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SYSTEM STATISTICAL RELIABILITY MODEL AND ANALYSIS

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SYSTEM STATISTICAL RELIABILITY MODEL AND ANALYSIS

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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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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.

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.

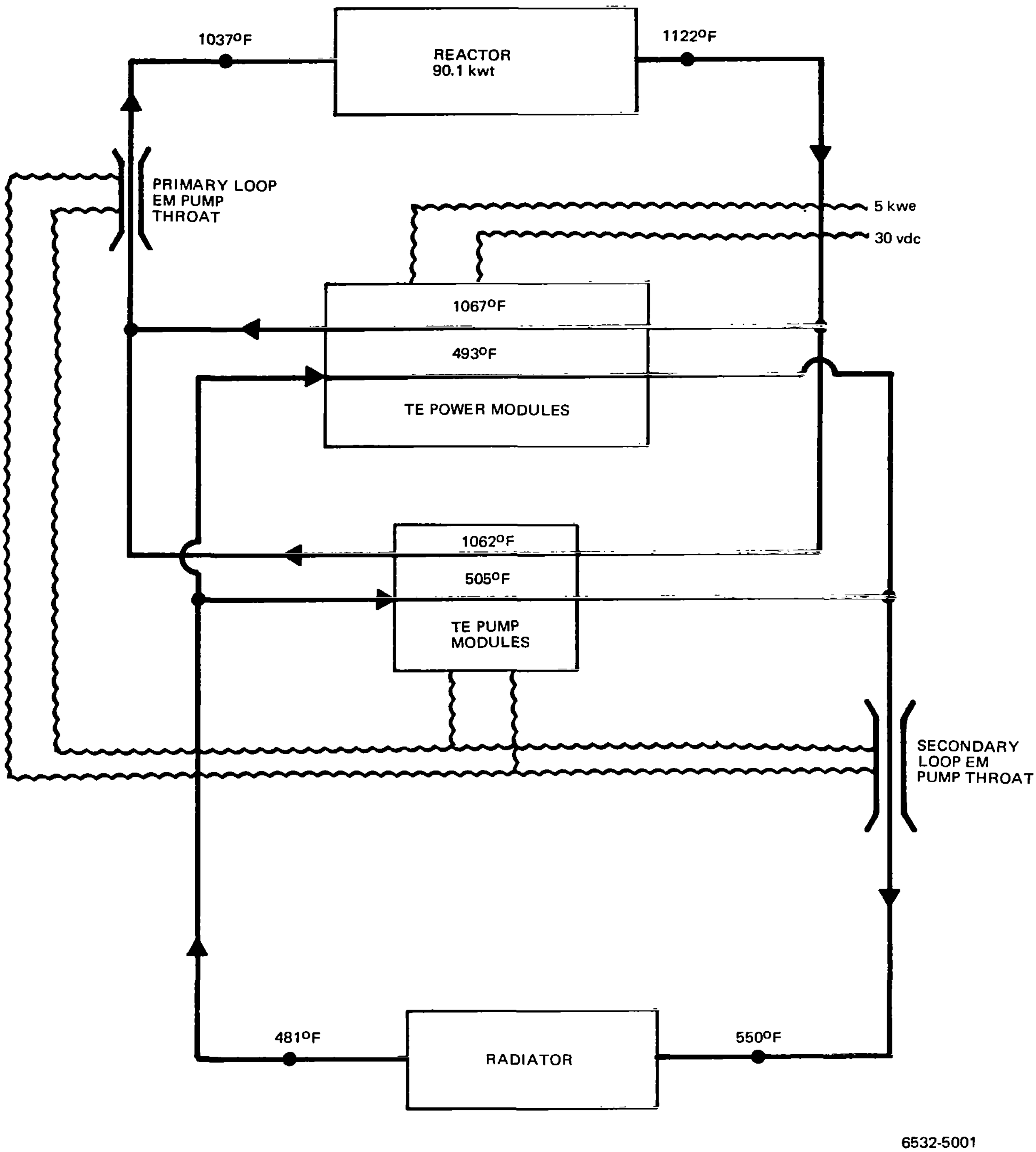

Figure 1. System Schematic, Showing BOL Conditions

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-

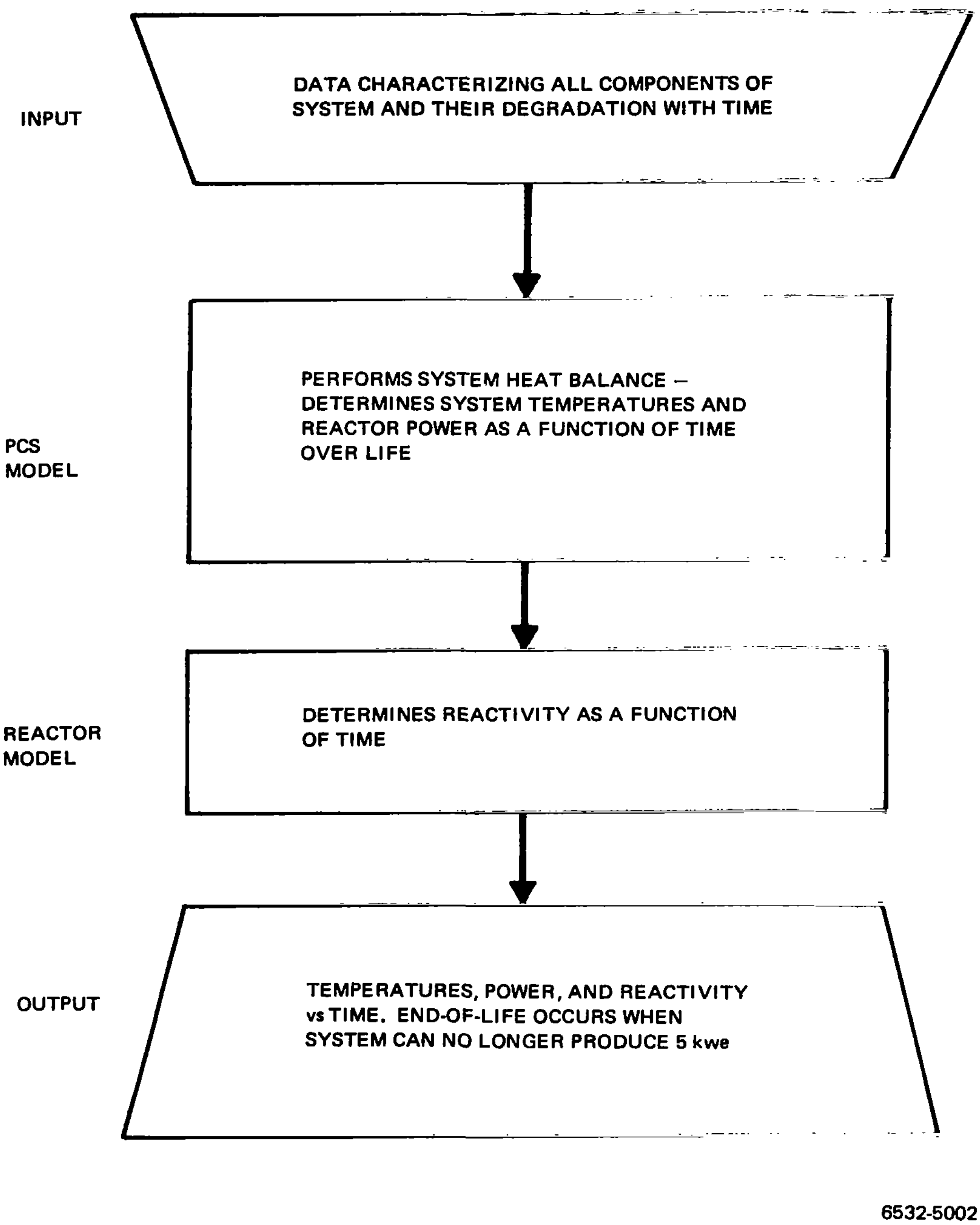

Figure 2. Schematic of System Model

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.

