SLB*SLB-FB*FB+FB)
  A1B=3./(BB-2.)
  A2B=2./(2.-BB)
  A3B=BB*BB-BB+1.
  A4B=LOG(FB+.001)
  PSB=2.*BB*FB**A1B**A2B**N*A3B**DB**A4B**N
  SUG3A=KPCA*(FT-1.0)+SYA
  PW=(SUG3A*THIK*12.0)/IRAD
  DUMY3B=DX3*SIG3B
  DUMY3A=(UV3-DYS)*SIG3A
  MC3=MH
  IF (.NOT.FOR3) MC3=MC3+MC0
  R3A=0.0

  IF (.NOT.RPT3A) R3A=SIG3A*AREAA*(1.+.02*DUMY3A/ABS(DUMY3A))
  R3B=0.0
  IF (.NOT.RPT3B) R3B=SIG3B*AREAB*(1.0+.02*DUMY3B/ABS(DUMY3B))
  R3=R3B
  IF (CONNECT) R3=R3A+R3B

```

```

DDY3= (-PA3*AREA+R3A-M2*G)/M2
FC3=PAI3*AREA
DUX3=0.0
IF (.NOT.SW3) DDY3=(FC3+PA31*AREA-R3-MC3*G)/MC3
DDELP=SOS**2*(UC3/TBDL-2.*FT*DFT-DX3/TBDL)*CRHO/G
IF (.NOT.BUM3) DELP=0.0
DUC3=0.0
IF (SW3) DUC3=PA3*AREA/MCU-G
DDFT=(PAI3+PA31-PW)*FT*6.28/TM
DDFB=(K*144.)/(I*AD**2*GAMB)*(PDB-PSB)*(FB+.25)
IF (SW3) DDYC3=DDYC3
IF (.NOT.SW3) DXC3=DX3
IF (.NOT.SW3) XC3=X3+.001
IF (SW3) UC3=DXC3+.0001
IF (.NOT.SW3) DDYC3=DDYC3
T(242)=DY3
T(241)=DX3
T(240)=DXC3
T(239)=DFT
T(238)=DFB
RETURN
END

```

SUBROUTINE ENRGY
 C ENRGY COMPUTES THE RATES OF THE ENERGY COMPONENTS
 INCLUDE PCP,LIST
 INCLUDE SCP,LIST
 INCLUDE LCP,LIST
 INCLUDE RCP,LIST
 INCLUDE XCP,LIST
 INCLUDE TCP,LIST
 INCLUDE CCP,LIST
 IF (SW3) DIP3=DY3
 EREMAN=0.0
 IF (LSTRK3) EREMAN=P0*V0*LOG(PA3/2115.)/ET
 ESLUG=.5*MCU*UC3**2/ET
 C THE RATE OF ENERGY ADDED:
 DEADEN=0.0
 IF (.NOT. SW3) DEADEN=PA3*(DX3-DY3)/ET
 DEUPVS=2.*AREA*TRDL*(PAI3+PA31)*FT*DFT/ET
 DESPVS=2.*AREA*TRDL*(PAI3*FT*DFT)/ET
 ELWVES=.5*M2*DY3**2/ET
 ELSVES=ELWVES-.5*M2*DIP3**2/ET
 DEVSLG=X*AREA*SIG3A*DEP3A/ET
 DEHBS=X*AREA*SIG3B*DEP3B/ET
 ESGCL=.5*(MCU*XC3**2+MH*DX3**2)/ET
 DEGBDL=1.0667*AREA*GBDL*PA3*(FB+.25)*DFB/ET
 IF (SW3) EVSSLG=EVESLG
 EVGSLG=EVESLG-EVSSLG
 RETURN
 END

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```

SUBROUTINE STSTC
INCLUDE RCP,LIST
INCLUDE SCP,LIST
INCLUDE XCP,LIST
INCLUDE TCP,LIST
INCLUDE LCP,LIST
STR3A=(JV-Y3-XCM)/XA
STR3B=X3/XB
IF (SET63A) GO TO 150
GO TO 151
150 DSG3A=(UV3-DY3)/(XA*EPPA/SYA)
DEP3A=0.0
151 IF (SET63B ) GO TO 152
GO TO 153
152 DSG3B=(DX3)/(XB*EPPB/SYB)
DEP3B=0.0
153 IF (SET73A) GO TO 154
GO TO 155
154 DSG3A=(UV3-DY3)/(XA*(EPPA/SYA+SIG3A/(YF3A*KPCA)))
DEP3A=DSG3A/(YF3A*KPCA)*SIG3A
155 IF (SET73B) GO TO 156
