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SYSTEM STATISTICAL RELIABILITY MODEL
AND
ANALYSIS

AEC Research and Development Report

Atomics International Division
Rockwell International

P.O. Box 309
Canoga Park, California 91304

MASTER

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**SYSTEM STATISTICAL RELIABILITY MODEL
AND
ANALYSIS**

**V. S. LEKACH
H. ROOD**

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FOREWORD

The work described here was done at the Atomics International Division of Rockwell International Corporation, under the direction of the Space Nuclear Systems Division, a joint AEC-NASA office. Project management was provided by NASA-Lewis Research Center and the AEC-SNAP Project Office.

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CONTENTS

	<u>Page</u>
Abstract	5
I. Introduction	7
II. Description of Model	9
A. Summary Description of System and Model	9
B. Power Conversion System Model	9
C. Reactor Model	11
III. Analyses Performed	13
A. Lifetime Behavior of Nominal System	13
B. Determination of Lifetime Sensitivity Coefficients	17
C. Degradation Reliability of System	21
IV. Conclusions	24
References	25
Appendix — Listing of the Control Program and the Reactor Model Program	27
NASA Supplementary Report Distribution List	54

TABLES

1. Base-Case Characteristics	13
2. Thermoelectric Module Sensitivity Coefficients	16
3. Radiator Sensitivity Coefficients	16
4. Pump Electromagnetic and Loop Hydraulic Coefficients	18
5. Reactor Sensitivity Coefficients	18
6. Combination of Uncertainties	22

FIGURES

	<u>Page</u>
1. System Schematic, Showing BOL Conditions	8
2. Schematic of System Model	10
3. Reactor Outlet Temperature and Core ΔT vs Time	12
4. Reactor Outlet Temperature vs Time and Electric Power	14
5. System Lifetime vs Power	15
6. Reactor Outlet Temperature vs Time, With Power Module Degradation Rate (%/year at 1085°) as Parameter	19
7. Probability Tree for Pump	20

ABSTRACT

A digital computer code was developed to simulate the time-dependent behavior of the 5-kwe Reactor Thermoelectric System. The code was used to determine lifetime sensitivity coefficients for a number of system design parameters, such as thermoelectric module efficiency and degradation rate, radiator absorptivity and emissivity, fuel element barrier defect constant, beginning-of-life reactivity, etc. A probability distribution (mean and standard deviation) was estimated for each of these design parameters. Then, error analysis was used to obtain a probability distribution for the system lifetime (mean = 7.7 years, standard deviation = 1.1 years). From this, the probability that the system will achieve the design goal of 5 years lifetime is 0.993. This value represents an estimate of the degradation reliability of the system.

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I. INTRODUCTION

The objectives of the studies described here were threefold:

- 1) Develop a model to predict the performance of the 5-kwe Reactor Thermoelectric (TE) System over its operating lifetime, from the start of full power operation until, through component degradation, the system is no longer capable of producing the required power level of 5 kwe. Use the model to determine the lifetime behavior of the system as it is nominally expected to perform in the flight environment.
- 2) Use the system model to determine lifetime sensitivity coefficients $[(\partial L/L)/(\partial X/X)]$ for each of the key design parameters affecting system performance. These coefficients allow the various component performance parameters to be ranked in the order of their influence on system lifetime, and thus provide a basis for allocating design margins and for allocating development effort toward those items which are most critical to mission success.
- 3) Determine a numerical estimate of the degradation reliability of the system. A probability distribution is estimated for each parameter for which a lifetime sensitivity coefficient has been determined. Using the law of propagation of errors, the mean system lifetime is determined, as well as the standard deviation in system lifetime. From these data, the probability that the system will fail in the degradation mode (i. e., will not, due to component degradation, achieve its design lifetime of 5 years) is calculated. One minus this failure probability is the system reliability, considering only the degradation modes of failure. The overall system reliability, of course, must include the catastrophic failure modes as well. Catastrophic failure is not treated in this report.

6532-5001

Figure 1. System Schematic, Showing BOL Conditions

II. DESCRIPTION OF MODEL

A. SUMMARY DESCRIPTION OF SYSTEM AND MODEL

The 5-kwe Reactor Thermoelectric System is designed to provide electric power in a space environment for 5 years. Thermal power is generated by the reactor, and transferred to the primary loop NaK coolant. Thermoelectric modules convert this thermal power to electrical power. The electrical power is used to drive the electromagnetic (EM) NaK pumps for both the primary and secondary loops, and to provide 5 kwe at the spacecraft mating interface. The secondary NaK loop and the radiator provide heat rejection capability for the system. A schematic of the system is shown in Figure 1.

The system model was developed from the digital computer models used to analyze each system component, and is subdivided into a power conversion system (PCS) model and a reactor model. The overall model is schematically illustrated in Figure 2. During nominal operation, the temperatures throughout the system increase, to compensate for degradation (particularly of the thermoelectric modules), and thus produce a constant 5 kwe of power. The end of system life occurs when 5 kwe can no longer be produced. In the present model, this may happen in one of two ways. Either the reactivity of the reactor becomes zero, or module degradation becomes so large that the required power cannot be produced, no matter how high the system temperatures are elevated.

B. POWER CONVERSION SYSTEM MODEL

The PCS model used in this study, called SYSTEM, is described in detail in Reference 1. The components modeled are: (1) the TE power modules, (2) the TE pump modules, (3) the radiator, (4) the primary and secondary NaK pumps, and (5) the primary and secondary loop piping. The radiator model is multinode, whereas all other components are single node. The model utilizes temperature-dependent power and pump TE module degradation of both efficiency and power per module.

The SYSTEM code starts by performing a system heat balance to determine beginning-of-life (BOL) temperatures around both primary and secondary loops. Also determined are the primary and secondary flow rates, and the reactor thermal power required. Then, a time step is taken, time- and temperature-

6532-5002

Figure 2. Schematic of System Model

dependent degradation is computed, and another heat balance is performed. This procedure is repeated until a given time has elapsed, or until the system can no longer produce the required power of 5 kwe. Thus, a time-dependent history of system temperatures, reactor power, and coolant flow rates is obtained. This part of the model assumes that the reactor can supply any thermal power level required, at any reactor outlet temperature required by the system. The "system" end of life (EOL) occurs when the module degradation is so large that no value of reactor power or outlet temperature will result in 5 kwe output. Figure 3 shows, for the nominal system, reactor outlet temperature and reactor ΔT as a function of time. The system EOL, shown as a dashed line, occurs at 8.8 years.

C. REACTOR MODEL

The reactor model used in these studies is based on the parametric reactor analysis code ZIP.⁽²⁾ It models the hot fuel element and the average fuel element in the reactor in 11 axial nodes, and determines time-dependent fuel temperatures, fuel swelling, and hydrogen leakage from the fuel. These are based on the time-dependent reactor power and inlet and outlet temperatures calculated previously by the SYSTEM subroutine. The reactor model then does a reactivity lifetime calculation, in which all reactivity losses (due to such factors as hydrogen leakage, fission product buildup, uranium burnout, xenon-135, etc.) are subtracted from the initial BOL excess reactivity. In this manner, the reactivity EOL is determined. For the nominal case, the reactivity EOL occurs at 7.7 years (see Figure 3). As will be shown later, either type of EOL may occur first.

A source program listing of the reactor subroutine and the control program is given in the appendix. A listing of the SYSTEM subroutine is given in Reference 1.

6532-5003

Figure 3. Reactor Outlet Temperature and Core ΔT vs Time

III. ANALYSES PERFORMED

A. LIFETIME BEHAVIOR OF NOMINAL SYSTEM

The overall system model was first used to determine the behavior of the base-case reactor TE system when operated at 5 kwe. Some of the key system parameters for this case are given in Table 1. Note that sufficient margin is available to provide a lifetime of 7.7 years, 2.7 years above the required 5. At this point, reactivity is zero, and the reactor outlet temperature is 1248° F.

TABLE 1
BASE-CASE CHARACTERISTICS

Parameter	Value at		
	BOL	5 years	7.7 years
Reactor			
Outlet Temperature (° F)	1122	1170	1248
ΔT (° F)	83.3	89.4	99.9
Power (kwt)	90.2	96.2	106.8
Thermoelectric Module			
Hot Cladding Temperature (° F)	1069	1113	1188
Cold Cladding Temperature (° F)	494	510	536
Power Module Degradation	0.000	0.051	0.1061
Power Module Efficiency (%)	6.65	6.24	5.63
Hot Reactivity (\$)	2.27	1.33	0.00
Hydrogen Loss (\$)	0.00	0.47	0.93

The first parametric study undertaken was to investigate the lifetime behavior of the nominal system when operated at power levels other than the required 5.0 kwe. The results of this study are illustrated in Figure 4, which shows time-dependent reactor outlet temperature for power levels between 4.8 and 5.3 kwe. Also shown in this figure is a dashed line, representing the set of points at which reactivity is zero. The same information is shown in Figure 5, which is a cross plot of the data of Figure 4. Note that, for powers

6532-5004

Figure 4. Reactor Outlet Temperature vs Time and Electric Power

Figure 5. System Lifetime vs Power

TABLE 2
THERMOELECTRIC MODULE SENSITIVITY COEFFICIENTS

Variable	Base Value	Sensitivity Coefficient [($\partial L/L$)/($\partial X/X$)]	Value Resulting in 5-year Lifetime
Power Modules			
Power per Module (Normalized)	1.0	+3.4	0.920
Module Efficiency (Normalized)	1.0	+4.8	0.930
Degradation Rate (fraction/year)	0.010	-0.30	0.019
Pump Modules			
Power per Module (Normalized)	1.0	-0.54	1.68
Module Efficiency (Normalized)	1.0	+0.63	0.62
Degradation Rate (fraction/year)	0.014	-0.001	Large

TABLE 3
RADIATOR SENSITIVITY COEFFICIENTS

Variable	Base Value	Sensitivity Coefficient [($\partial L/L$)/($\partial X/X$)]	Value Resulting in 5 year Lifetime
Emissivity	0.91	+5.3	0.85
Solar Absorptivity	0.40	-0.27	0.93
Fin-Tube Thermal Bond Resistance ($^{\circ}$ F)	2	-0.039	17.2
Radiator Dimensional Tolerance Factor (Normalized)	1.0	+3.2	0.87

below 5.15 kwe, reactivity EOL is the limiting parameter. Above 5.15 kwe, system EOL is limiting. From this study it was determined that:

- 1) System lifetime is sensitive to electric power demand at a rate of 1.3 years/0.1 kwe
- 2) The nominal lifetime margin of 2.7 years would be used up, if the system were operated at a power of 5.19 kwe.

B. DETERMINATION OF LIFETIME SENSITIVITY COEFFICIENTS

A number of key design variables were selected for sensitivity coefficient determination, and the system model was run to obtain each coefficient. In many cases, two off-nominal values were run for a given variable, where it was suspected that the lifetime-vs-variable curve was nonlinear. In these cases, one off-nominal point was selected on each side of the nominal point.