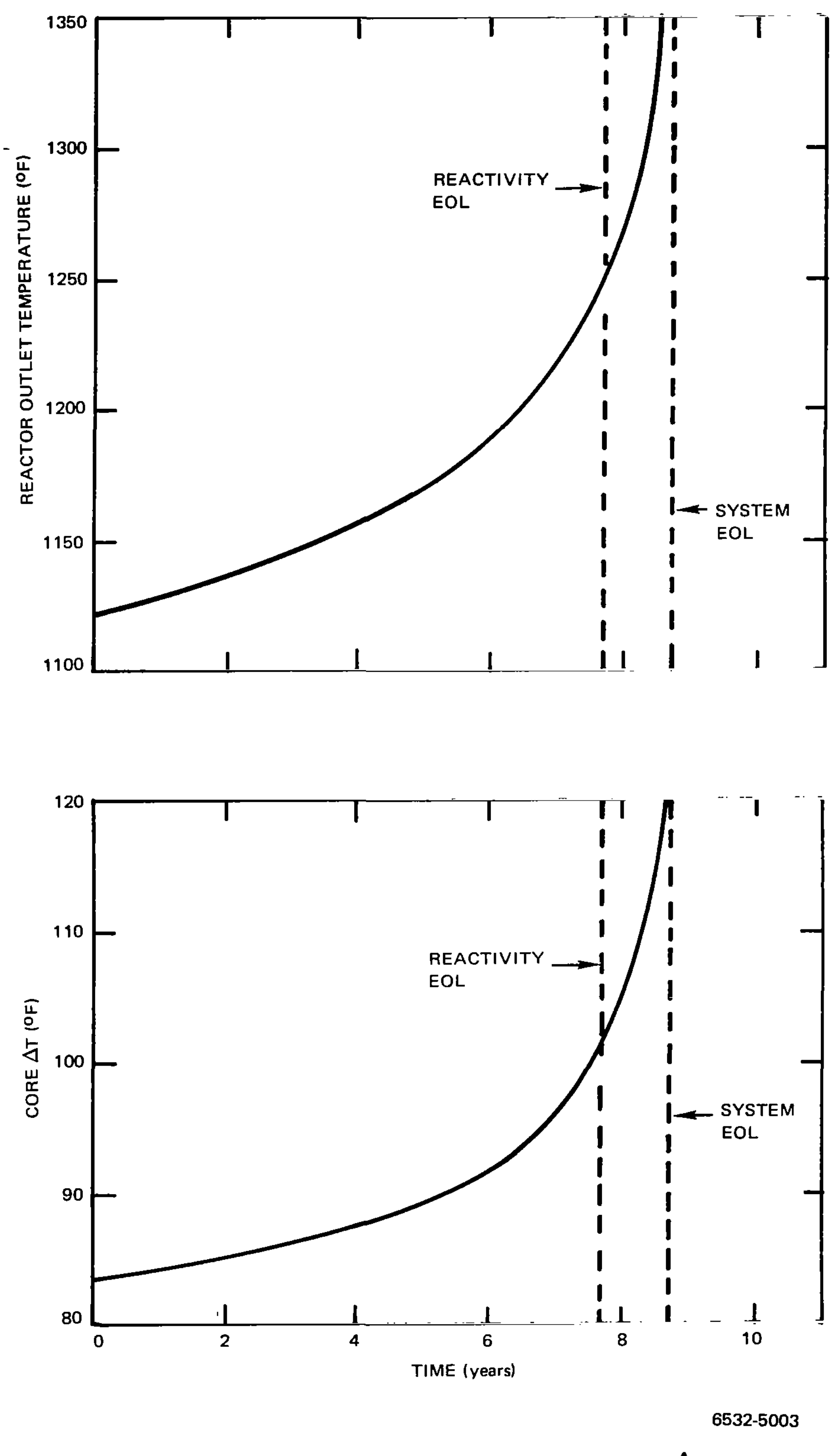

Figure 3. Reactor Outlet Temperature and Core ΔT vs Time

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

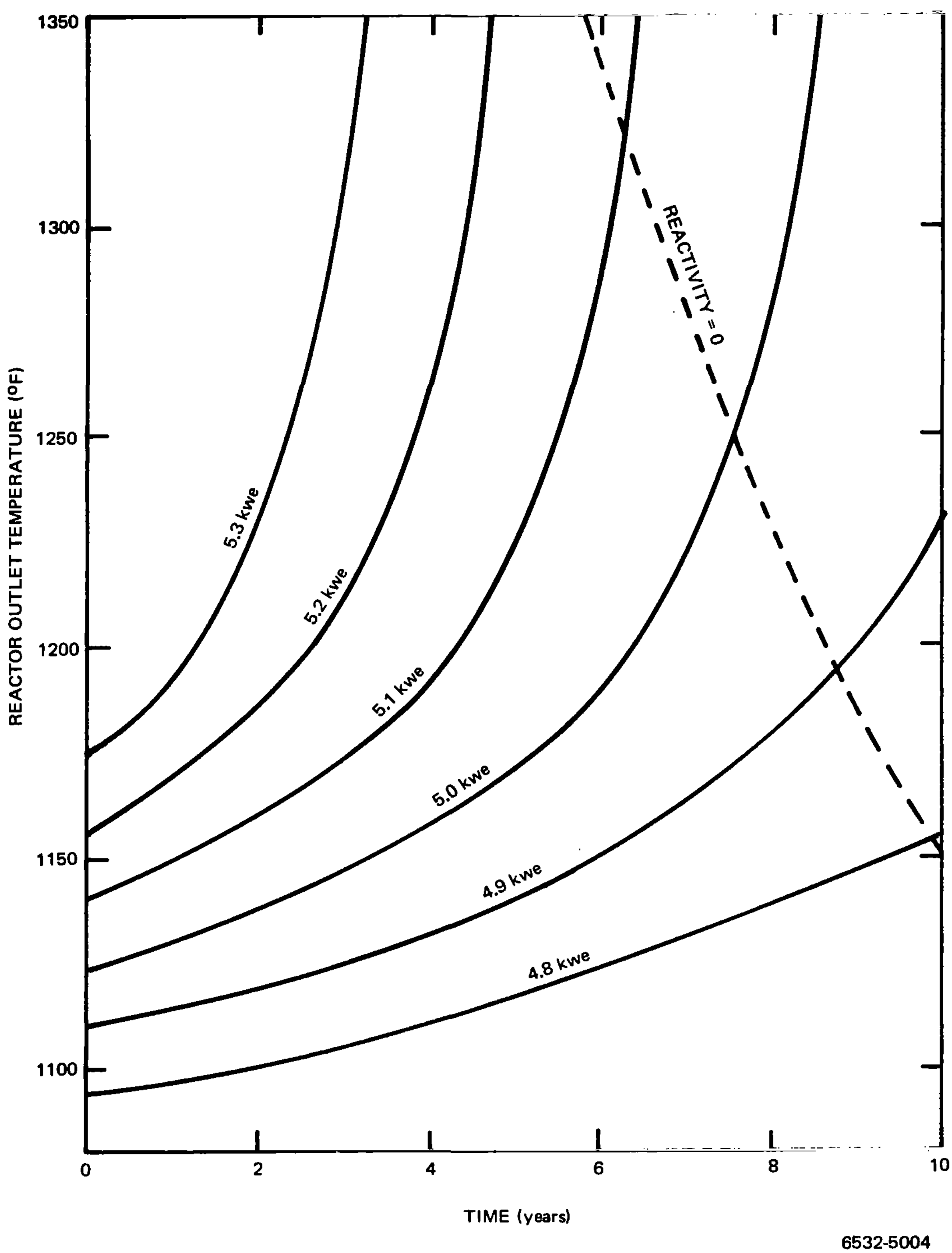