GO TO 157
156 DSG3B=DX3/(XB*(EPPB/SYB+SIG3B/(YF3B*KPCB)))
DEP3B=DSG3B/(YF3B*KPCB)*SIG3B
157 IF (.NOT.RPT3A) GO TO 430
DSG3A=0.0
SIG3A=0.0
DEP3A=0.0
430 IF (.NOT.RPT3B) GO TO 431
DSG3B=0.0
SIG3B=0.0
DEP3B=0.0
431 CONTINUE
RETURN
END

```

```

SUBROUTINE SIGMA
C   SIGMA ESTABLISHES THE LIMITS FOR THE BOLT AND VESSEL STRESSES
C   THAT IS IT MAKE SURE THAT IT IS WITH IN THE RANGE OF THE YIELD STRESS
  INCLUDE TCP,LIST
  INCLUDE SCP,LIST
  INCLUDE LCP,LIST
  INCLUDE RCP,LIST
  INCLUDE XCP,LIST
C   CALCULATE THE YIELD STRESS FOR THE BOL AND VESSEL
  YF3A=KPCA*EP3A+SYA
  YF3B=KPCB *EP3B+SYB
291 IF (RPT3A ) GO TO 300
  IF (SIG3A.LT.-YF3A) GO TO 292
  IF (SIG3A.GT.YF3A) GO TO 293
  GO TO 294
292 SIG3A=-YF3A
  GO TO 294
293 SIG3A=YF3A
  GO TO 294
300 SIG3A =0.0
294 IF (RPT3B) GO TO 301
  IF (SIG3B.LT.-YF3B) GO TO 295
  IF (SIG3B.GT.YF3B) GO TO 296
  GO TO 297
295 SIG3B=-YF3B
  GO TO 297
296 SIG3B=YF3B
  GO TO 297
301 SIG3B=0.0
297 CONTINUE
  RETURN
END

```

```

        INCLUDE LCP,LIST
        INCLUDE TCP,LIST
        INCLUDE SCP,LIST
        NT=NT+1
        IF (.NOT.SET13A.AND.NT.GT.5) GO TO 414
        IF (SIG3A**2-YF3A**2) 412,413,413
412 SET13A=.TRUE.
        GO TO 414
413 SET13A=.FALSE.
414 IF (.NOT.SET13A.AND.NT.GT.5) GO TO 417
        IF (SIG3B**2-YF3B**2) 415,416,416
415 SET13B=.TRUE.
        GO TO 417
416 SET13B=.FALSE.
417 IF (SIG3A*DSG3A) 418,419,419
418 SET23A=.TRUE.
        SET13A=.TRUE.
        GO TO 420
419 SET23A=.FALSE.
420 IF (SIG3B*DSG3B) 421,422,422
421 SET23B=.TRUE.
        SET13B=.TRUE.
        GO TO 423
422 SET23B=.FALSE.
423 SET33A=SET23A.AND..NOT.SET13A
        SET33B=SET23B.AND..NOT.SET13B
        SET43A=SET33A.R.SET33A
        SET43B=SET33B.R.SET33B
        SET53A=.NOT.SET43A
        SET53B=.NOT.SET43B
        SET63A=.NOT.RPT3A.AND.SET43A
        SET63B=.NOT.RPT3B.AND.SET43B
        SET73A=.NOT.RPT3A.AND.SET53A
        SET73B=.NOT.RPT3B.AND.SET53B
        RETURN
        END

```

```

C     THE FOLLOWING IS A LIST OF VARIABLES WHICH COME OUT OF THE BEEP ROUTINE
C     FT=INT(DFT) , DF=LIMITED INT (DDFT)
C     FE=INT(DFB) , DE=LIMITED INT(DDFB)
C     DELP=INT(ODELP)
C     MOMTUM=INT(DMO T.)