The results of the lifetime sensitivity coefficient study are shown in Tables 2 through 5, and in Figure 5.

Table 2 lists the variables associated with the thermoelectric power and pump modules that were selected for coefficient determination. These are the electrical power produced by a module for a given hot cladding and cold cladding temperature, the module efficiency for a given hot and cold cladding temperature, and the module degradation rate per year at an average temperature of 1085° F. Note that the power module parameters are much more critical than the pump module parameters. For example, reducing the power module efficiency by 7% (while holding all other parameters at their nominal values) results in reducing the nominal 7.7-year lifetime to the required 5.0-year value.

Figure 6 shows the strong influence of power module degradation rate on reactor outlet temperature. Virtually all of the PCS performance degradation over lifetime results from power module degradation (TE module degradation, in the model used here, applies both to power per module and module efficiency).

Table 3 lists the key radiator parameters and their sensitivity coefficients. Also given is the value of each parameter which would result in a 5.0-year lifetime (while holding all other parameters at their nominal values. From this table, it may be seen that the emissivity of the radiator surface is a critical parameter.

TABLE 4
PUMP ELECTROMAGNETIC AND LOOP
HYDRAULIC COEFFICIENTS

Parameter	Base Value	$(\partial L/L)/(\partial X/X)$
Primary Pump Throat Magnet Field Strength (G)	2380	+0.008
Secondary Pump Throat Magnet Field Strength (G)	2380	+0.005
Electrical Resistance of Pump Bus and Braze Joint (Normalized)	1.0	+0.013
Primary Loop Hydraulic Resistance	0.03576	-0.01
Secondary Loop Hydraulic Resistance	0.1519	-0.004

TABLE 5
REACTOR SENSITIVITY COEFFICIENTS

Variable	Base Value	Sensitivity Coefficient $[(\partial L/L)/(\partial X/X)]$	Value Resulting in 5-year Lifetime
Barrier Defect Constant, A_D (Fractional area of defects)	0.0015	-0.16	0.0064
Fuel-Cladding Gap at BOL (mils)	12	-0.034	Large
Hot BOL Reactivity (\$)	2.27	2.28	0.94
Reactivity Loss Rate, Excluding Hydrogen Loss (\$/year)	0.17	-3.19	0.36

6532-5006

Figure 6. Reactor Outlet Temperature vs Time, With Power Module Degradation Rate (%/year at 1085° F) as Parameter

6532-5007

Figure 7. Probability Tree for Pump

Table 4 lists the parameters selected for sensitivity coefficient analysis in the pump electromagnetics and loop hydraulics areas. Since the coefficients for all these variables are small, no column was entered showing the value resulting in a 5-year life.

Table 5 lists the key reactor variables selected for coefficient determination. From this table, it may be seen that the BOL fuel-cladding gap has a weak influence on lifetime, but that BOL reactivity and the nuclear reactivity loss rate are important. Here, the nuclear reactivity loss rate includes uranium burnout and fission product buildup.

C. DEGRADATION RELIABILITY OF SYSTEM

In general, reliability prediction is accomplished by: (1) construction of an analytical model to represent the system, (2) determination of the necessary physical constants, failure rates, and probability distributions required for input to the model, and (3) performing a calculation with the model to find the probability that the system will not fail prior to achieving its design objective (in this case, producing 5 kwe for 5 years). This overall success probability is, by definition, the predicted reliability of the system.

The standard approach to the problem of reliability prediction is the use of a probability tree to characterize all failure mechanisms for each individual component of the system. The separate trees for each component are then integrated into an overall system tree, to obtain a system reliability prediction. A quantitative success probability estimate is obtained for each block at the base level of the tree, and these probabilities are combined appropriately, through and-gates and or-gates, to determine the success probability at each higher level. An illustrative example of a probability tree for the pump is shown in Figure 7. The probability tree is an adequate model to represent the catastrophic failure mechanisms whereby the system fails suddenly.

For degradation modes of system failure, in which the loss of performance is gradual, and may or may not cause failure, the probability tree is not sufficient. This is particularly true for interactive modes of performance degradation; for example, degradation of the radiator emissivity coating results in increased system temperatures, which then results in increased degradation of power module efficiency. To properly account for degradational failure modes,

TABLE 6
COMBINATION OF UNCERTAINTIES

Variable	Base Value	σ_{Variable}	σ_{Life} (years)
Barrier Defect Constant, A_D	0.0015	0.00037	0.30
Fuel-Cladding Gap at BOL (mils)	12	1.75	0.07
Hot Reactivity at BOL (\$)	2.27	0.25	0.37
Reactivity Loss Rate — Nuclear (\$/year)	0.17	0.06	0.74
Radiator Emissivity	0.919	0.011	0.46
Emissivity Degradation Rate (fraction/year)	0	0.001	0.14
Solar Absorptivity	0.3	0.05	0.26
Absorptivity Degradation Rate (fraction/year)	-0.04	0.02	0.12
Fin-Tube Bond Thermal Resistance ($^{\circ}\text{F}$)	2	0.1	0.02
Bond Degradation Rate ($^{\circ}\text{F}/\text{year}$)	0.05	0.02	0.02
Radiator Dimensional Tolerance	1.0	0.0024	0.06
Pump Magnet Field (G)			
Primary	2380	15	0.004
Secondary	2380	15	0.001
Magnet Degradation (fraction/year)			
Primary	0.03	0.01	0.007
Secondary	0.03	0.01	0.015
Pump Bus and Braze Joint Electrical Resistance	1.0	0.04	0.050
Resistance Degradation Rate (fraction/year)	0.005	0.0017	0.005
Hydraulic Resistance			
Primary Loop	0.0358	0.0021	0.040
Secondary Loop	0.1519	0.0076	0.003
Root-Sum-Square Combination of σ_{Life} 's			1.1 year

the system model described in this report is used. Specifically, a probability distribution is estimated for each of the key system performance parameters affecting system lifetime. For each such parameter, a lifetime sensitivity coefficient is calculated, using the system performance model, as previously discussed. Then, the law of propagation of errors⁽³⁾ is used to obtain an estimate of the probability distribution associated with the system lifetime. From the mean and standard deviation of this distribution, the probability of not achieving the design lifetime due to excessive degradation may be determined. Degradation reliability is simply one minus the degradation failure probability.

Table 6 lists each of the key parameters, gives the expected mean value of each, and the estimated one-standard-deviation uncertainty in each. The appropriate sensitivity coefficients are then used to obtain the final column of Table 6, the lifetime uncertainty due to the expected uncertainty in the given parameter. Finally, root-sum-square combination of the lifetime uncertainties results in a standard deviation in the overall lifetime of 1.1 years. In conjunction with the mean lifetime estimate of 7.7 years, this implies a system degradation reliability of 0.993.

Note that the TE module performance parameters are not included in Table 6, and thus do not contribute to the degradation reliability value given. The justification for this omission is that the modules are still under development, and the exact level of their performance and the uncertainty in this performance, after completion of the development program, is virtually impossible to estimate at this time. Therefore, it was assumed that the development program will, as a minimum, achieve its current performance goals, which would result in module performance as good as, or better than, that used in the system model. Thus, the system degradation reliability quoted will be achieved or exceeded, if the TE module development program is successful.

IV. CONCLUSIONS

The principal conclusion of these studies is that the current reference 5-kwe Reactor Thermoelectric System is estimated to have a mean lifetime of 7.7 ± 1.1 years, which implies a degradation reliability of 0.993 and therefore a 0.7% probability of not achieving the design lifetime of 5 years. Although this estimate is approximate, its accuracy appears adequate for the current conceptual design phase. Further, the degree of overall design margin implied by this estimate appears to be adequate, and no design changes are recommended at this time.

REFERENCES

1. R. V. Anderson, "Performance Modeling of the 5-kwe Reactor Thermoelectric System," AI-AEC-13058 (April 3, 1973)
2. H. Rood, "Selected Computer Codes and Libraries, Volume I. ZIP - A Timeshare Program for SNAP Reactor Parametric Studies," AI-AEC-13076, Vol I (to be published)
3. A. W. Barsell, L. D. Montgomery, and J. E. Arnold, "Thermal Behavior of SNAP Reactor Fuel Elements During Atmospheric Reentry," NAA-SR-11502 (March 25, 1966)

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APPENDIX
LISTING OF THE CONTROL PROGRAM AND THE REACTOR MODEL PROGRAM

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CØNTRL

```

100$ØVR, SYSTEM
110$ØVR, REX
120$LIB, INTRP2
130$LIB, BNDHZR
140     INTEGER NCA(10)
150     REAL EPØWER(21)
160     REAL TØUTLT(21), PREACT(21), CØREDT(21)
170     REAL THØTCL(21), TCØLCL(21)
180     REAL EFFPØM(21), DGRPØM(21)
190     REAL EFFPMM(21), DGRPMM(21)
200     REAL TAVRAD(21), PRADTR(21), DTRADT(21)
210     REAL TINLET(21), RHØ(21)
220& , H3L(21), SNAME(30)
230     REAL XDATA(50,10)
240     REAL DUMMY(25)
250& , THØTCP(21), TCØLCP(21)
260& , TYME(21), VØLTAG(21)
270& , BASE(35)
280 CØMMØN DUMDUM(933), IJIDUM(4)
290     DATA SNAME/"S1","S2","S3","S4","S5","S6",
300&     "S7","S8","S9","S10","S11","S12","S13",
310&     "S14","S15","S16","S17","S18","S19","S20"
320&     ,"S21","S22","S23","S24","S25","S26","S27","S28","S29","S30"
330& /
340 80 CØNTINUE
350C BEGIN SUPER-LØØP, I.E., NEW FILE CASE.
360     PRINT, +, "NØ. CASES, CASE ID NUMBERS", +*
370     READ(50,), NCASES, (NCA(J), J = 1, NCASES)
380     DØ 82 J = 1, NCASES
390     JG = NCA(J)
400C TRANSFERS THE DATA FRØM FILE INTØ PRØGRAM
410     CALL ØPENF(1, SNAME(JG))
420     READ(1,), NVAR, (XDATA(J,J), J = 1, NVAR)
430     CALL CLØSEF(1)
440 82 CØNTINUE
450C GIVES NAMES TØ FILE DATA.VARIABLES "PØMPPM" THROUGH "RDJMTL"
460C ARE EXPLAINED IN "SYSTEM" RØUTINE.
470     DØ 83 M = 1, NCASES
480     PØMPPM = XDATA(1,M)
490     PØMEFF = XDATA(2,M)
500     PØMDGB = XDATA(3,M)
510     PMMPPM = XDATA(4,M)
520     PMMEFF = XDATA(5,M)
530     PMMDGB = XDATA(6,M)
540     PTFSIN = XDATA(7,M)
550     PTFSDG = XDATA(8,M)
560     STFSIN = XDATA(9,M)
570     STFSDG = XDATA(10,M)
580     PBUSIN = XDATA(11,M)
590     PBUSDG = XDATA(12,M)