Figure 4. Reactor Outlet Temperature vs Time and Electric Power

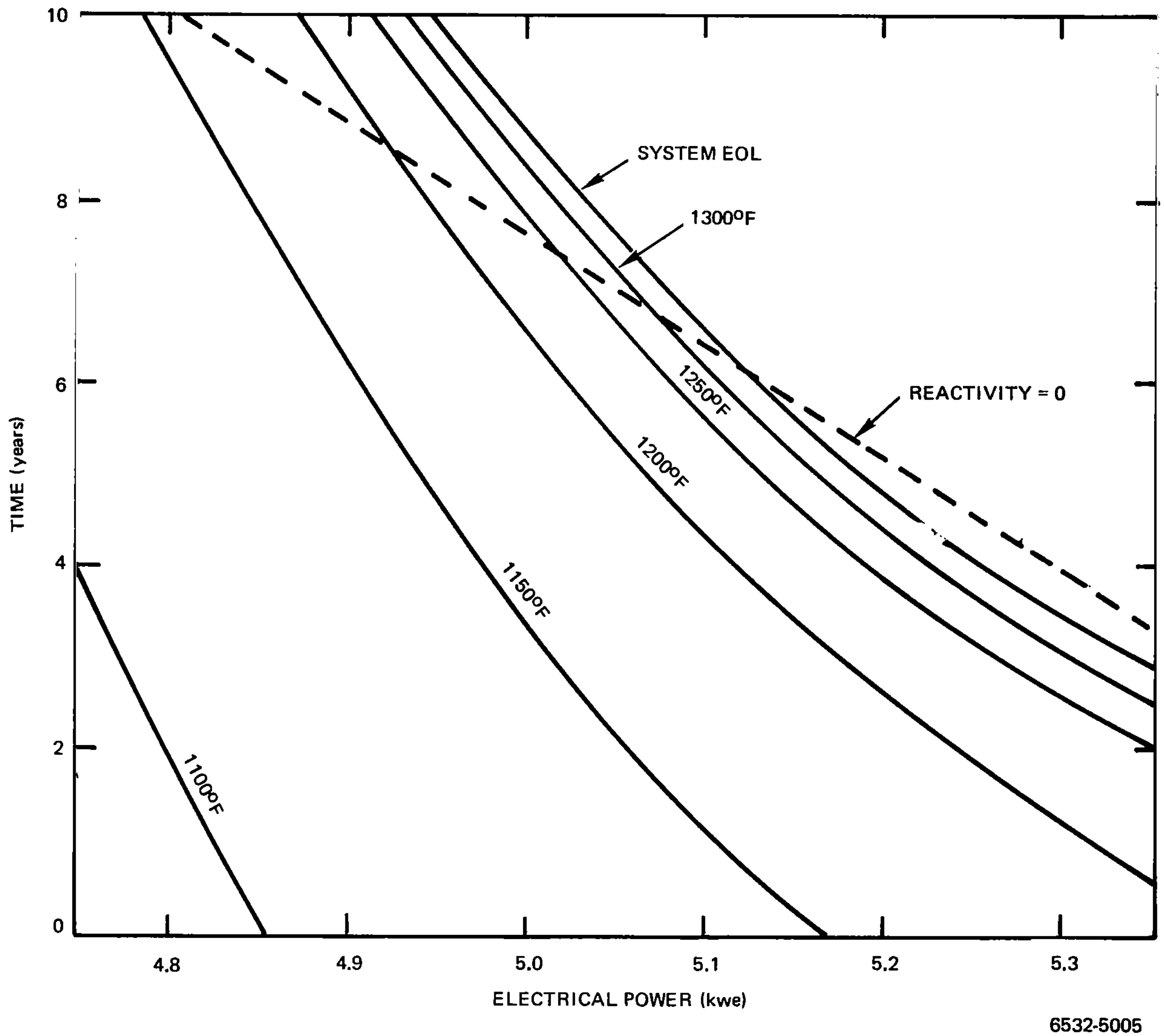

Figure 5. System Lifetime vs Power

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 (°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