C     UC3=INT(DUC3)
C     DXC3=INT(DUC3), XCR=INT(DXC3)
C     DX3= INT(DDX3) , X3=INT(DX3)
C     DY3= INT(DDY3) , Y3=INT(DY3)
C     DEFINE THE STRESSES FOR THE COVER AND BOLT
C     Y3 IS THE VESSEL COORDINATE
C     X3 IS THE COVER COORDINATE
C     XC3 IS THE COORDINATE COORDINATE
C     STORC IS THE BALANCE OF GAS BUBBLE WORK ENERGY THAT WAS RELEASED
C     A DENOTES A VESSEL STRESS OR STRAIN WHILE B DENOTS A BOLT STRESS OR STRAIN
C     F1 IS THE UPPER WALL EXPANSION
C     FE IS THE LOWER WALL EXPANSION
C     INCLUDE RCP,LIST
C     INCLUDE LCP,LIST
C     INCLUDE TCP,LIST
C     INCLUDE XCP,LIST
C     INCLUDE SCP,LIST
C     INCLUDE OCP,LIST
C
C     READ INPUT TO PROGRAM
C 830 CALL IPT
C     KLIN=-2
C
C     CALCULATE THE CONSTANTS THAT DO NOT CHANGE IN THE CODE
C     CALL CONST
C
C     INITIAL VALUES FOR THE INTEGRATION SUBROUTINE
C     CALL INTL
C     ENTER THE INTEGRATION SUBROUTINE
C     IND=0
C     NUM=NUM1
C     CALL DES (NUM1,IND,NTEST)
107 IF (NTEST) 115,115,111
111 CALL DEI(NUM,IND,NTEST)
115 CONTINUE
C
C     CALCULATE THE VOLUME CHANGES
C     CALL DELVOL
C
C
C     CALCULATE THE VESSEL PRESSURES
C     CALL DEPRS
C
C     CALCULATE THE STRESS AND STRAIN RATES
C     CALL STSIC

```

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```

C      CALCULATE THE DISPLACEMENT RATES
C      CALL MORAT
C
C      CALCULATE THE ENERGY OF THE SYSTEM
C      CALL ENRGY
C
C      EXIT INTEGRATION ROUTINE
C      CALL JED (NARG)
C
C      STORE THE ENERGY BALANCE
C      STORE=ESLUG+EA DEN-ESPVES-EVGSLOC-EHDBTS-ELSVES-ESGCL
C      TEST1=AMAX1 (FT,FT)-FSTRK
C      LSTRK3=.TRUE.
C      IF (TEST1.GT.0.0) LSTRK3=.FALSE.
C      RATE=MCU/MH
C      VHM3=2.*RATE*UC3/(RATE+1.)