```

CONTROL CONTINUED

```

600     PPIPFH = XDATA(13,M)
610     SPIPFH = XDATA(14,M)
620     REMMIN = XDATA(15,M)
630     REMMDG = XDATA(16,M)
640     RABSIN = XDATA(17,M)
650     RABSDG = XDATA(18,M)
660     RBNDIN = XDATA(19,M)
670     RBNDG = XDATA(20,M)
680     RDIMTL = XDATA(21,M)
690     NSTEPS = XDATA(22,M)
700C    MAX. NO. OF TIME STEPS (EACH STEP=1/2 YEAR)
710     EPWB = XDATA(23,M)
720C    ELECTRICAL POWER (CONSTANT IN TIME)
730C    "SYSTEM" WILL GIVE POWER AS A TIME-DEPENDENT VARIABLE.
740     KSYS=XDATA(31,M)
750     NWORD=XDATA(35,M)
760C    KSYS=0/1--QUANTITIES ARE TIME DEPENDENT/CONSTANT
770C    NWORD IS -2/0/1=EXECUTES SYSTEM AND SAVES OUTPUT FOR NEXT
780C    ROUTINE IN A FILE/EXECUTES SYSTEM/DOES NOT EXECUTE SYSTEM
790C    BUT READS THE FILE(FROM PREVIOUS CASE) FOR THE NEXT ROUTINE.
800     DO 81 N=24,30
810     NZ=N-23
820     DUMMY(NZ) = XDATA(N,M)
830C    EXPLAINED AT THE BEGINNING OF "REX"
840     CONTINUE
850     IF(KSYS.EQ.1.OR.NWORD.EQ.1)GOTO 30
860     LCNTRL = 2
870     CALL LINK(4,"OSYSSTE")
880     CALL SYSTEM(P0MPPM,
890&    P0MEFF,P0MDGB,EPWB,
900&    PMPPM,PMMEFF,PMMDGB,
910&    PTFSIN,PTFSDG,STFSIN,STFSDG,PBUSIN,PBUSDG,
920&    PPIPFH,SPIPFH,
930&    REMMIN,REMMDG,RABSIN,RABSDG,RBNDIN,RBNDG,RDIMTL,
940&    NSTEPS,LCNTRL,KCNTRL,
950&    EPWER,V0LTAG,FINTIM,
960&    T0UTLT,PREACT,C0REDT,
970&    TH0TCL,TC0LCL,
980&    TH0TCP,TC0LCP,
990&    EFFP0M,DGRP0M,EFFPMM,DGRPMM,
1000&    TAVRAD,PRADTR,DTRADT)
1010C    EXECUTES "SYSTEM" AND PROVIDES TIN,T0UT,C0REDT,POWER AS
1020C    FUNCTIONS OF TIME.
1030    PRINT 99, FINTIM
1040    99 FORMAT("FINTIM  =  ",F7.4)
1050    PRINT,
1060    IF(NWORD.NE.-2)GOTO 30
1070    WRITE(2,3333),NSTEPS
1080    LIFE=NSTEPS+1
1090    WRITE(2,500),(T0UTLT(I),C0REDT(I),PREACT(I),EPWER(I),I=1,LIFE)