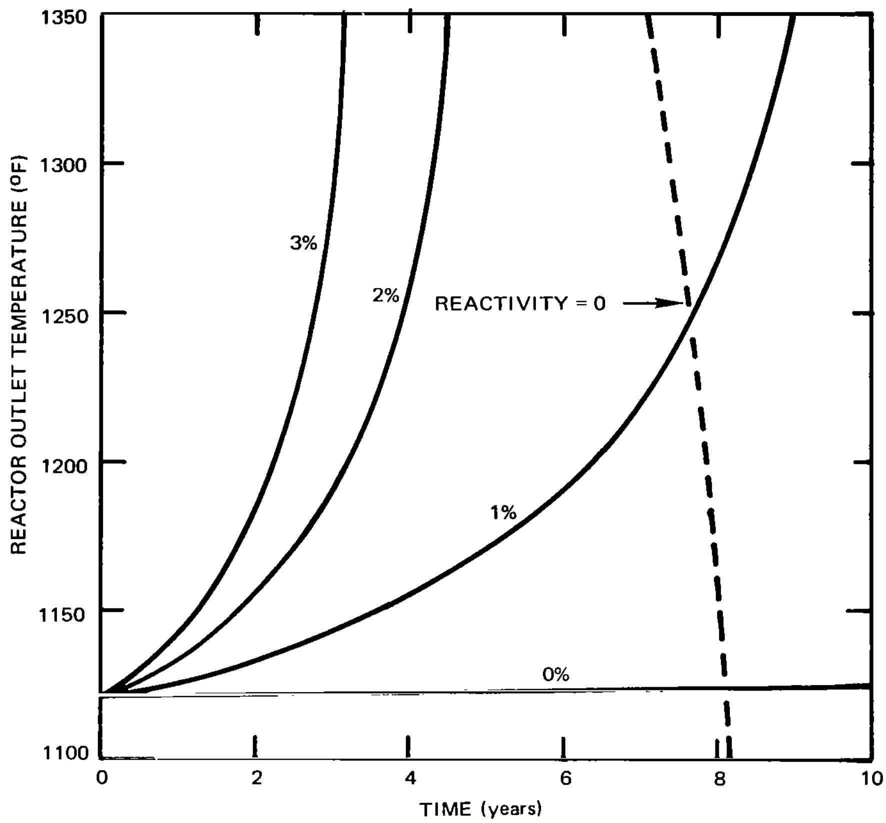

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Figure 6. Reactor Outlet Temperature vs Time, With Power Module Degradation Rate (%/year at 1085°F) as Parameter

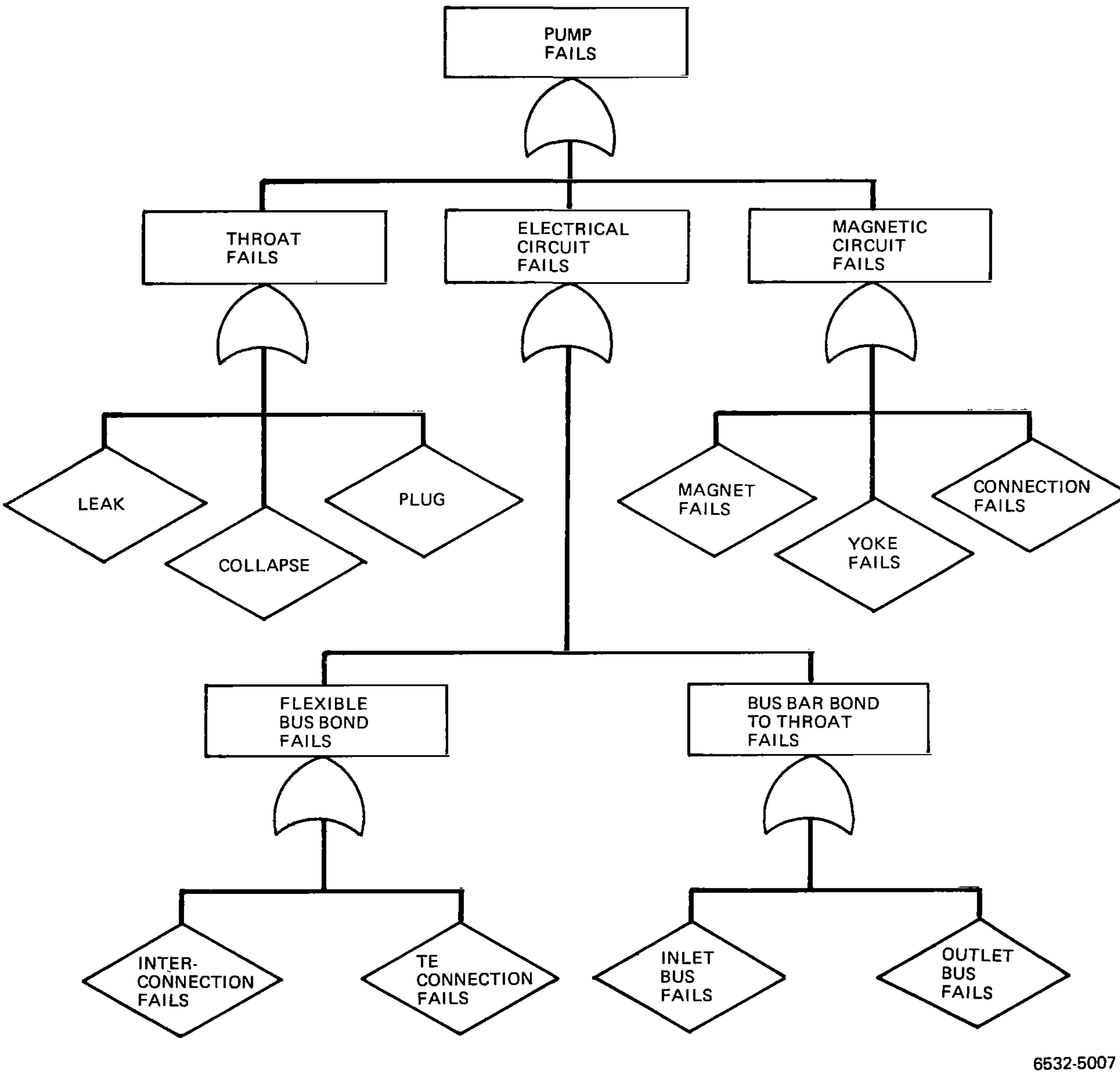

Figure 7. Probability Tree for Pump

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	$\sigma_{Variable}$	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 (°F)	2	0.1	0.02
Bond Degradation Rate (°F/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)