C
C      CALCULATE THE LOGICAL VARIABLES
291 IF (STORE) 400,403,401
400 FOR3=.FALSE.
   GO TO 402
401 FOR3=.TRUE.
402 IF (.NOT.SW3.AND.NIT.GT.5) GO TO 405
   IF (XC3-X3) 403,403,404
403 SW3=.TRUE.
   GO TO 405
404 SW3=.FALSE.
405 SUM3=FOR3.AND.(.NOT.SW3)
   IF (STR3A-EPRB) 406,407,407
406 RPT3A=.FALSE.
   GO TO 408
407 RPT3A=.TRUE.
408 IF (STR3B-EPRB) 409,410,410
409 RPT3B=.FALSE.
   GO TO 411
410 RPT3B=.TRUE.
411 CONTINUE
C
C      LIMITS ON THE STRESS
C      CALL SIGMA
C      IF (KLIN.LT.0) CALL OPT
C      KLIN=2
C      IF (NARG.EQ.0) GO TO 107
C
C      CALCULATE THE LOGICAL VARIABLES THAT DETERMINE IF WE HAVE PLASTIC DEFORMATION
C      CALL LOGIK
C      IF (DFB.LT.0.0) DFB=0.0
C      IF (DFT.LT.0.0) DFT=0.0

```

```

C
C   OUT PUT
    INTM=INTM+1
    ICT=ICT
    IF (ABS(XC3).LT..200) ICT=ICT/5
    IF (INTM.GE.ICT) CALL OUT
    IF (INTM.GE.ICT) INTM=0
    IF (INTM.GE.ICT) INTM=0
    NT=NT+1
    IF (OUTM-T1) 201,201,111
201 GO TO 800
    END

```

PMAX=	6.1600+02	DBWAK=	1.5000+03	SYA=	2.4000+04	SUA=	6.6000+04	EPPA=	2.0000-03
SYB=	2.4000+04	SUB=	6.6000+04	EPPB=	2.0000-03	EPRB=	4.0000-01		
CRHO=	5.2300+01	SOS=	7.1600+03	FSTRK=	1.2500+00	M2=	2.0000+04		
K=	1.2600+05	N=	3.8000-01	FF1=	1.0000+00				
AREAA=	1.2700+03	XA=	2.0000+01	AREAB=	7.0000+02	XB=	1.0000+01		
ORAD=	8.5000+00	WTHIK=	2.0000+00						
GBDL=	1.7000+01	MCU=	3.4600+03	NH=	1.7100+04	VGG=	1.7680+03		
TBDL=	5.0000+00	VRHOT=	1.2200+03	VRHOB=	1.7100+03	CONECT=	F	DELAYT=	3.0000-03
P0=	1.3039+06	V0=	1.3209+02	KPCA=	2.1212+05	KPCB=	1.0553+05	XCM=	8.1039+00
TM=	6.8830+02	AREA=	2.1817+02	IRAD=	8.3333+00	RCA=	2.5372+06		

TIME= 0.0000

DXC3=	0.0000	XC3=	-8.1039+00	DX3=	0.0000	X3=	0.0000	SW3=	T
DY3=	0.0000	Y3=	-8.1039+00	MC3=	1.7100+04	PA3=	1.3039+06	R3=	0.0000
FC3=	0.0000	STR3A=	-0.0000	STR3B=	0.0000	DEP3A=	0.0000	DEP3B=	0.0000
EP3A=	0.0000	EP3B=	0.0000	DSG3A=	0.0000	DSG3B=	0.0000		
SIG3A=	0.0000	SIG3B=	0.0000	DELAYP=	0.0000				
YF3A=	2.4000+04	YF3B=	2.4000+04	RPT3A=	F	RPT3B=	F	PAI3=	0.0000
SET13A=	T	SET13B=	T	SET23A=	F	SET23B=	F	SET33A=	F
SET33B=	F	SET43A=	F	SET43B=	F	SET53A=	F	SET53B=	F
SET63A=	F	SET63B=	F	SET73A=	F	SET73B=	F		
LSTRK3=	T	FOR3=	T	BUM3=	F	ELSVES=	0.0000	ESPVES=	0.0000
DFT=	0.0000	FT=	1.0000+00	DELV3T=	0.0000	PW=	6.9120+04	MOMTUM=	-0.0000
DFB=	0.0000	FB=	1.0000+00	DELV3B=	0.0000	PDB=	0.0000	PSB=	3.6828-02