```

CØNTRL CØNTINUED

```
1100 WRITE(2,600),FINTIM
1110 600 FØRMAT(F11.4)
1120 500 FØRMAT((4F11.4))
1130 3333 FØRMAT(I6)
1140 CALL CLØSEF(2)
1150C SAVES "SYSTEM" ØUTPUT FØR FUTURE USE (NWØRD=-2 HERE).
1160 30 CØNTINUE
1170 IF(NWØRD.NE.1)GØTØ 700
1180 CALL ØPENF(3,"MØRDAT")
1190C READS THE FILE WITH "SYSTEM" ØUTPUT FRØM SØME PREVIOUS RUN.
1200 READ(3,3333,ERR=66),NSTEPS
1210 LIFE=NSTEPS+1
1220 READ(3,500,ERR=67),(TØUTLT(I),CØREDT(I),PREACT(I),EPØWER(I),
1230& I=1,LIFE)
1240 READ(3,600,ERR=65),FINTIM
1250 GØ TØ 68
1260 66 PRINT,12," ERRØR IN NSTEPS READ",12
1270 CALL EXIT
1280 67 PRINT,12," ERRØR IN ARRAY READ",12
1290 CALL EXIT
1300 65 PRINT,12,"ERRØR IN READING FINTIM",12
1310 CALL EXIT
1320 68 CALL CLØSEF(3)
1330 700 CØNTINUE
1340 DØ 85 JTIME=1,21
1350 85 TYME(JTIME)=.5*FLØAT(JTIME-1)
1360 LIFE=1+NSTEPS
1370 IF(KSYS.EQ.0)GØTØ 35
1380C IF THE ØPTION TØ AVØID "SYSTEM" HAS BEEN USED, I.E., IF
1390C QUANTITIES ARE CØNSTANT IN TIME, TØUT, CØREDT, REACTØR PØWER
1400C ARE READ IN FRØM FILE WHICH SHØULD PRØVIDE THEM.
1410 DØ 10 I=1,LIFE
1420 TØUTLT(I)=XDATA(32,M)
1430 CØREDT(I)=XDATA(33,M)
1440 PREACT(I)=XDATA(34,M)
1450 10 EPØWER(I)=EPØWB
1460 35 CØNTINUE
1470 DØ 84 J = 1,LIFE
1480 TINLET(J) = TØUTLT(J)-CØREDT(J)
1490 84 CØNTINUE
1500 2300 FØRMAT( " SYSTEM E Ø L IS ",F10.2)
1510 CALL LINK(5,"ØREX")
1520C EXECUTES THE MAIN PART ØF THE PRØGRAM. FINDS REACTØR
1530C CHARACTERISTICS AS A FUNCTIØN ØF TIME.
1540 CALL REX(TINLET,CØREDT,PREACT,NSTEPS,RHØ,TIMEND,H3L,DUMMY)
1550 ZERØ=0.
1560 PRINT 2200,ZERØ,TIMEND
1570 2200 FØRMAT( " TIME (WHEN REACTIVITY IS",F10.1," ) = ",F10.2)
1580 VALUE=1200
1590 NLØC=0
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CØNTRL CØNTINUED

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1600 TTEMP=FUNCT1(TØUTLT, TYME, 21, VALUE, NLØC, 2)
1610 PRINT 2100, VALUE, TTEMP
1620 2100 FØRMAT( " TIME (WHEN TØUTLT IS ", F10.1, " ) = ",
1630&F10.2)
1640 IF(KSYS.EQ.0)PRINT 2300,FJNTIM
1650 PRINT,
1660 PRINT 2000,
1670 2000 FØRMAT(2X,"TIME",2X,"KWE",3X,"TØUT",3X,"TIN",2X,"DEL T",
1680& 3X,"KWT",3X,"RHØ",3X,"$ HL")
1690 PRINT 2001,(TYME(L),EPØWER(L),TØUTLT(L),TINLET(L),CØREDT(L),
1700& PREACT(L),RHØ(L),H3L(L),L = 1,LIFE)
1710 2001 FØRMAT((F5.1,F7.2,2F6.2,2F7.2,2F6.2))
1720 PRINT,
1730 IF(KSYS.EQ.1.ØR.NWØRD.EQ.1)GØTØ 40
1740 PRINT,1,"TIME THCL TCCL THCP TCCP PM EFF PM DEG PU EFF PU DEG"
1750 PRINT 2002, (TYME(I),THØTCL(I),TCØLCL(I),THØTCP(I),TCØLCP(I),
1760&EFFPØM(I),DGRPØM(I),EFFPMM(I),DGRPMM(I),I=1,LIFE)
1770 2002 FØRMAT((F4.1,4F5.4,F8.4))
1780 PRINT,1,"TIME VØLTAGE TAVRAD DTRADT P RAD"
1790 PRINT 2400,(TYME(I),VØLTAG(I),TAVRAD(I),DTRADT(I),PRADTR(I),
1800&I=1,LIFE)
1810 2400 FØRMAT(
1820&(F4.1,3X,F6.1,3X,F6.1,3X,F6.1,3X,F6.2))
1830 40 CØNTINUE
1840 PRINT, 1,"S-FILE DATA"
1850C PRINTS ØUT THE FILE THAT WAS USED.
1860 PRINT 2010, PØMPPM,PØMEFF,PØMDGB,PMMPPM,PMMEFF,PMMDGB,
1870&PTFSIN,PTFSDG,STFSIN,STFSDG,PBUSIN,PBUSDG,PIPFH,SPIPFH,
1880&REMMJN,REMMDG,RABSIN,RABSDG,RBNDIN,RBNDG,RDJMTL,EPØWB,
1890&(DUMMY(I),I=1,7),NSTEPS,KSYS,NWØRD
1900 2010 FØRMAT("/PØMPPM ",F8.3," PØMEFF ",F8.3,
1910&" PØMDGB ",F8.3," PMMPPM ",F8.3,"/PMMEFF ",F8.3,
1920&" PMMDGB ",F8.3," PTFSIN ",F8.1," PTFSDG ",F8.3,/
1930&"STFSIN ",F8.1," STFSDG ",F8.3," PBUSIN ",F8.3,
1940&" PBUSDG ",F8.3,"/PIPFH ",F8.5," SPIPFH ",F8.5,
1950&" REMMJN ",F8.3," REMMDG ",F8.3,"/RABSIN ",F8.3,
1960&" RABSDG ",F8.3," RBNDIN ",F8.1," RBNDG ",F8.3,/
1970&"RDJMTL ",F8.3," EPØWB ",F8.3," GAP ",F8.4,
1980&" BØLRHØ ",F8.3,"/ACØEFF ",E9.3," AEXP ",F8.1,
1990&" KPT ",J8," BUZ ",F8.4,"/AMO ",F8.5,
2000&" NSTEPS ",J8," KSYS ",J8," NWØRD ",J8)
2010 BASTIM=8.24
2020 IF(NCA(M).EQ.20)GØTØ 366
2030 CALL ØPENF(1,"BASDAT")
2040 READ(1,),BASTIM
2050 CALL CLØSEF(1)
2060C BASTIM IS THE LIFETIME ØF THE BASE CASE AND IS USED FØR
2070C THE SENSITIVITY CØEFFICIENTS CALCULATØNS (IF A FILE
2080C PARAMETER HAS BEEN CHANGED IT WILL PRØBABLY CAUSE A CHANGE IN
2090C LIFE TIME; HENCE THE SENS.CØEF.=DELTA LIFE/DELTA PARAMETER)

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CØNTRL CØNTINUED

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2100 CALL ØPENF(1,"S20")
2110 READ(1, ),NVAR,(BASE(I),I=1,NVAR)
2120 CALL CLØSEF(1)
2130 DØ 333 I=1,34
2140 DELTA=XDATA(I,M)-BASE(I)
2150 IF (ABS(DELTA).GT.0.000001)GØTØ 334
2160 GØTØ 333
2170 334 JACK=I
2180 GØTØ 335
2190 333 CØNTINUE
2200 335 DELTIM=TIMEND-BASTIM
2210 CØEFF=DELTIM/DELTA
2220 PRINT 336,JACK,CØEFF
2230 336 FØRMAT(/" CHANGING THE MEMBER NØ. ",I3,
2240&" ØF THE XDATA ARRAY"/"GIVES ",F12.4,/" AS THE
2250& SENSITIVITY CØEFFICIENT (DEL LIFE/DEL X)")
2260 IF(NCA(M).NE.20)GØTØ 399
2270 366 CØNTINUE
2280 WRITE(4, ),TIMEND
2290 CALL CLØSEF(4,"BASDAT")
2300 399 CØNTINUE
2310 IF(KSYS.EQ.0)GØTØ 83
2320 PRINT, +2
2330 PRINT 2016,
2340 PRINT 2004, (XDATA(I,M),I=32,34)
2350 2004 FØRMAT(5F14.6)
2360 2016 FØRMAT("      TØUTLT      CØREDT      PREACT")
2370 83 CØNTINUE
2380 GØTØ 80
2390C END SUPER-LØØP.
2400 END
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REX

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30000 SUBROUTINE      REX(TJNX,DELTX,P0WX,NXX,RH0,TIMEND,H3L,DUMMY)
30010 REAL TN(11),TCG(11),TF(11),TFS(11),TC(11),
30020&      TJNX(21),PHJA(11),
30030&      DELTX(21),P0WX(21),TMX(21),BUX(25),BUM(21),RH0(21)
30040&      ,H3L(21),DUMMY(25),TGS(11)
30050&,L00G(23),MIT(23)
30060 COMMON P0,ZAD,EAD,AZR,ALIF,0GP,G0LD,TFMX,TFME,CBL,CEL,AHL,
30070&      AKA,AK1,AK2,WHY,BSRCH,TMNF,BTB0L,BTE0L,SADC,TCCE,SADT,TCT,
30080&      SADH,TCHE,ZADC,ZADT,ZADH,GTH,AGL,CLTH,CGL,Z0P,CCLD,AC0EF,
30090&      AEXP,BUZ,P0WJNT,TIN,DELT
30100&      ,TCDGP(11),TIM(25),TFUEL(11),G(11),ATFU(25),ADCE(5),
30110&      ADT(5),ADHE(5),TBD(5),AM(10),TPPK(25),P(25),BTNA(11),
30120&      BTCDG(11),BDTGP(11),BTFUE(11),E0TN(11),E0TC(11),E0DT(11),
30130&      E0TF(11),TNAK(11),DTGP(11),AHZR(25)
30140&,H2L(21),HYL(25),HRCC(25),TSWELL(25),G00L(23)
30150&      ,0SSW(25),BUSW(25),TINZ(25),DELTZ(25),P0WZ(25)
30160&      ,AM1(25),AM2(25),AM3(25)
30170&      ,TCLAD(25,11)
30180&      ,KPT,NJK,JSTP,NSTEPS
30190C
30200      GAP=DUMMY(1)
30210C RADIAL GAP IN MILS
30220      B0LRH0=DUMMY(2)
30230C B 0 L REACTIVITY IN $
30240      AC0EF=DUMMY(3)
30250C 0FF=AC0EFF*EXP(AEXP/TFUEL)
30260      AEXP=DUMMY(4)
30270      KPT=DUMMY(5)
30280C -1/0/1/2=STANDARD/FULL/MIDI/MINI PRINT
30290      BUZ=DUMMY(6)
30300C C0RE AVERAGE BURNUP(MA/0)
30310      AM0=DUMMY(7)
30320C INITIAL AM(1) IN H.L. EXPRESSION BELOW
30330C
30340      CALL 0PENF(1,"AXDAT")
30350 READ(1,)ALIFE,ELN0,ALEN,AKWKG,DIACL,DIAFU,AZR,BSRCH
30360C ALIFE: LIFE IN YRS.
30370C ELN0: # 0F ELEMENTS
30380C ALEN: FUEL ELEMENT LENGTH IN IN.
30390C AKWKG: KWT/KG-U
30400C DIACL: UNCOATED CLADDING ID IN IN.
30410C DIAFU: FUEL MEAT DIA IN IN.
30420C AZR: INITIAL H/ZR
30430C BSRCH: 0/1=CALC. MAX. INITIAL H/ZR F0R ALL DELTA FUEL/BYPASS
30440&      ,CLTH,CCLD,Z0P,WHY,NJK
30450C CLTH: CLAD THICKNESS IN MILS
30460C CCLD CLAD DIFF. C0NST.
30470C Z0P: LE.99=AD DEPENDS 0N AM0 FR0M S-FILES/GT.99,LE.199=
30480C USE LINEAR AD (HE,CE,T)/GT.199=USE EXP0NENTIAL TYPE AD
30490C WHY: HYDR0GEN W0RTH ($/.INSUB H)

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REX CONTINUED

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30500C NJK: 0/1=SONZER-SWENSON/S8DR CORRELATION (NOT USED)
30510& ,AK1,AGL,CGL,GTH,AK2
30520C AK1,CGL,GTH,AK2 ARE USED IN THE HYDROGEN LOSS EQUATION BELOW:
30530C H.L.=CONST.*(AM(I)*CCLD*SQRT(P)*EXP(-AK1/T SUB C)/CLTH+
30540C AGL*CGL*P*EXP(-AK2/T SUB C)/GTH)
30550C I IS THE AXIAL TEMP. INDEX
30560& ,ADCE,ADT,ADHE,TBD
30570C ADCE (COLD END),ADT(TUBE),ADHE(HOT END); SEE ZOP ABOVE
30580C TBD: TIME FOR AD ARRAYS
30590& ,TMX,TJM
30600C TMX: ARRAY OF OPERATING TIME STEPS
30610C TJM: TIME ARRAY (MORE DETAILED AT BEGINNING THAN TMX)
30620& ,ZADC,SADC,TCCE,ZADT,SADT,TCT,ZADH,SADH,TCHE
30630C AM(I)=ZAD+SAD(1-EXP(DELTA TIME/TC))
30640C THIS EQUATION APPLIES FOR AM(I) AT THE COLD END
30650C (CE VALUES), AT THE TUBE (T), AT THE HOT END (HE) AND USES
30660C ZAD,SAD,TC AT CE,HE,T
30670& ,TN,TCG,TF,TFS,TGS,OGP,OPT,AMARG,PHJA
30680C TN: NAK COOLANT TEMP.
30690C TCG: CLAD/GLASS INTERFACE TEMP.
30700C TF: FUEL AVG. TEMP.
30710C TFS: FUEL SURFACE TEMP.
30720C OGP: -1/0/1=CONSTANT GAP/CALC.GAP/OPTIMIZES GAP WITH
30730C AMARG(BELOW) AT E O L
30740C OPT: 0/1=PRINT GAP (ONLY IF OGP.GE.0)/BYPASS
30750C AMARG: USED ABOVE IN OGP
30760C PHJA: AXIAL TEMP. DISTRIBUTION (BOTTOM TO TOP)
30770& ,FPK,UBUKK,SMK,BUMOM1,BUMOM2,PPBUK
30780C THE PARAMETERS BELOW ARE CONSTANTS IN THE FOLLOWING
30790C REACTIVITY LOSS EQUATIONS:
30800C FISSION PRODUCTS(I)=FPK*BURNUP(I)
30810C U BURNOUT(I)=UBUKK*BURNUP(I)
30820C SAMARIUM(I)=SMK0*(1-EXP(BURNUP(I)*SMK))
30830C PREPOISON BU(I)=PPBUK*(FRAC1*EXP(-BURNUP(I)*BUMOM1*219.05)
30840C +FRAC2*EXP(-BURNUP(I)*BUMOM2*219.05)), WHERE
30850C 219.05 IS A UNITS CONVERSION FACTOR, INDICES 1 AND 2
30860C REFER TO THE TWO POISONS IN THE REACTOR
30870& ,FRAC1,FRAC2,TDEFK,XENONK,HRDK,PDEFK,SMK0
30880C XENON(I)=XENONK*POWER(I)
30890C TEMPERATURE DEFECT(I)=TDEFK*TEMP(I)
30900C POWER DEF.(I)=PDEFK*POWER(I)
30910C H DEF.(I)=HRDK*POWER(I)
30920C THE INDEX I REFERS TO THE TIME STEPS
30930 CALL CLOSEF(I)
30940C
30950 NSTEPS=NX
30960 GOLD=GAP*1000.
30970 POWINT=0.
30980 BUZ=BUZ/(110.*8766.*5)
30982 POWXX=POWX(21)

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REX CONTINUED