APPENDIX

LISTING OF THE CONTROL PROGRAM AND THE REACTOR MODEL PROGRAM

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),IIIDUM(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(I,J),I = 1,NVAR)
430      CALL CLØSEF(1)
440 82 CØNTINUE
450C GIVES NAMES TØ FILE DATA.VARIABLES "PØMPPM" THRØUGH "RDIMTL"
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)
```

CØNTRL CØNTINUED

```
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     RBNDDG = XDATA(20,M)
680     RDIMTL = XDATA(21,M)
690     NSTEPS = XDATA(22,M)
700C MAX. NØ. ØF TIME STEPS (EACH STEP=1/2 YEAR)
710     EPØWB  = XDATA(23,M)
720C ELECTRICAL PØWER (CØNSTANT IN TIME)
730C "SYSTEM" WILL GIVE PØWER AS A TIME-DEPENDENT VARIABLE.
740 KSYS=XDATA(31,M)
750 NWØRD=XDATA(35,M)
760C KSYS=0/1--QUANTITIES ARE TIME DEPENDENT/CØNSTANT
770C NWØRD IS -2/0/1=EXECUTES SYSTEM AND SAVES ØUTPUT FØR NEXT
780C RØUTINE IN A FILE/EXECUTES SYSTEM/DØES NØT EXECUTE SYSTEM
790C BUT READS THE FILE(FRØM PREVIØUS CASE) FØR THE NEXT RØUTINE.
800 DØ 81 N=24,30
810     NZ=N-23
820     DUMMY(NZ) = XDATA(N,M)
830C EXPLAINED AT THE BEGINNING ØF "REX"
840 81 CØNTINUE
850 IF(KSYS.EQ.1.ØR.NWØRD.EQ.1)GØTØ 30
860     LCNTRL = 2
870     CALL LINK(4,"OSYSTE")
880     CALL SYSTEM(PØMPPM,
890&    PØMEFF,PØMDGB,EPØWB,
900&    PMMPPM,PMMEFF,PMMDGB,
910&    PTFSIN,PTFSDG,STFSIN,STFSDG,PBUSIN,PBUSDG,
920&    PPIPFH,SPIPFH,
930&    REMMIN,REMMDG,RABSIN,RABSDG,RBNDIN,RBNDDG,RDIMTL,
940&    NSTEPS,LCNTRL,KCNTRL,
950& EPØWER,VØLTAG,FINTIM,
960&    TØUTLT,PREACT,CØREDT,
970&    THØTCL,TCØLCL,
980&THØTCP,TCØLCP,
990&    EFFPØM,DGRPØM,EFFPMM,DGRPMM,
1000&    TAVRAD,PRADTR,DTRADT)
1010C EXECUTES "SYSTEM" AND PRØVIDES TIN,TØUT,CØREDT,PØWER AS
1020C FUNCTIØNS ØF TIME.
1030 PRINT 99, FINTIM
1040 99 FØRMAT("FINTIM  =  ",F7.4)
1050     PRINT,
1060 IF(NWØRD.NE.-2)GØTØ 30
1070 WRITE(2,3333),NSTEPS
1080 LIFE=NSTEPS+1
1090 WRITE(2,500),(TØUTLT(I),CØREDT(I),PREACT(I),EPØWER(I),I=1,LIFE)
```

CØNTRL CØNTINUED