VHM3=	5.1412-05	V3=	1.3209+02	UC3=	1.0000-04	CONECT=	F		
ET=	1.1064+09	ESLUG=	1.5637-14	EADDEN=	0.0000	EUPVES=	0.0000	EVESLG=	0.0000
EHDPTS=	0.0000	ELWVES=	0.0000	ESGCL=	0.0000	EGBDL=	0.0000	EREMAN=	1.0001+00

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TIME= 9.0469-03

DXC3= 3.3716+02	XC3= -6.0975+00	DX3= 0.0000	X3= 0.0000	SW3= T
DY3= -4.6563+01	Y3= -8.4239+00	MC3= 1.7100+04	PA3= 1.4008+05	R3= 0.0000
FC3= 0.0000	STR3A= 1.5998-02	STR3B= 0.0000	DEP3A= 2.2877+00	DEP3B= 0.0000
EP3A= 1.3734-02	EP3B= 0.0000	DSG3A= 4.8583+05	DSG3B= 0.0000	
SIG3A= 2.6882+04	SIG3B= 0.0000	DELAYP= 1.4008+05		
YF3A= 2.6913+04	YF3B= 2.4000+04	RPT3A= F	RRT3B= F	PAI3= 0.0000
SET13A= F	SET13B= T	SET23A= F	SET23B= F	SET33A= F
SET33B= F	SET43A= F	SET43B= T	SET53A= T	SET53B= F
SET63A= F	SET63B= T	SET73A= T	SET73B= F	
LSTRK3= T	FOR3= T	BUM3= F	ELSVES= 0.0000	EBPVES= 0.0000
DFT= 0.0000	FT= 1.0000+00	DELV3T= 0.0000	PW= 6.9120+04	MOMTUM= -0.0000
CFB= 2.3604+01	FB= 1.1105+00	DELV3B= 5.7051+02	PDB= 3.8603-01	PBB= 4.7865-01
VHM3= 1.1348+02	V3= 7.0241+02	UC3= 3.3716+02	CONFCT= F	
ET= 1.1064+09	ESLUG= 1.7775-01	EAD0EN= 0.0000	EUPVES= 0.0000	EVESLG= 8.0163-03
EHD8TS= 0.0000	ELWVES= 1.9597-02	ESGCL= 1.7775-01	EGBDL= 1.4109-01	EREMAN= 6.5281-01

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TIME= 2.9659-02

DXC3= 4.0977+02	XC3= -7.9871-03	DX3= 0.0000	X3= 0.0000	SW3= T
LY3= -2.8620+01	Y3= -9.0433+00	MC3= 1.7100+04	PA3= 5.0008+04	R3= 0.0000
FC3= 0.0000	STR3A= 4.6972-02	STR3B= 0.0000	DEP3A= 1.4061+00	DEP3B= 0.0000
EP3A= 4.4176-02	EP3B= 0.0000	DSG3A= 2.9850+05	DSG3B= 0.0000	
SIG3A= 3.3344+04	SIG3B= 0.0000	DELAYP= 5.0008+04		
YF3A= 3.3369+04	YF3B= 2.4000+04	RPT3A= F	RPT3B= F	PAI3= 0.0000
SET13A= F	SET13B= T	SET23A= F	SET23B= F	SET33A= F
SET33B= F	SET43A= F	SET43B= T	SET53A= T	SET53B= F
SET63A= F	SET63B= T	SET73A= T	SET73B= F	
LSTRK3= T	FOR3= T	BUM3= F	ELSVES= 0.0000	ESPVES= 0.0000
LFT= 0.0000	FT= 1.0000+00	DELV3T= 0.0000	PW= 6.9120+04	MOMTUM= -0.0000
DFB= 0.0000	FB= 1.2469+00	DELV3B= 1.3410+03	PDR= 1.3781-01	PSB= 6.0751-01
VHM3= 1.3792+02	V3= 1.4731+03	UC3= 4.0977+02	CONFCT= F	
ET= 1.1064+09	ESLUW= 2.6257-01	EADDEN= 0.0000	EUPVES= 0.0000	EVESLG= 2.9058-02
EHDBTS= 0.0000	ELNVES= 7.4036-03	ESGCL= 2.6257-01	EGBDL= 2.0677-01	EREMAN= 4.9245-01

TIME= 2.4922-02

DXC3= 1.3918-01	XC3= 1.0022-03	DX3= 1.3918-01	X3= 2.1531-06	OW3= F