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30983 DELTXX=DELTX(21)
30984 TJNXX=TJNX(21)
30990 CALL TEMPS(GAP,ALIFE,DIAFU,DIACL,ELNØ,ALEN,PHIA,
31000& TJNX,DELTX,PØWX,TMX,PØW,BUX,TN,TCG,TF,TFS,TGS,ØPT,AMARG)
31010C USES TJN,TØUT TØ FIND AXIAL TEMPERATURE DISTRIBUTIONS
31020 IF(BSRCH.GT.0) GØ TØ 12
31030 AZZ=AZR
31040 TMMMF=TMNF
31050 ATFUEL=ATFU(1)
31060 CALL BNDHZR(BBZR,AZZ,ATFUEL,TMMMF)
31070C FINDS H/ZR
31080 AZR=AZZ
31090 12 CONTINUE
31100C
31110 CALL BHLØSS(ALIFE,ELNØ,ALEN,DIACL,AHLØS,DIAFU,AMO)
31120C HYDRØGEN LØSS CALCULATIONS
31130 CALL BETABN(JSTP)
31140C BETA BØUNDARY CALCULATIONS
31150 GGP=GAP*1000.
31160C
31170 H2L(1)=0
31180 BUM(1)=0.0
31190 TJNX(1)=TJNZ(1)
31200 DELTX(1)=DELTZ(1)
31210 PØWX(1)=PØWZ(1)
31220 DØ 45 KK=2,21
31230 JJ=KK+2
31240 H2L(KK)=HYL(JJ)
31250 BUM(KK)=BUX(JJ)
31260 TJNX(KK)=TJNZ(JJ)
31270 DELTX(KK)=DELTZ(JJ)
31280 PØWX(KK)=PØWZ(JJ)
31290 45 CONTINUE
31300 TJNX(21)=TJNXX
31301 DELTX(21)=DELTX
31302 PØWX(21)=PØWXX
31310 DØ 48 LL=1,21
31320 H3L(LL)=H2L(LL)
31330 48 CONTINUE
31340C
31350 CALL XPLØDE(TJNX,DELTX,TMX,BUM,PØWX,RHØ,TIMEND,BØLRHØ
31360& ,FPK,UBUKK,SMK,BUMØM1,BUMØM2,PPBUK
31370& ,FRAC1,FRAC2,TDEFK,XENØNK,HRDK,PDEFK,SMKØ
31380& )
31390C BALANCES REACTIVITIES,FINDS EOL TIME (WHEN SUM ØF REACTIVITIES
31400C EQUALS ZERO)
31410 IF(KPT.LT.0)GØTØ 47
31420 JMZ=JSTP+1
31430 JM1N=JSTP
31440 JMAX=JSTP

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RELX CONTINUED

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31450      IF(KPT.LT.1) JMIN=1
31460      PRINT 31,
31470 31 FØRMAT(2X,"TIME",2X,"T IN",2X,"DEL T",2X,"PØW",3X,
31480&    "M A Z",3X,"TSWEL",2X,"ØFFSET",2X,"BU SW",4X,"GAP")
31490      PRINT 32,(TIM(J),TINZ(J),DELTZ(J),PØWZ(J),BUX(J),
31500&    TSWELL(J),ØSSW(J),BUSW(J),GØØL(J),J=JMIN,JMAX)
31510 32 FØRMAT(I6,F6.1,2F7.1,F8.4,F6.1,3F8.4)
31520      PRINT 33,TIM(JMZ),BUX(JMZ),ØSSW(JMZ),BUSW(JMZ),GØØL(JMZ)
31530 33 FØRMAT(I6,20X,F8.4,6X,3F8.4)
31540      PRINT,
31550      PRINT 85,
31560      PRINT 86,(TIM(J),AHZR(J),ATFU(J),P(J),HRCC(J),HYL(J),
31570&    AM1(J),AM2(J),AM3(J),J=JMIN,JMAX)
31580      PRINT 87,TIM(JMZ),AHZR(JMZ),P(JMZ),HYL(JMZ)
31590 85 FØRMAT(2X,"TIME",3X,"H/ZR",2X,"AV TF",2X,"PRESS",
31600&    4X,"CC/HR",2X,"$ H LØSS",2X,"AD1",5X,"AD2",5X,"AD3")
31610 86 FØRMAT(I6,F8.4,I6,2F9.5,F6.2,3F8.4)
31620 87 FØRMAT(I6,F8.4,6X,F9.5,9X,F6.2)
31630      PRINT,
31640C
31650      IF(KPT.GT.0) GØ TØ 74
31660      PRINT,
31670      PRINT 76
31680      PRINT 77,(BTNA(I),BTCDG(I),BDTGP(I),BTFUE(I),I=1,11)
31690      PRINT,
31700      PRINT 76
31710      PRINT 77,(EØTN(I),EØTC(I),EØDT(I),EØTF(I),I=1,11)
31720      PRINT,
31730      PRINT 76
31740      PRINT 77,(TNAK(I),TCDGP(I),DTGP(I),TFUEL(I),I=1,11)
31750 76 FØRMAT(5X,"TNAK",2X,"CLAD/GL",3X,"GAP DT",3X,"AVG FU")
31760 77 FØRMAT( 4F9.2)
31770 74 CØNTINUE
31780C
31790      PRINT,
31800      PRINT 35,PØW,ALIFE,BUX(JMZ),TIN,DELT,ELNØ,GGP,ALEN,DJAFU,
31810&    DJACL,TFMX,TFME,CBL,AHL,GØLD,AHLØS,AZR,ZØP,EAD,PØ,WHY,
31820&    BTBØL,TPPK(I),BTEØL,TPPK(JSTP)
31830&    ,AK1,CLTH,AGL,CGL,AK2
31840&    ,CCLD
31850 35 FØRMAT( 5X,"PØWER",2X,"LIFE(YR)",2X,"BU(MA/Ø)",5X,
31860&    "INLET",2X,"DEL TEMP"/2F10.1,F10.4,2F10.2/
31870&    4X,"ELM'TS",7X,"GAP",4X,"LENGTH",2X,"DJA FUEL",
31880&    2X,"DJA CLAD"/F10.0,2F10.2,2F10.4/
31890&    4X,"TFMX:Ø",4X,"TF:EØL",2X,"CC/HR(Ø)",2X,"H/ZR:EØL",
31900&    6X,"LIFE"/2F10.2,2F10.4,F10.2/
31910&    1X,"H LØSS($)",3X,"H/ZR(Ø)",3X,"AD(END)",2X,"AD(TUBE)",
31920&    2X,"PØ(PSJA)"/F10.2,F10.3,2F10.5,F10.2
31930&    /1X,"WØR($/NH)",4X,"BØL BT",2X,"BØL TMAX",4X,"EØL BT  EØL TMAX",

31940&    /F10.3,4F10.2/4X,"Q CLAD",3X,"CLAD TH",2X,"GLASS AG",

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REX CONTINUED

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31950& 1X,"GLASS CØN",3X,"Q GLASS"/
31960& F10.0,F10.1,F10.4,F10.5,F10.0/
31970& 2X,"CLAD CØN"/F10.0/)
31980C
31990 47 CØNTINUE
32000 LUMP=3+NSTEPS
32010 PRINT 198,
32020 DØ 101 J=1,LUMP
32030 TIMPAN=TIM(J)/8766.
32040 101 PRINT 199, TIMPAN,BUX(J),ØSSW(J),BUSW(J),GØØL(J),P(J)
32050 PRINT 197,
32060 DØ 102 J=1,LUMP
32070 TIMPAN=TIM(J)/8766.
32080 102 PRINT 196, TIMPAN,TSWELL(J),AHZR(J),ATFU(J)
32090 199 FØRMAT(F6.2,5F9.4)
32100 196 FØRMAT(F6.2,F9.1,F9.4,F9.1)
32110 198 FØRMAT(/" TIME MA % ØFFSET BU SW GAP PRESS")
32120 197 FØRMAT(/" TIME TSWELL H/ZR AV TF")
32130 GAPØ=1.
32140 CALL FINDGA(GØØL,LØØG,TIM,MIT,LUMP,GAPTIM,GAPØ)
32150C EXTRAPØLATES TØ FIND THE TIME WHEN THE GAP = GAPØ (SØME
32160C SPECIFIED GAP VALUE).
32170 PRINT 3001,GAPØ,GAPTIM
32180 3001 FØRMAT(/"TIME (WHEN THE GAP IS ",F10.1," ) = ",F10.2)
32190 RETURN
32200 END
32210C
32220C
32230C
32240 SUBRØUTINE TEMPS(GAP,ALIFE,DIAFU,DIACL,ELNØ,ALEN,PHJA,
32250& TINX,DELTX,PØWX,TMX,PØW,BUX,TN,TCG,TF,TFS,TGS,ØPT,AMARG)
32260C
32270 REAL TINX(21),DELTX(21),PØWX(21),TMX(21),
32280& PHJA(11)
32290& ,TN(21),TCG(21),TF(21),
32300& TFS(21),TGS(11),BUX(25)
32310C
32320 CØMMØN PØ,ZAD,EAD,AZR,ALIF,ØGP,GØLD,TFMX,TFME,CBL,CEL,AHL,
32330& AKA,AK1,AK2,WHY,BSRCH,TMNF,BTBØL,BTEØL,SADC,TCCE,SADT,TCT,
32340& SADH,TCHE,ZADC,ZADT,ZADH,GTH,AGL,CLTH,CGL,ZØP,CCLD,ACØEF,
32350& AEXP,BUZ,PØWJNT,TJN,DELT
32360& ,TCDGP(11),TIM(25),TFUEL(11),G(11),ATFU(25),ADCE(5),
32370& ADT(5),ADHE(5),TBD(5),AM(10),TPPK(25),P(25),BTNA(11),
32380& BTCDG(11),BDTGP(11),BTFUE(11),EØTN(11),EØTC(11),EØDT(11),
32390& EØTF(11),TNAK(11),DTGP(11),AHZR(25)
32400& ,H2L(21),HYL(25),HRCC(25),TSWELL(25),GØØL(23)
32410& ,ØSSW(25),BUSW(25),TJNZ(25),DELTZ(25),PØWZ(25)
32420& ,AMI(25),AM2(25),AM3(25)
32430& ,TCLAD(25,11)
32440& ,KPT,NJK,JSTP,NSTEPS

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REX CONTINUED

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32450C
32460 GP=GAP
32470 ALIF=ALIFE*8766.
32480 98 CONTINUE
32490 JSTEP=1
32500 GAP=GP
32510 GG=GAP
32520 POWINT=0.0
32530 BUX(1)=0
32540 DØ 17 J=1,11
32550 17 G(1)=GAP
32560 99 CONTINUE
32570C
32580 TTIM=TIM(JSTEP)
32590 NLIFE=NSTEPS+1
32600 NLØC=0
32610 TJN=FUNCT1(TMX,TJNX,NLIFE,TTIM,NLØC,1)
32620 TJNZ(JSTEP)=TJN
32630 NLØC=0
32640 DELT=FUNCT1(TMX,DELTX,NLIFE,TTIM,NLØC,1)
32650 DELTZ(JSTEP)=DELT
32660 NLØC=0
32670 POW=FUNCT1(TMX,POWX,NLIFE,TTIM,NLØC,1)
32680 POWZ(JSTEP)=POW
32690C
32700 JSTEP7=JSTEP+1
32710 POWINT=POWINT+POW*(TIM(JSTEP7)-TIM(JSTEP))
32720 BUX(JSTEP7)=POWINT*BUZ
32730 AKWFT=POW*12./(ELNØ*ALEN)
32740 TFM=0.
32750 TNAK(1)=TJN
32760 DMP = 0.9752/DIACL
32770 GMP = G(1)*DMP/0.0067
32780 AKWMP=AKWFT*85.*16./(95.*12.)
32790 TCDGP(1)=TJN+(TCG(1)-TN(1))*AKWMP*DMP
32800 TCLAD(JSTEP,1)=TCDGP(1)
32810 DTGP(1)=(TFS(1)-TGS(1))*AKWMP*GMP
32820 DTGL=(TGS(1)-TCG(1))*AKWMP*DMP
32830 TFUEL(1)=TCDGP(1)+DTGP(1)+(TF(1)-TFS(1))*AKWMP+DTGL
32840 TMNF=TCDGP(1)+DTGP(1)+DTGL
32850 DTM=DELT/80.
32860C
32870 DØ 10 J=2,11
32880 TNAK(J)=(TN(J)-TN(J-1))*DTM+TNAK(J-1)
32890 TCDGP(J)=TNAK(J)+(TCG(J)-TN(J))*AKWMP*DMP
32900 TCLAD(JSTEP,J)=TCDGP(J)
32910 GMP=G(1)*DMP/0.0067
32920 DTGP(J)=(TFS(J)-TGS(J))*AKWMP*GMP
32930 DTGL=(TGS(J)-TCG(J))*AKWMP*DMP
32940 TFUEL(J)=TCDGP(J)+DTGP(J)+(TF(J)-TFS(J))*AKWMP+DTGL
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REX CONTINUED

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32950 10 CONTINUE
32960C
32970   AT=TFUEL(1)+TFUEL(11)
32980   KST=1
32990   DØ 20      I=2,10
33000   AT =AT+TFUEL(I)*2.
33010   TFM=AMAX1(TFM,TFUEL(I))
33020   IF(TFUEL(I).LT.TFM) GØ TØ 20
33030   KST=KST+1
33040 20 CONTINUE
33050C
33060   TPPK(JSTEP)=TFUEL(KST)+(TF(KST)-TFS(KST))*AKWMP
33070   ATFU(JSTEP)=AT*0.05
33080   IF(JSTEP.EQ.1)TFMX=TFM
33090   IF(JSTEP.NE.1)GØ TØ 59
33100C
33110   DØ 59 IJ=1,11
33120   BTNA(IJ)=TNAK(IJ)
33130   BTCDG(IJ)=TCDGP(IJ)
33140   BDTGP(IJ)=DTGP(IJ)
33150   BTFUE(IJ)=TFUEL(IJ)
33160 59 CONTINUE
33170   IF(JSTEP.NE.10)GØ TØ 68
33180C
33190   DØ 68 IJ=1,11
33200   EØTN(IJ)=TNAK(IJ)
33210   EØTC(IJ)=TCDGP(IJ)
33220   EØDT(IJ)=DTGP(IJ)
33230   EØTF(IJ)=TFUEL(IJ)
33240 68 CONTINUE
33250C
33260   CALL GAG(ØPT,JSTEP,GG,GP,BUX(JSTEP7),DIAFU,AMARG,PHJA)
33270C FINDS THE GAP BETWEEN CLAD AND FUEL.
33280   JSTP=JSTEP-1
33290   IF(ØGP.LT.0)GØ TØ 16
33300   IF(TIM(JSTEP).LT.ALIF)GØ TØ 99
33310   IF(GG.NE.GP)GØ TØ 98
33320 16 CONTINUE
33330   TFME=TFM
33340   RETURN
33350   END
33360C
33370C
33380C
33390C
33400   SUBROUTINE BHLØSS(ALIFE,ELNØ,ALEN,DIACL,AHLØS,DIAFU,AMO)
33410C HYDRØGEN LØSS RØUTINE
33420   DIMENSION TC(10)
33430   CØMMØN PØ,ZAD,EAD,AZR,ALIF,ØGP,GØLD,TFMX,TFME,CBL,CEL,AHL,
33440&   AKA,AK1,AK2,WHY,BSRCH,TMNF,BTBØL,BTEØL,SADC,TCCE,SADT,TCT,

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REX CONTINUED

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33450& SADH,TCHE,ZADC,ZADT,ZADH,GTH,AGL,CLTH,CGL,ZØP,CCLD,ACØEF,
33460& AEXP,BUZ,PØWJNT,TJN,DELT
33470& ,TCDGP(11),TJM(25),TFUEL(11),G(11),ATFU(25),ADCE(5),
33480& ADT(5),ADHE(5),TBD(5),AM(10),TPPK(25),P(25),BTNA(11),
33490& BTCDG(11),BDTGP(11),BTFUE(11),EØTN(11),EØTC(11),EØDT(11),
33500& EØTF(11),TNAK(11),DTGP(11),AHZR(25)
33510& ,H2L(21),HYL(25),HRCC(25),TSWELL(25),GØØL(23)
33520& ,ØSSW(25),BUSW(25),TJNZ(25),DELTZ(25),PØWZ(25)
33530& ,AM1(25),AM2(25),AM3(25)
33540& ,TCLAD(25,11)
33550& ,KPT,NJK,JSTP,NSTEPS
33560C RAYMØND'S PRESSURE EQUATION
33570 FPRES(X,AT)=EXP(-8.8455+88.9801*X-78.8961*X**2+21.3731*X**3)
33580& *EXP((-12.972+9.770/*A-2.4984*X**2)*1.0E04/AT)
33590 DØ 777 JACK=1,10