```
WRITE(2,600),FINTIM
600 FØRMAT(F11.4)
500 FØRMAT((4F11.4))
3333 FØRMAT(I6)
CALL CLØSEF(2)
C SAVES "SYSTEM" ØUTPUT FØR FUTURE USE (NWØRD=-2 HERE).
30 CØNTINUE
IF(NWØRD.NE.1)GØTØ 700
CALL ØPENF(3,"MØRDAT")
C READS THE FILE WITH "SYSTEM" ØUTPUT FRØM SØME PREVIØUS RUN.
READ(3,3333,ERR=66),NSTEPS
LIFE=NSTEPS+1
READ(3,500,ERR=67),(TØUTLT(I),CØREDT(I),PREACT(I),EPØWER(I),
& I=1,LIFE)
READ(3,600,ERR=65),FINTIM
GØ TØ 68
66 PRINT,↑2," ERRØR IN NSTEPS READ",↑2
CALL EXIT
67 PRINT,↑2," ERRØR IN ARRAY READ",↑2
CALL EXIT
65 PRINT,↑2,"ERRØR IN READING FINTIM",↑2
CALL EXIT
68 CALL CLØSEF(3)
700 CØNTINUE
DØ 85 JTIME=1,21
85 TYME(JTIME)=.5*FLØAT(JTIME-1)
LIFE=1+NSTEPS
IF(KSYS.EQ.0)GØTØ 35
C IF THE ØPTIØN TØ AVØID "SYSTEM" HAS BEEN USED, I.E., IF
C QUANTITIES ARE CØNSTANT IN TIME, TØUT, CØREDT, REACTØR PØWER
C ARE READ IN FRØM FILE WHICH SHØULD PRØVIDE THEM.
DØ 10 I=1,LIFE
TØUTLT(I)=XDATA(32,M)
CØREDT(I)=XDATA(33,M)
PREACT(I)=XDATA(34,M)
10 EPØWER(I)=EPØWB
35 CØNTINUE
   DØ 84 J = 1,LIFE
   TINLET(J) = TØUTLT(J)-CØREDT(J)
84 CØNTINUE
2300 FØRMAT( " SYSTEM E Ø L IS  ",F10.2)
CALL LINK(5,"OREX")
C EXECUTES THE MAIN PART ØF THE PRØGRAM. FINDS REACTØR
C CHARACTERISTICS AS A FUNCTIØN ØF TIME.
   CALL REX(TINLET,CØREDT,PREACT,NSTEPS,RHØ,TIMEND,H3L,DUMMY)
ZERØ=0.
PRINT 2200,ZERØ,TIMEND
2200 FØRMAT( " TIME (WHEN REACTIVITY IS",F10.1," )  = ",F10.2)
VALUE=1200
NLØC=0
```

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,FINTIM
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,F7.2,2I6,2F7.2,2F6.2))
1720     PRINT,
1730 IF(KSYS.EQ.1.ØR.NWØRD.EQ.1)GØTØ 40
1740 PRINT,↑,"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((F4.1,4I5,4F8.4))
1780 PRINT,↑,"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, ↑,"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,PPIPFH,SPIPFH,
1880&REMMIN,REMMDG,RABSIN,RABSDG,RBNDIN,RBNDDG,RDIMTL,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,/"PPIPFH  ",F8.5,"  SPIPFH  ",F8.5,
1950&"  REMMIN  ",F8.3,"  REMMDG  ",F8.3,/"RABSIN  ",F8.3,
1960&"  RABSDG  ",F8.3,"  RBNDIN  ",F8.1,"  RBNDDG  ",F8.3,/
1970&"RDIMTL  ",F8.3,"  EPØWB   ",F8.3,"  GAP     ",F8.4,
1980&"  BØLRHØ  ",F8.3,/"ACØEFF ",E9.3,"  AEXP    ",F8.1,
1990&"  KPT     ",I8,"  BUZ     ",F8.4,/"AMO     ",F8.5,
2000&"  NSTEPS  ",I8,"  KSYS    ",I8,"  NWØRD   ",I8)
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 CALCULATIØNS (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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SUBRØUTINE    REX(TINX,DELTX,PØWX,NXX,RHØ,TIMEND,H3L,DUMMY)
REAL TN(11),TCG(11),TF(11),TFS(11),TC(11),
&      TINX(21),PHIA(11),
&      DELTX(21),PØWX(21),TMX(21),BUX(25),BUM(21),RHØ(21)
&      ,H3L(21),DUMMY(25),TGS(11)
&,LØØG(23),MIT(23)
CØMMØN PØ,ZAD,EAD,AZR,ALIF,ØGP,GØLD,TFMX,TFME,CBL,CEL,AHL,
&      AKA,AK1,AK2,WHY,BSRCH,TMNF,BTBØL,BTEØL,SADC,TCCE,SADT,TCT,
&      SADH,TCHE,ZADC,ZADT,ZADH,GTH,AGL,CLTH,CGL,ZØP,CCLD,ACØEF,
&      AEXP,BUZ,PØWINT,TIN,DELT
&      ,TCDGP(11),TIM(25),TFUEL(11),G(11),ATFU(25),ADCE(5),
&      ADT(5),ADHE(5),TBD(5),AM(10),TPPK(25),P(25),BTNA(11),
&      BTCDG(11),BDTGP(11),BTFUE(11),EØTN(11),EØTC(11),EØDT(11),
&      EØTF(11),TNAK(11),DTGP(11),AHZR(25)
&,H2L(21),HYL(25),HRCC(25),TSWELL(25),GØØL(23)
&      ,ØSSW(25),BUSW(25),TINZ(25),DELTZ(25),PØWZ(25)
&      ,AM1(25),AM2(25),AM3(25)
&      ,TCLAD(25,11)
&      ,KPT,NJK,JSTP,NSTEPS
C
       GAP=DUMMY(1)
C RADIAL GAP IN MILS
       BØLRHØ=DUMMY(2)
C B Ø L REACTIVITY IN $
       ACØEF=DUMMY(3)
C ØFF=ACØEFF*EXP(AEXP/TFUEL)
       AEXP=DUMMY(4)
       KPT=DUMMY(5)
C -1/0/1/2=STANDARD/FULL/MIDI/MINI PRINT
       BUZ=DUMMY(6)
C CØRE AVERAGE BURNUP(MA/Ø)
       AM0=DUMMY(7)
C INITIAL AM(I) IN H.L. EXPRESSIØN BELØW
C
      CALL ØPENF(1,"AXDAT")
READ(1,)ALIFE,ELNØ,ALEN,AKWKG,DIACL,DIAFU,AZR,BSRCH
C ALIFE: LIFE IN YRS.
C ELNØ: # ØF ELEMENTS
C ALEN: FUEL ELEMENT LENGTH IN IN.
C AKWKG: KWT/KG-U
C DIACL: UNCØATED CLADDING ID IN IN.
C DIAFU: FUEL MEAT DIA IN IN.
C AZR: INITIAL H/ZR
C BSRCH: 0/1=CALC. MAX. INITIAL H/ZR FØR ALL DELTA FUEL/BYPASS
&     ,CLTH,CCLD,ZØP,WHY,NJK
C CLTH: CLAD THICKNESS IN MILS
C CCLD CLAD DIFF. CØNST.
C ZØP: LE.99=AD DEPENDS ØN AMO FRØM S-FILES/GT.99,LE.199=
C USE LINEAR AD (HE,CE,T)/GT.199=USE EXPØNENTIAL TYPE AD
C WHY: HYDRØGEN WØRTH ($/.1NSUB H)
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REX CØNTINUED

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30500C NJK: 0/1=BØNZER-SWENSØN/S8DR CØRRELATIØN (NØT USED)
30510&   ,AK1,AGL,CGL,GTH,AK2
30520C AK1,CGL,GTH,AK2 ARE USED IN THE HYDRØGEN LØSS EQUATIØN BELØW:
30530C H.L.=CØNST.*(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 (CØLD END),ADT(TUBE),ADHE(HØT END); SEE ZØP ABØVE
30580C TBD: TIME FØR AD ARRAYS
30590&   ,TMX,TIM
30600C TMX: ARRAY ØF ØPERATING TIME STEPS
30610C TIM: TIME ARRAY (MØRE 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 EQUATIØN APPLIES FØR AM(I) AT THE CØLD END
30650C (CE VALUES), AT THE TUBE (T), AT THE HØT END (HE) AND USES
30660C ZAD,SAD,TC AT CE,HE,T
30670&   ,TN,TCG,TF,TFS,TGS,ØGP,ØPT,AMARG,PHIA
30680C TN: NAK CØØLANT TEMP.
30690C TCG: CLAD/GLASS INTERFACE TEMP.
30700C TF: FUEL AVG. TEMP.
30710C TFS: FUEL SURFACE TEMP.
30720C ØGP: -1/0/1=CØNSTANT GAP/CALC.GAP/ØPTIMIZES GAP WITH
30730C            AMARG(BELØW) AT E Ø L
30740C ØPT: 0/1=PRINT GAP (ØNLY IF ØGP.GE.0)/BYPASS
30750C AMARG: USED ABØVE IN ØGP
30760C PHIA: AXIAL TEMP. DISTRIBUTIØN (BØTTØM TØ TØP)
30770&   ,FPK,UBUKK,SMK,BUMØM1,BUMØM2,PPBUK
30780C THE PARAMETERS BELØW ARE CØNSTANTS IN THE FØLLØWING
30790C REACTIVITY LØSS EQUATIØNS:
30800C FISSIØN PRØDUCTS(I)=FPK*BURNUP(I)
30810C U BURNØUT(I)=UBUKK*BURNUP(I)
30820C SAMARIUM(I)=SMK0*(1-EXP(BURNUP(I)*SMK))
30830C PREPØISØN BU(I)=PPBUK*(FRAC1*EXP(-BURNUP(I)*BUMØM1*219.05)
30840C +FRAC2*EXP(-BURNUP(I)*BUMØM2*219.05)), WHERE
30850C 219.05 IS A UNITS CØNVERSIØN FACTØR, INDICES 1 AND 2
30860C REFER TØ THE TWØ PØISØNS IN THE REACTØR
30870&   ,FRAC1,FRAC2,TDEFK,XENØNK,HRDK,PDEFK,SMK0
30880C XENØN(I)=XENØNK*PØWER(I)
30890C TEMPERATURE DEFECT(I)=TDEFK*TEMP(I)
30900C PØWER DEF.(I)=PDEFK*PØWER(I)
30910C H DEF.(I)=HRDK*PØWER(I)
30920C THE INDEX I REFERS TØ THE TIME STEPS
30930    CALL CLØSEF(1)
30940C
30950    NSTEPS=NXX
30960    GØLD=GAP*1000.
30970    PØWINT=0.
30980    BUZ=BUZ/(110.*8766.*5)
30982 PØWXX=PØWX(21)
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REX CØNTINUED