DY3= -2.8521+01	Y3= -9.0451+00	MC3= 1.7100+04	PA3= 4.9973+04	3= 1.8447+03
FC3= 6.9748+07	STR3A= 4.7062-02	STR3B= 2.1531-07	DEP3A= 1.4013+00	EP3B= 0.0000
EP3A= 4.4257-02	EP3B= 0.0000	DSG3A= 2.9747+05	DSG3B= 1.6701+05	
SIG3A= 3.3362+04	SIG3B= 2.5837+00	DELAYP= 4.9973+04		
YF3A= 3.3388+04	YF3B= 2.4000+04	RPT3A= F	RPT3B= F	PAI3= 3.1970+05
SET13A= F	SET13B= T	SET23A= F	SET23B= F	SET33A= F
SET33B= F	SET43A= F	SET43B= T	SET53A= T	SET53B= F
SET63A= F	SET63B= T	SET73A= T	SET73B= F	
LSTRK3= T	FOR3= T	BUM3= T	ELSVES= -2.5531-05	ESPVES= 6.9042-07
LFT= 3.0588-02	FT= 1.0000+00	DELV3T= 2.7308-03	PW= 6.9121+04	MOMTUM= 1.4363-03
DFB= 0.0000	FB= 1.2469+00	DELV3B= 1.3410+03	PDR= 1.3765-01	PSB= 6.0751-01
VHM3= 1.3795+02	V3= 1.4731+03	UC3= 4.0987+02	CONFCT= F	
ET= 1.1064+09	ESLUW= 2.6269-01	EADDEN= 4.2913-08	EUPVES= 8.1429-07	EVESLG= 2.9125-02
EHDBTS= 0.0000	ELNVES= 7.3525-03	ESGCL= 1.7998-07	EGBDL= 2.0677-01	EREMAN= 4.9234-01

TIME= 2.6047-02

DX3= 4.6401+01	XC3= 2.1693-02	DX3= 4.6401+01	X3= 2.0693-02	SW3= F
DY3= -2.6725+01	Y3= -9.0762+00	MC3= 1.7100+04	PA3= 4.9356+04	R3= 1.7136+07
FC3= 9.2218+08	STR3A= 4.8616-02	STR3B= 2.0693-03	DEP3A= 1.3130+00	DEP3B= 0.0000
EP3A= 4.5784-02	EP3B= 0.0000	DSG3A= 2.7873+05	DSG3B= 5.5682+07	
SIG3A= 3.3686+04	SIG3B= 2.4000+04	DELAYP= 4.9356+04		
YF3A= 3.3712+04	YF3B= 2.4000+04	RPT3A= F	RPT3B= F	PAI3= 4.2270+06
SET13A= F	SET13B= F	SET23A= F	SET23B= F	SET33A= F
SET33B= F	SET43A= F	SET43B= F	SET53A= T	SET53B= T
SET63A= F	SET63B= F	SET73A= T	SET73B= T	
LSTRK3= T	FOR3= T	BUM3= T	ELSVES= -9.2226-04	ESPVES= 1.1735-01
DFT= 3.2355+01	FT= 1.0145+00	DELV3T= 3.1822+01	PW= 7.7967+04	MOMTUM= 6.2582-01
DFB= 0.0000	FB= 1.2469+00	DELV3B= 1.3410+03	PDB= 1.3601-01	PSB= 6.0751-01
VHM3= 2.3795+02	V3= 1.5049+03	UC3= 4.0987+02	CONFCT= F	
ET= 0.1064+09	ESLUG= 2.6269-01	EADDEN= 2.3698-06	EUPVES= 1.1878-01	EVESLG= 3.0300-02
ENDBTS= 0.0000	ELWVES= 6.4558-03	ESGCL= 2.0006-02	EGBDL= 2.0677-01	EREMAN= 4.9041-01

TIME= 2.6422-02

DX3= 6.4227+01	XC3= 4.2761-02	DX3= 6.4227+01	X3= 4.1761-02	SW3= F
DY3= -2.6119+01	Y3= -9.0861+00	MC3= 2.0560+04	PA3= 4.8794+04	R3= 1.7213+07
FC3= 0.0000	STR3A= 4.9111-02	STR3B= 4.1761-03	DEP3A= 1.2832+00	DEP3B= 6.3665+00
EP3A= 4.6271-02	EP3B= 2.0523-03	DSG3A= 2.7241+05	DSG3B= 6.7486+05	
SIG3A= 3.3790+04	SIG3B= 2.4108+04	DELAYP= 4.8794+04		
YF3A= 3.3815+04	YF3B= 2.4217+04	RPT3A= F	RPT3B= F	PAI3= 0.0000