33600 777 AM(JACK)=AMØ
33610 JKD=2
33620 AKA=AGL*CGL/(GTH*.0254)
33630 J=1
33640 ZAD=ZØP
33650 ZØP=AM(1)
33660 EAD=AM(2)
33670 BKD=CCLD/(CLTH*0.0254)
33680 AHZR(1)=AZR
33690 AREA=ALEN*3.14159*DIACL*2.54**2*0.1
33700 WØRH=WHY/.0287
33710 CCELM=22.4E03*6.3E22*0.7854*16.39*ALEN*DIAFU**2/(1.81*6.023E23)
33720 CCELM=CCELM/2.
33730 DØLCC=WØRH/CCELM
33740 CC=0.0
33750 DNH=0.0
33760 AT=ATFU(1)+459.7
33770 P(1)=FPRES(AZR,AT)
33780 PØ=P(1)*14.696
33790 IF(ZAD.GT.199.)GØ TØ 70
33800 IF(ZAD.GT.99.)GØ TØ 22
33810 28 CØNTINUE
33820 ALJF=ALIFE*8766.
33830 DØ 32 J=1,10
33840 TC(J)=(TCLAD(J,J)+TCLAD(J,J+1))*0.5+459.7
33850 CC=CC+(AM(J)*BKD*SQRT(P(J))*EXP(-AK1/TC(J))+
33860& AKA*P(J)*EXP(-AK2/TC(J)))*AREA*TJM(2)
33870 32 CØNTINUE
33880 DNH=CC/CCELM
33890 CCHR=CC/TJM(2)
33900 HRCC(1)=CCHR
33910 CBL=CCHR
33920 DLØS=DNH*WØRH
33930 HYL(1)=0
33940 HYL(2)=DLØS

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REX CONTINUED

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33950 J=2
33960 87 CONTINUE
33970 IF(TIM(J+1).GT.ALIF)TIM(J+1)=ALIF
33980 AHZR(J)=AHZR(J-1)-CC/CCELM
33990 AZR=AHZR(J)
34000 IF(ØGP.LT.0)ATFU(J)=ATFU(1)
34010 AT=ATFU(J)+459.7
34020 P(J)=FPRES(AZR,AT)
34030 IF(ZAD.GT.199.)GØ TØ 70
34040 IF(ZAD.GT.99.)GØ TØ 22
34050 29 CONTINUE
34060 TIME=TIM(J+1)-TIM(J)
34070 81 CC=0.
34080 DØ 57 J=1,10
34090 TC(I)=(TCLAD(J,I)+TCLAD(J,I+1))*0.5+459.7
34100 CC=CC+(AM(I)*BKD*SQRT(P(J))*EXP(-AK1/TC(I)))+
34110& AKA*P(J)*EXP(-AK2/TC(I)))*AREA*TIME
34120 57 CONTINUE
34130 DNH=DNH+CC/CCELM
34140 DLØS=DNH*WØRH
34150 HYL(J+1)=DLØS
34160C
34170 CCHR=CC/TIME
34180 HRCC(J)=CCHR
34190 IF(TIM(J+1).EQ.ALIF)GØ TØ 31
34200 J=J+1
34210 GØ TØ 87
34220 70 CONTINUE
34230 TMM=0.5*(TIM(J+1)+TIM(J))
34240 AM(1)=SADC*(1-EXP(-TMM/TCCE))+ZADC
34250 AM(2)=SADT*(1-EXP(-TMM/TCT))+ZADT
34260 AM(10)=SADH*(1-EXP(-TMM/TCHE))+ZADH
34270 AM1(J)=AM(1)
34280 AM2(J)=AM(2)
34290 AM3(J)=AM(10)
34300 DØ 76 JIL=3,9
34310 76 AM(JIL)=AM(2)
34320 IF(J.EQ.1)GØ TØ 28
34330 GØ TØ 29
34340 22 CONTINUE
34350 IF(TBD(JKD).GT.TIM(J+1))GØ TØ 13
34360 JKD=JKD+1
34370 13 TSTP=TBD(JKD)-TBD(JKD-1)
34380 SC=(ADCE(JKD)-ADCE(JKD-1))/TSTP
34390 ST=(ADT(JKD)-ADT(JKD-1))/TSTP
34400 SH=(ADHE(JKD)-ADHE(JKD-1))/TSTP
34410 24 TMKD=0.5*(TIM(J)+TIM(J+1))-TBD(JKD-1)
34420 AM(1)=ADCE(JKD-1)+SC*TMKD
34430 AM(2)=ADT(JKD-1)+ST*TMKD
34440 AM(10)=ADHE(JKD-1)+SH*TMKD
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REX CONTINUED

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34450    AM1(J)=AM(1)
34460    AM2(J)=AM(2)
34470    AM3(J)=AM(10)
34480    DØ 27 JIL=3,9
34490    27 AM(JIL)=AM(2)
34500    IF(J.EQ.1) GØ TØ 28
34510    GØ TØ 29
34520    31 CONTINUE
34530    AHZR(J+1)=AHZR(J)-CC/CCELM
34540    AZR=AHZR(J+1)
34550    P(J+1)=FPRES(AZR,AT)
34560    AHLØS=DNH*WØRH
34570    AZR=AHZR(1)
34580    CEL=CCHR
34590    AHL=AHZR(J+1)
34600    RETURN
34610    END
34620C
34630C
34640C
34650    SUBROUTINE BETABN(JJST)
34660    CØMMØN PØ,ZAD,EAD,AZR,ALIF,ØGP,GØLD,TFMX,TFME,CBL,CEL,AHL,
34670&    AKA,AK1,AK2,WHY,BSRCH,TMNF,BTBØL,BTEØL,SADC,TCCE,SADT,TCT,
34680&    SADH,TCHE,ZADC,ZADT,ZADH,GTH,AGL,CLTH,CGL,ZØP,CCLD,ACØEF,
34690&    AEXP,BUZ,PØWINT,TJN,DELT
34700&    ,TCDGP(11),TJM(25),TFUEL(11),G(11),ATFU(25),ADCE(5),
34710&    ADT(5),ADHE(5),TBD(5),AM(10),TPPK(25),P(25),BTNA(11),
34720&    BTCDG(11),BDTGP(11),BTFUE(11),EØTN(11),EØTC(11),EØDT(11),
34730&    EØTF(11),TNAK(11),DTGP(11),AHZR(25)
34740&    ,H2L(21),HYL(25),HRCC(25),TSWELL(25),GØØL(23)
34750&    ,ØSSW(25),BUSW(25),TJNZ(25),DELTZ(25),PØWZ(25)
34760&    ,AM1(25),AM2(25),AM3(25)
34770&    ,TCLAD(25,11)
34780&    ,KPT,NJK,JSTP,NSTEPS
34790    FBETA(Z)=1615.97+89.9747*(ALØG(Z))+3.8810*(ALØG(Z))**2
34800&    +0.13459*(ALØG(Z))**3
34810    BTBØL=FBETA(P(1))
34820    PZ=P(JSTP)
34830    BTEØL=FBETA(PZ)
34840    IF(BTBØL.LE.TPPK(1))GØ TØ 5
34850    6 K=JSTP-1
34860    DØ 14 I=2,K
34870    JD=J
34880    BTP=FBETA(P(1))
34890    IF(BTP.LE.TPPK(1))GØ TØ 17
34900    14 CONTINUE
34910    26 TFEL=TPPK(JSTP)
34920    IF(BTEØL.LE.TFEL)GØ TØ 9
34930    GØ TØ 2
34940    5 PRINT 22,TJM(1),BTBØL,TPPK(1)

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REX CONTINUED

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34950      G0 T0 6
34960 17 PRINT 22,TIM(ID),BTP,TPPK(ID)
34970      G0 T0 26
34980 9 PRINT 22,TIM(JSTP),BTE0L,TPPK(JSTP)
34990      G0 T0 2
35000 22 FORMAT( "CAUTION!! BETA PHASE FUEL HAS OCCURRED AT TIME",
35010& F8.1," HOURS."/"BETA FUEL TEMPERATURE IS ",F8.2,/"BUT PEAK
35020& FUEL TEMPERATURE IS ",F8.2/)
35030 2 RETURN
35040      END
35050C
35060C
35070C
35080 SUBROUTINE XPL0DE(TJNX,DELTX,TMX,BUM,P0WX,RH0,TIMEND,B0LRH0
35090& ,FPK,UBUKK,SMK,BUM0M1,BUM0M2,PPBUK
35100& ,FRAC1,FRAC2,TDEFK,XEN0NK,HRDK,PDEFK,SMK0
35110& )
35120C
35130 COMMON P0,ZAD,EAD,AZR,ALIF,0GP,G0LD,TFMX,TFME,CBL,CEL,AHL,
35140& AKA,AK1,AK2,WHY,BSRCH,TMNF,BTB0L,BTE0L,SADC,TCCE,SADT,TCT,
35150& SADH,TCHE,ZADC,ZADT,ZADH,GTH,AGL,CLTH,CGL,Z0P,CCLD,AC0EF,
35160& AEXP,BUZ,P0WINT,TJN,DELT
35170& ,TCDGP(11),TIM(25),TFUEL(11),G(11),ATFU(25),ADCE(5),
35180& ADT(5),ADHE(5),TBD(5),AM(10),TPPK(25),P(25),BTNA(11),
35190& BTCDG(11),BDTGP(11),BTfUE(11),E0TN(11),E0TC(11),E0DT(11),
35200& E0TF(11),TNAK(11),DTGP(11),AHZR(25)
35210& ,H2L(21),HYL(25),HRCC(25),TSWELL(25),G00L(23)
35220& ,0SSW(25),BUSW(25),TJNZ(25),DELTZ(25),P0WZ(25)
35230& ,AM1(25),AM2(25),AM3(25)
35240& ,TCLAD(25,11)
35250& ,KPT,NJK,JSTP,NSTEPS
35260C
35270 DIMENSION FP(21),UBU(21),SM(21),PPBU(21),TBAR(21),
35280& TDEF(21),XEN0N(21),HRD(21),PDEF(21),RL0SS(21),RH0(21)
35290& ,TMX(21),DELTX(21),BUM(21),P0WX(21),TJNX(21)
35300& ,0HR(21),XMT(21)
35310C
35320      D0 1 J=1,21
35330      FP(J)=BUM(J)*FPK
35340      UBU(J)=BUM(J)*UBUKK
35350      SM(J)=SMK0*(1.-EXP(BUM(J)/SMK))
35360      PPBU(J)=PPBUK*(FRAC1*EXP(-BUM(J)*219.05*BUM0M1)+
35370& FRAC2*EXP(-BUM(J)*219.05*BUM0M2))
35380      TBAR(J)=TJNX(J)+DELTX(J)/2
35390      TDEF(J)=TBAR(J)*TDEFK
35400      XEN0N(J)=P0WX(J)*XEN0NK
35410      HRD(J)=P0WX(J)*HRDK
35420      PDEF(J)=P0WX(J)*PDEFK
35430      RL0SS(J)=FP(J)+UBU(J)+SM(J)+H2L(J)+PPBU(J)+TDEF(J)+
35440& XEN0N(J)+HRD(J)+PDEF(J)

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REX CONTINUED

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35450   RH0(I)=B0LRH0-RL0SS(I)
35460   1 CONTINUE
35470   NL0C=0
35480   VALUE=0.
35490   LIFE=1+NSTEPS
35500C
35510   D0 5 I=1,21
35520   I12=22-I
35530   0HR(I)=RH0(I12)
35540   5 XMT(I)=TMX(I12)
35550   TIMEND=FUNCT1(0HR,XMT,LIFE,VALUE,NL0C,2)
35560   TIMEND=TIMEND/8766.
35570C
35580   IF(KPT.LT.0) G0 T0 78
35590   PRINT 77, TIMEND
35600   77 F0RMAT("E0L (YRS)",3X,F10.3)
35610   PRINT 20,
35620   D0 2 I=1,21
35630   2 PRINT 10, FP(I),UBU(I),SM(I),PPBU(I),H2L(I),TDEF(I),XEN0N(I),
35640&   HRD(I),PDEF(I),RL0SS(I),RH0(I)
35650   10 F0RMAT(11F6.2)
35660   20 F0RMAT(
35670&   "   FP   UBU   SM   PP0I   H2L
35680&   TDEF XEN0N HRD PDEF RL0SS RH0")
35690   78 CONTINUE
35700   RETURN
35710   END
35720C
35730C
35740C
35750   SUBROUTINE GAG(0PT,JSTEP,GG,GP,BU,DIAFU,AMARG,PHIA)
35760C CALCULATES GAP AND 0THER FUEL SWELLING CHARACTERISTICS
35770   C0MM0N P0,ZAD,EAD,AZR,ALIF,0GP,G0LD,TFMX,TFME,CBL,CEL,AHL,
35780&   AKA,AK1,AK2,WHY,BSRCH,TMNF,BTB0L,BTE0L,SADC,TCCE,SADT,TCT,
35790&   SADH,TCHE,ZADC,ZADT,ZADH,GTH,AGL,CLTH,CGL,Z0P,CCLD,AC0EF,
35800&   AEXP,BUZ,P0WINT,TIN,DELT
35810&   ,TCDGP(11),TIM(25),TFUEL(11),G(11),ATFU(25),ADCE(5),
35820&   ADT(5),ADHE(5),TBD(5),AM(10),TPPK(25),P(25),BTNA(11),
35830&   BTCDG(11),BDTGP(11),BTFUE(11),E0TN(11),E0TC(11),E0DT(11),
35840&   E0TF(11),TNAK(11),DTGP(11),AHZR(25)
35850&   ,H2L(21),HYL(25),HRCC(25),TSWELL(25),G00L(23)
35860&   ,0SSW(25),BUSW(25),TINZ(25),DELTZ(25),P0WZ(25)
35870&   ,AM1(25),AM2(25),AM3(25)
35880&   ,TCLAD(25,11)
35890&   ,KPT,NJK,JSTP,NSTEPS
35900C
35910   DIMENSION A0F(11),PHIA(11)
35920   ALAM=5000.
35930   GMX=0.
35940   0SSW(1)=0

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REX CONTINUED

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35950    BUSW(1)=0
35960    GØØL(1)=GG*1000.
35970    J=JSTEP
35980    JK=J+1
35990    DØ 82 JC=1,11
36000 82  G(JC)=GG
36010    IF(ØGP.LT.0)GØ TØ 10
36020    IF(JSTEP.GT.1)GØ TØ 20
36030    DØ 22 JA=1,11
36040 22  AØF(JA)=0.
36050 20  IF(TIM(JK).GT.ALIF)TIM(JK)=ALIF
36060    AXPJ=(1.-EXP(-(TIM(JK)-TIM(J))/ALAM))
36070    DØ 69 K=1,11
36080    AT=TFUEL(K)+459.7
36090    AØFF=ACØEF*EXP(AEXP/AT)
36100    DDV=(AØFF-AØF(K))*AXPJ
36110    IF(ØPT.GT.0)GØ TØ 7
36120    IF(K.NE.7)GØ TØ 7
36130    PRINT, AØFF,AØF(K)
36140 7   CØNTINUE
36150    IF(DDV.LE.0.)DDV=0.
36160    AØF(K)=AØF(K)+DDV
36170    ABU=BU*PHIA(K)*1.45
36180    BNUP=3.21*ABU
36190    IF(K.EQ.8) BUSW(J+1)=BNUP*DIAFU*5./2.8
36200    GR=(BNUP+AØF(K))*DIAFU*0.01/2.8
36210    G(K)=GG-GR/2.
36220    GRR=GR/2.
36230    GMX=AMAX1(GMX,GRR)
36240    IF(GRR.LT.GG)GØ TØ 81
36250    G(K)=0.
36260 81  CØNTINUE
36270 69  CØNTINUE
36280    TSWELL(J)=TFUEL(8)
36290    ØSSW(JK)=AØF(8)*DIAFU*5./2.8
36300    IF(ØPT.GT.0)GØ TØ 11
36310    PRINT 57,(G(K),K=2,11)
36320 57  FØRMAT(10F7.4)
36330 11  CØNTINUE
36340    IF(TIM(JK).LT.ALIF)GØ TØ 10
36350    IF(ØGP.LT.1)GØ TØ 10
36360    RG=GMX+AMARG
36370    DIF=ABS(GG-RG)
36380    IF(DIF.LT.0.00001)GØ TØ 10
36390    GP=RG
36400 10  JSTEP=JK
36410    GØLD=(GG-GMX)*1000.
36420    GØØL(JK)=GØLD
36430    RETURN
36440    END
```