```
 DELTXX=DELTX(21)
 TINXX=TINX(21)
    CALL TEMPS(GAP,ALIFE,DIAFU,DIACL,ELNØ,ALEN,PHIA,
& TINX,DELTX,PØWX,TMX,PØW,BUX,TN,TCG,TF,TFS,TGS,ØPT,AMARG)
C USES TIN,TØUT TØ FIND AXIAL TEMPERATURE DISTRIBUTIØNS
    IF(BSRCH.GT.0) GØ TØ 12
    AZZ=AZR
    TMMMF=TMNF
    ATFUEL=ATFU(1)
    CALL BNDHZR(BBZR,AZZ,ATFUEL,TMMMF)
C FINDS H/ZR
    AZR=AZZ
 12 CØNTINUE
C
    CALL BHLØSS(ALIFE,ELNØ,ALEN,DIACL,AHLØS,DIAFU,AMO)
C HYDRØGEN LØSS CALCULATIØNS
    CALL BETABN(JSTP)
C BETA BØUNDARY CALCULATIØNS
    GGP=GAP*1000.
C
    H2L(1)=0
    BUM(1)=0.0
    TINX(1)=TINZ(1)
    DELTX(1)=DELTZ(1)
    PØWX(1)=PØWZ(1)
    DØ 45 KK=2,21
    JJ=KK+2
    H2L(KK)=HYL(JJ)
    BUM(KK)=BUX(JJ)
    TINX(KK)=TINZ(JJ)
    DELTX(KK)=DELTZ(JJ)
    PØWX(KK)=PØWZ(JJ)
 45 CØNTINUE
 TINX(21)=TINXX
 DELTX(21)=DELTXX
 PØWX(21)=PØWXX
    DØ 48 LL=1,21
    H3L(LL)=H2L(LL)
 48 CØNTINUE
C
    CALL XPLØDE(TINX,DELTX,TMX,BUM,PØWX,RHØ,TIMEND,BØLRHØ
&   ,FPK,UBUKK,SMK,BUMØM1,BUMØM2,PPBUK
&   ,FRAC1,FRAC2,TDEFK,XENØNK,HRDK,PDEFK,SMKO
&   )
C BALANCES REACTIVITIES,FINDS EOL TIME (WHEN SUM ØF REACTIVITIES
C EQUALS ZERØ)
 IF(KPT.LT.0)GØTØ 47
    JMZ=JSTP+1
    JMIN=JSTP
    JMAX=JSTP
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REX CØNTINUED

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        IF(KPT.LT.1) JMIN=1
        PRINT 31,
     31 FØRMAT(2X,"TIME",2X,"T IN",2X,"DEL T",2X,"PØW",3X,
&       "M A %",3X,"TSWEL",2X,"ØFFSET",2X,"BU SW",4X,"GAP")
        PRINT 32,(TIM(J),TINZ(J),DELTZ(J),PØWZ(J),BUX(J),
&       TSWELL(J),ØSSW(J),BUSW(J),GØØL(J),J=JMIN,JMAX)
     32 FØRMAT(I6,F6.1,2F7.1,F8.4,F6.1,3F8.4)
        PRINT 33,TIM(JMZ),BUX(JMZ),ØSSW(JMZ),BUSW(JMZ),GØØL(JMZ)
     33 FØRMAT(I6,20X,F8.4,6X,3F8.4)
        PRINT,
        PRINT 85,
        PRINT 86,(TIM(J),AHZR(J),ATFU(J),P(J),HRCC(J),HYL(J),
&       AM1(J),AM2(J),AM3(J),J=JMIN,JMAX)
        PRINT 87,TIM(JMZ),AHZR(JMZ),P(JMZ),HYL(JMZ)
     85 FØRMAT(2X,"TIME",3X,"H/ZR",2X,"AV TF",2X,"PRESS",
&       4X,"CC/HR",2X,"$ H LØSS",2X,"AD1",5X,"AD2",5X,"AD3")
     86 FØRMAT(I6,F8.4,I6,2F9.5,F6.2,3F8.4)
     87 FØRMAT(I6,F8.4,6X,F9.5,9X,F6.2)
        PRINT,
C
        IF(KPT.GT.0) GØ TØ 74
        PRINT,
        PRINT 76
        PRINT 77,(BTNA(I),BTCDG(I),BDTGP(I),BTFUE(I),I=1,11)
        PRINT,
        PRINT 76
        PRINT 77,(EØTN(I),EØTC(I),EØDT(I),EØTF(I),I=1,11)
        PRINT,
        PRINT 76
        PRINT 77,(TNAK(I),TCDGP(I),DTGP(I),TFUEL(I),I=1,11)
     76 FØRMAT(5X,"TNAK",2X,"CLAD/GL",3X,"GAP DT",3X,"AVG FU")
     77 FØRMAT( 4F9.2)
     74 CØNTINUE
C
        PRINT,
        PRINT 35,PØW,ALIFE,BUX(JMZ),TIN,DELT,ELNØ,GGP,ALEN,DIAFU,
&       DIACL,TFMX,TFME,CBL,AHL,GØLD,AHLØS,AZR,ZØP,EAD,PØ,WHY,
&       BTBØL,TPPK(1),BTEØL,TPPK(JSTP)
&       ,AK1,CLTH,AGL,CGL,AK2
&       ,CCLD
     35 FØRMAT( 5X,"PØWER",2X,"LIFE(YR)",2X,"BU(MA/Ø)",5X,
&       "INLET",2X,"DEL TEMP"/2F10.1,F10.4,2F10.2/
&       4X,"ELM'TS",7X,"GAP",4X,"LENGTH",2X,"DIA FUEL",
&       2X,"DIA CLAD"/F10.0,2F10.2,2F10.4/
&       4X,"TFMX:0",4X,"TF:EØL",2X,"CC/HR(0)",2X,"H/ZR:EØL",
&       6X,"LIFE"/2F10.2,2F10.4,F10.2/
&       1X,"H LØSS($)",3X,"H/ZR(0)",3X,"AD(END)",2X,"AD(TUBE)",
&       2X,"PØ(PSIA)"/F10.2,F10.3,2F10.5,F10.2
&       /1X,"WØR($/NH)",4X,"BØL BT",2X,"BØL TMAX",4X,"EØL BT  EØL TMAX",
&       /F10.3,4F10.2/4X,"Q CLAD",3X,"CLAD TH",2X,"GLASS AG",
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REX CØNTINUED