SET13A= F	SET13B= F	SET23A= F	SET23B= F	SET33A= F
SET33B= F	SET43A= F	SET43B= F	SET53A= T	SET53B= T
SET63A= F	SET63B= F	SET73A= T	SET73B= T	
LSTRK3= T	FOR3= F	BUM3= F	ELSVES= -1.2120-03	ESPVES= 2.2902-01
DFT= 4.5864+01	FT= 1.0295+00	DELV3T= 6.5253+01	PW= 8.7127+04	MOMTUM= 9.1513-01
DFB= 0.0000	FB= 1.2469+00	DELV3B= 1.3410+03	PDB= 1.3447-01	PSB= 6.0751-01
VHM3= 1.3795+02	V3= 1.5384+03	UC3= 4.0987+02	CONFCT= F	
ET= 1.1000+09	ESLUG= 2.6269-01	EADDEN= 3.7440-06	EUPVES= 2.3193-01	EVESLG= 3.0677-02
ENDBTS= 5.1177-04	ELWVES= 6.1661-03	ESGCL= 3.8329-02	EGBDL= 2.0677-01	EREMAN= 4.8863-01

TIME= 3.1297-02

LXC3= 6.2040+01	XC3= 3.5691-01	DX3= 6.2040+01	X3= 3.4991-01	SW3= F
DY3= -1.7810+01	Y3= -9.1935+00	MC3= 2.0560+04	PA3= 4.1515+04	R3= 1.9524+07
FC3= 0.0000	STR3A= 5.4483-02	STR3B= 3.4991-02	DEP3A= 8.7505-01	DEP3B= 6.1497+00
EP3A= 5.1547-02	EP3B= 3.2598-02	DSG3A= 1.8575+05	DSG3B= 6.5124+05	
SIG3A= 3.4909+04	SIG3B= 2.7344+04	DELAYP= 4.1515+04		
YF3A= 3.4934+04	YF3B= 2.7446+04	RPT3A= F	RPT3B= F	PAI3= 0.0000
SET13A= F	SET13B= F	SET23A= F	SET23B= F	SET33A= F
SET33B= F	SET43A= F	SET43B= F	SET53A= T	SET53B= T
SET63A= F	SET63B= F	SET73A= T	SET73B= T	
LSOR3= T	FOR3= F	BUM3= F	ELSVES= -4.5109-03	ESPVES= 2.2902-01
DFO= 4.0254+01	FT= 1.2426+00	DELV3T= 5.9358+02	PW= 2.1735+05	MOMTUM= 9.0938-01
DFB= 0.0000	FB= 1.2469+00	DELV3B= 1.3410+03	PDB= 1.1440-01	PSB= 6.0751-01
VHM3= 1.3795+02	V3= 2.0667+03	UC3= 4.0987+02	CONFCT= F	
ET= 1.1064+09	ESLUG= 2.6269-01	EADDEN= 2.0665-05	EUPVES= 2.5339-01	EVESLG= 3.4838-02
ENDBT3= 5.2837-03	ELWVES= 2.8672-03	ESGCL= 3.5763-02	EGBDL= 2.0677-01	EREMAN= 4.6347-01

TIME= 3.1672-02

LXC3= 6.1752+01	XC3= 3.7413-01	DX3= 6.1752+01	X3= 3.7313-01	SW3= F
DY3= -1.7058+01	Y3= -9.2000+00	MC3= 2.0560+04	PA3= 0.0000	R3= 1.9698+07
FC3= 0.0000	STR3A= 5.4867-02	STR3B= 3.7313-02	DEP3A= 8.3806-01	DEP3B= 6.1211+00
EP3A= 5.1868-02	EP3B= 3.4899-02	DSG3A= 1.7789+05	DSG3B= 6.4818+05	
SIG3A= 3.4978+04	SIG3B= 2.7588+04	DELAYP= 0.0000		
YF3A= 3.5002+04	YF3B= 2.7683+04	RPT3A= F	RPT3B= F	PAI3= 0.0000
SET13A= F	SET13B= F	SET23A= F	SET23B= F	SET33A= F
SET33B= F	SET43A= F	SET43B= F	SET53A= T	SET53B= T
SET63A= F	SET63B= F	SET73A= T	SET73B= T	
LSTR3= F	FOR3= F	BUM3= F	ELSVES= -4.7482-03	ESPVES= 2.2902-01
DFT= 3.9392+01	FT= 1.2576+00	DELV3T= 6.3434+02	PW= 2.2648+05	MOMTUM= 9.0863-01
DFB= 0.0000	FB= 1.2469+00	DELV3B= 1.3410+03	PDB= 0.0000	PSB= 6.0751-01