REX CONTINUED

```
36450 SUBROUTINE FINDGA(G00L,L00G,TIM,MIT,LUMP,GAPTIM,GAP0)
36460C G00L(LUMP) IS THE X-ARRAY; TIM IS THE Y-ARRAY. SINCE G00L
36470C IS IN DESCENDING ORDER, HAVE TO INVERT IT TO L00G (ALSO INVERT
36480C TIM TO MIT). GAPTIM IS THE CALCULATED TIME AT WHICH GAP=GAP0.
36490 REAL G00L(LUMP),L00G(LUMP),TIM(LUMP),MIT(LUMP)
36500 DO 1 I=1,LUMP
36510 J=LUMP-I+1
36520 L00G(J)=G00L(I)
36530 I MIT(J)=TIM(I)
36540 NL0C=0
36550 GAPTIM=FUNCT1(L00G,MIT,LUMP,GAP0,NL0C,2)
36560 GAPTIM=GAPTIM/8766.
36570 RETURN
36580 END
```

BNDHZR

```

40000 SUBROUTINE BNDHZR(BBZR,AZZ,ATFUEL,TMMMF)
40005 COMMON DUMDUM(933),IBUM(4)
40010 FBP(Y)=1.434E-10*EXP(.01806*Y)
40020 FPRES(X,AT)=EXP(-8.8455+88.8901*X-78.8961*X**2+21.3731*X**3)
40030& *EXP((-12.972+9.7707*X-2.4984*X**2)*1.0E04/AT)
40040 ADD=.1
40050 AZZR=AZZ
40060 3 CONTINUE
40070 AT=ATFUEL+459.7
40080 P1=FPRES(AZZR,AT)
40090 IF(AZZR.GT.1.7)GØ TØ 6
40100 BZR=AZZR+ADD
40110 GØ TØ 7
40120 6 BZR=AZZR-ADD
40130 7 P2=FPRES(BZR,AT)
40140 A=(AZZR-BZR)/(ALØG(P1)-ALØG(P2))
40150 B=AZZR-A*ALØG(P1)
40160 BP=FBP(TMMMF)
40170 BHZR=AZZR
40180 AZZR=A*ALØG(BP)+B
40190 DJF=BHZR-AZZR
40200 IF(DIF.LT.0.0)DJF=-DIF
40210 IF(DIF.LT.0.001)GØ TØ 4
40220 ADD=ADD*.2
40230 GØ TØ 3
40240 4 AZZ=AZZR
40250 RETURN
40260 END

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INTRP2

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11000 FUNCTION FUNCT2(X1,X2,Z,NP1,NP2,LP1,XP1,XP2,JS,JC)
11010C
11020C FEBRUARY 4, 1972
11030C TWO-DIMENSIONAL LAGRANGIAN INTERPOLATION ROUTINE
11040C X1 = FIRST ABSCISSA ARRAY
11050C (MUST BE IN ASCENDING ØRDER IN ARRAY)
11060C X2 = SECOND ABSCISSA ARRAY
11070C (MUST BE IN ASCENDING ØRDER IN ARRAY)
11080C Z = TWO-DIMENSIONAL ØRDINATE ARRAY
11090C NP1= LENGTH ØF X1 ARRAY
11100C NP2= LENGTH ØF X2 ARRAY
11110C LP1= TØTAL FIRST DIMENSIONAL STØRAGE FØR Z ARRAY

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INTRP2 CONTINUED

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11120C      XP1= VALUE OF FIRST ABSCISSA FOR INTERPOLATION
11130C      XP2= VALUE OF SECOND ABSCISSA FOR INTERPOLATION
11140C      JS  REMEMBERS PLACE IN TABLE (MUST BE SET EQUAL
11150C           TO ZERO BEFORE FIRST CALL TO FUNCTION)
11160C      IC  CONTROLS INTERPOLATION METHOD:
11170C           = 1 FOR LINEAR INTERPOLATION
11180C           = 2 FOR LAGRANGIAN INTERPOLATION
11190C      FUNCT2 SET TO CORRESPONDING ORDINATE VALUE
11200C      (FUNCT2 WILL EXTRAPOLATE)
11210C
11220      DIMENSION X1(1),X2(1),Z(LP1,NP2),Y(20)
11230      DIMENSION ED(3),XA(3),YA(3)
11240      EQUIVALENCE (ED(1),XA(1))
11250      NJNT=3
11260      JS1=0
11270      IF(NP1.GE.3 .AND. IC.GE.2) GO TO 15
11280C      LINEAR INTERPOLATION
11290      NN=1
11300      J=0
11310      IF(NP1.LE.1) GO TO 38
11320      NJNT=2
11330      15 NN=MAX0(2,NP1+2-NJNT)
11340      XP=XP1
11350      NN1=2
11360      IF(JS.LE.1 .OR. JS.GE.NP1) GO TO 102
11370C      TEST WHICH DIRECTION TO SEARCH - MUST FIND THE SMALLEST
11380C      X1 GREATER THAN XP, BUT WITH J GREATER THAN 1 AND LESS
11390C      THAN NP1 (OR EQUAL TO NP1 FOR LINEAR INTERPOLATION)
11400      211 NN1=JS
11410      IF(XP.LT.X1(NN1)) GO TO 101
11420C      SEARCH UPWARD IN TABLE
11430      102 DO 20 J=NN1,NN
11440      IF(XP.LE.X1(J)) GO TO 10
11450      20 CONTINUE
11460      J=NN
11470      GO TO 10
11480C      SEARCH DOWNWARD IN TABLE
11490      101 DO 21 J=2,NN1
11500      J=NN1-J+1
11510      IF(XP.GT.X1(J)) GO TO 11
11520      21 CONTINUE
11530      J=1
11540      11 J=J+1
11550      10 SPAN=1.0E-06*XP
11560      NN=0
11570      DO 12 J=1,NJNT
11580      NN1=J+J-2
11590      ED(J)=XP-X1(NN1)
11600      12 IF(ABS(ED(J)).LE.SPAN) NN=NN1
11610      IF(NN.EQ.0) GO TO 90