VHM3= 1.3795+02	V3= 2.1074+03	UC3= 4.0987+02	CONFCT= F	
ET= 1.1064+09	ESLUG= 2.6269-01	EADDEN= 2.1218-05	EUPVES= 2.5415-01	EVESLG= 3.5096-02
ENDBT3= 5.6836-03	ELWVES= 2.6299-03	ESGCL= 3.5432-02	EGBDL= 2.0677-01	EREMAN= 0.0000

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TIME= 4.6375-02

DXC3= 4.4967+01	XC3= 1.1639+00	DX3= 4.4967+01	X3= 1.1629+00	SW3= F
DY3= 1.1118+01	Y3= -9.2169+00	MC3= 2.0560+04	PA3= 0.0000	R3= 2.5611+07
FC3= 0.0000	STR3A= 5.5648-02	STR3B= 1.1629-01	DEP3A= 0.0000	DEP3B= 4.4574+00
EP3A= 5.5038-02	EP3B= 1.1318-01	DSG3A= -6.6709+06	DSG3B= 4.7135+05	
SIG3A= 7.0364+03	SIG3B= 3.5870+04	DELAYP= 0.0000		
YF3A= 3.5675+04	YF3B= 3.5944+04	RPT3A= F	RPT3B= F	PAI3= 0.0000
SET13A= T	SET13B= F	SET23A= T	SET23B= F	SET33A= F
SET33B= F	SET43A= T	SET43B= F	SET53A= F	SET53B= T
SET63A= T	SET63B= F	SET73A= F	SET73B= T	
LSTRK3= F	FOR3= F	BUM3= F	ELSVES= -6.2608-03	ESPVES= 2.2902-01
DFT= 0.0000	FT= 1.4703+00	DELV3T= 1.2672+03	PW= 3.5641+05	MOMTUM= 8.6683-01
DFB= 0.0000	FB= 1.2469+00	DELV3B= 1.3410+03	PDB= 0.0000	PSB= 6.0751-01
VHM3= 1.3795+02	V3= 2.7403+03	UC3= 4.0987+02	CONFCT= F	
ET= 1.1064+09	ESLUG= 2.6269-01	EADDEN= 2.1218-05	EUPVES= 2.5415-01	EVESLG= 3.7665-02
EHDBTS= 2.1399-02	ELWVES= 1.1173-03	ESGCL= 1.8788-02	EGBDL= 2.0677-01	EREMAN= 0.0000

TIME= 7.7655-02

DXC3= -4.2988-01	XC3= 1.8816+00	DX3= -4.2988-01	X3= 1.8806+00	SW3= F
DY3= 1.0162+01	Y3= -9.2261+00	MC3= 2.0560+04	PA3= 0.0000	R3= 2.9715+07
FC3= 0.0000	STR3A= 5.6104-02	STR3B= 1.8806-01	DEP3A= 0.0000	DEP3B= 0.0000
EP3A= 5.5038-02	EP3B= 1.8434-01	DSG3A= -6.0973+06	DSG3B= -5.1585+05	
SIG3A= 1.2505+04	SIG3B= 4.3316+04	DELAYP= 0.0000		
YF3A= 3.5675+04	YF3B= 4.3452+04	RPT3A= F	RPT3B= F	PAI3= 0.0000
SET13A= T	SET13B= T	SET23A= T	SET23B= T	SET33A= F
SET33B= F	SET43A= T	SET43B= T	SET53A= F	SET53B= F
SET63A= T	SET63B= T	SET73A= F	SET73B= F	
LSTRK3= F	FOR3= F	BUM3= F	ELSVES= -6.4446-03	ESPVES= 2.2902-01
DFT= 0.0000	FT= 1.4703+00	DELV3T= 1.2672+03	PW= 3.5641+05	MOMTUM= 7.7092-01
DFB= 0.0000	FB= 1.2469+00	DELV3B= 1.3410+03	PDB= 0.0000	PSB= 6.0751-01
VHM3= 1.3795+02	V3= 2.7403+03	UC3= 4.0987+02	CONFCT= F	
ET= 1.1064+09	ESLUG= 2.6269-01	EADDEN= 2.1218-05	EUPVES= 2.5415-01	EVESLG= 3.7665-02
EHDBTS= 3.9241-02	ELWVES= 9.3342-04	ESGCL= 1.7170-06	EGBDL= 2.0677-01	EREMAN= 0.0000

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