```

INTRP2 CONTINUED

```

11620 38 DØ 40 K=1, NP2
11630 40 Y(K)=Z(NN, K)
11640 FUNCT2=FUNCT1(X2, Y, NP2, XP2, JS1, IC)
11650 GØ TØ 80
11660 90 DØ 93 J=1, NJNT
11670 NN1=J+J-2
11680 DØ 92 K=1, NP2
11690 92 Y(K)=Z(NN1, K)
11700 YA(J)=FUNCT1(X2, Y, NP2, XP2, JS1, IC)
11710 93 XA(J)=X1(NN1)
11720 NN1=3
11730 IF(NJNT.LT.3) NN1=2
11740 JS1=0
11750 FUNCT2=FUNCT1(XA, YA, NN1, XP, JS1, IC)
11760 80 JS=J
11770 RETURN
11780 END
12000 FUNCTION FUNCT1(X, Y, NP, XPJ, JS, IC)
12010C
12020C FEBRUARY 4, 1962
12030C THREE POINT LANGRANGIAN INTERPOLATION
12040C OR
12050C TWO POINT LINEAR INTERPOLATION
12060C X = ABSCISSA ARRAY
12070C (MUST BE IN ASCENDING ORDER IN ARRAY)
12080C Y = ORDINATE ARRAY
12090C NP = LENGTH OF X & Y ARRAYS
12100C XPJ= VALUE OF ABSCISSA FOR INTERPOLATION
12110C JS REMEMBERS PLACE IN TABLE (MUST BE SET TO
12120C ZERO BEFORE FIRST CALL TO FUNCTION)
12130C IC CONTROLS INTERPOLATION METHOD:
12140C = 1 FOR LINEAR INTERPOLATION
12150C = 2 FOR LAGRANGIAN INTERPOLATION
12160C FUNCT1 SET TO CORRESPONDING ORDINATE VALUE
12170C (FUNCT1 WILL EXTRAPOLATE)
12180C
12190 DIMENSION X(1), Y(1), ED(3)
12200 EQUIVALENCE (ED(1),E1), (ED(2),E2), (ED(3),E3)
12210 NJNT=3
12220 IF(NP.GE.3 .AND. IC.GE.2) GØ TØ 15
12230C LINEAR INTERPOLATION
12240 NN=1
12250 J=0
12260 IF(NP.LE.1) GØ TØ 38
12270 NJNT=2
12280 15 NN=MAX0(2, NP+2-NJNT)
12290 XP=XPJ
12300 NN1=2
12310 IF(JS.LE.1 .OR. JS.GE.NP) GØ TØ 102
12320C TEST WHICH DIRECTION TO SEARCH - MUST FIND THE SMALLEST

```

INTRP2 CONTINUED

```

12330C      X GREATER THAN XP, BUT WITH J GREATER THAN 1 AND LESS
12340C      THAN NP (OR EQUAL TO NP FOR LINEAR INTERPOLATION)
12350  211 NN1=JS
12360      IF(XP.LT.X(NN1)) GO TO 101
12370C      SEARCH UPWARD IN TABLE
12380  102 DO 20 J=NN1,NN
12390      IF(XP.LE.X(J)) GO TO 10
12400  20 CONTINUE
12410      J=NN
12420      GO TO 10
12430C      SEARCH DOWNWARD IN TABLE
12440  101 DO 21 J=2,NN1
12450      J=NN1-J+1
12460      IF(XP.GT.X(J)) GO TO 11
12470  21 CONTINUE
12480      J=1
12490  11 J=J+1
12500C      INTERPOLATE FOR FUNCT1 IN Y-TABLE CORRESPONDING TO
12510C      XP IN X-TABLE USING THREE POINT LAGRANGIAN
12520C      INTERPOLATION SCHEME
12530  10 SPAN=1.0E-06*XP
12540      NN=0
12550      DO 12 J=1,NJNT
12560      NN1=J+J-2
12570      ED(J)=XP-X(NN1)
12580  12 IF(ABS(ED(J)).LE.SPAN) NN=NN1
12590      IF(NN.EQ.0) GO TO 90
12600  38 FUNCT1=Y(NN)
12610      GO TO 80
12620  90 E12=X(J-1)-X(J)
12630      IF(NJNT.EQ.3) GO TO 360
12640      FUNCT1=Y(J)-(Y(J)-Y(J-1))*E2/E12
12650      GO TO 80
12660  360 E13=X(J-1)-X(J+1)
12670      E23=X(J)-X(J+1)
12680  36 FUNCT1=Y(J-1)*E2*E3/(E12*E13)
12690&      -Y(J) *E1*E3/(E12*E23)
12700&      +Y(J+1)*E1*E2/(E13*E23)
12710  80 JS=J
12720      RETURN
12730      END

```

AXDAT

100 10,
110 85,
120 16,0,
130 .9552,.9352,
140 1.638,1,
150 25,2900,98,.933,0,
160 14750,1,2.4125,2.5,20800,
170 .0015,.0015,0,0,0,
180 .0015,.0015,0,0,0,
190 .0015,.0015,0,0,0,
200 0,100000,0,0,0,
210 0,4383,8766,13149,17532,21915,26298,30681,
220 35064,39447,43830,48213,52596,56979,61362,65745,
230 70128,74511,78894,83277,87660,
240 0,876.6,2191.5,4383,8766,13149,17532,21915,26298,
250 30681,35064,39447,43830,48213,52596,56979,61362,
260 65745,70128,74511,78894,83277,87660,92043,96426,
270 .01,.05,2000,
280 .00125,.006,2000,
290 .01,.05,2000,
300 1120,1125,1134,1146,1161,1177,1192,1207,1219,1228,1233,
310 1122,1129,1140,1154,1170,1186,1202,1215,1226,1232,1235,
320 1138,1171,1204,1235,1260,1280,1293,1296,1289,1274,1251,
330 1135,1163,1191,1218,1241,1260,1272,1277,1275,1265,1248,
340 1122,1130,1143,1158,1174,1190,1206,1219,1228,1234,1235,
350 0,1,.004,
360 0.31,0.659,0.960,1.193,1.339,1.389,1.339,1.193,0.960,
370 0.659,0.310,
380 9.047,
390 10.797,
400 -.0434,
410 .02697,
420 .09352,
430 3,
440 .19,
450 .81,
460 .00186,
470 .00163,
480 .00093,
490 .00037,
500 1.04,

S1

100 35,
110 1,
120 1,
130 .01,
140 1.,
150 1,
160 .014,
170 2380,
180 .01,
190 2380,
200 .01,
210 1.0,
220 .005,
230 .03576,
240 .1519,
250 .919,
260 0,
270 .3,
280 -.04,
290 2.4,
300 .0208,
310 1.0,
320 20,
325 5,
330 .007,
340 7.54,
350 5.76E06,
360 -27000,
370 -1,
380 .102,
390 .0015,
400 0,
410 1200,
420 90,
430 110,
440 1,

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