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&    1X,"GLASS CØN",3X,"Q GLASS"/
&    F10.0,F10.1,F10.4,F10.5,F10.0/
&    2X,"CLAD CØN"/F10.0/)
C
 47 CØNTINUE
 LUMP=3+NSTEPS
 PRINT 198,
 DØ 101 J=1,LUMP
 TIMPAN=TIM(J)/8766.
 101 PRINT 199, TIMPAN,BUX(J),ØSSW(J),BUSW(J),GØØL(J),P(J)
 PRINT 197,
 DØ 102 J=1,LUMP
 TIMPAN=TIM(J)/8766.
 102 PRINT 196, TIMPAN,TSWELL(J),AHZR(J),ATFU(J)
 199 FØRMAT(F6.2,5F9.4)
 196 FØRMAT(F6.2,F9.1,F9.4,F9.1)
 198 FØRMAT(/"  TIME   MA %     ØFFSET   BU SW    GAP       PRESS")
 197 FØRMAT(/"  TIME   TSWELL    H/ZR    AV TF")
 GAPØ=1.
 CALL FINDGA(GØØL,LØØG,TIM,MIT,LUMP,GAPTIM,GAPØ)
C EXTRAPØLATES TØ FIND THE TIME WHEN THE GAP = GAPØ (SØME
C SPECIFIED GAP VALUE).
 PRINT 3001,GAPØ,GAPTIM
 3001 FØRMAT(/"TIME (WHEN THE GAP IS ",F10.1," ) = ",F10.2)
 RETURN
 END
C
C
C
     SUBRØUTINE TEMPS(GAP,ALIFE,DIAFU,DIACL,ELNØ,ALEN,PHIA,
&    TINX,DELTX,PØWX,TMX,PØW,BUX,TN,TCG,TF,TFS,TGS,ØPT,AMARG)
C
     REAL TINX(21),DELTX(21),PØWX(21),TMX(21),
&    PHIA(11)
&    ,TN(21),TCG(21),TF(21),
&    TFS(21),TGS(11),BUX(25)
C
     CØMMØN PØ,ZAD,EAD,AZR,ALIF,ØGP,GØLD,TFMX,TFME,CBL,CEL,AHL,
&    AKA,AK1,AK2,WHY,BSRCH,TMNF,BTBØL,BTEØL,SADC,TCCE,SADT,TCT,
&    SADH,TCHE,ZADC,ZADT,ZADH,GTH,AGL,CLTH,CGL,ZØP,CCLD,ACØEF,
&    AEXP,BUZ,PØWINT,TIN,DELT
&    ,TCDGP(11),TIM(25),TFUEL(11),G(11),ATFU(25),ADCE(5),
&    ADT(5),ADHE(5),TBD(5),AM(10),TPPK(25),P(25),BTNA(11),
&    BTCDG(11),BDTGP(11),BTFUE(11),EØTN(11),EØTC(11),EØDT(11),
&    EØTF(11),TNAK(11),DTGP(11),AHZR(25)
&    ,H2L(21),HYL(25),HRCC(25),TSWELL(25),GØØL(23)
&    ,ØSSW(25),BUSW(25),TINZ(25),DELTZ(25),PØWZ(25)
&    ,AM1(25),AM2(25),AM3(25)
&    ,TCLAD(25,11)
&    ,KPT,NJK,JSTP,NSTEPS
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REX CØNTINUED

```
C
      GP=GAP
      ALIF=ALIFE*8766.
   98 CØNTINUE
      JSTEP=1
      GAP=GP
      GG=GAP
      PØWINT=0.0
      BUX(1)=0
      DØ 17 I=1,11
   17 G(I)=GAP
   99 CØNTINUE
C
      TTIM=TIM(JSTEP)
      NLIFE=NSTEPS+1
      NLØC=0
      TIN=FUNCT1(TMX,TINX,NLIFE,TTIM,NLØC,1)
      TINZ(JSTEP)=TIN
      NLØC=0
      DELT=FUNCT1(TMX,DELTX,NLIFE,TTIM,NLØC,1)
      DELTZ(JSTEP)=DELT
      NLØC=0
      PØW=FUNCT1(TMX,PØWX,NLIFE,TTIM,NLØC,1)
      PØWZ(JSTEP)=PØW
C
      JSTEP7=JSTEP+1
      PØWINT=PØWINT+PØW*(TIM(JSTEP7)-TIM(JSTEP))
      BUX(JSTEP7)=PØWINT*BUZ
      AKWFT=PØW*12./(ELNØ*ALEN)
      TFM=0.
      TNAK(1)=TIN
      DMP = 0.9752/DIACL
      GMP = G(1)*DMP/0.0067
      AKWMP=AKWFT*85.*16./(95.*12.)
      TCDGP(1)=TIN+(TCG(1)-TN(1))*AKWMP*DMP
      TCLAD(JSTEP,1)=TCDGP(1)
      DTGP(1)=(TFS(1)-TGS(1))*AKWMP*GMP
      DTGL=(TGS(1)-TCG(1))*AKWMP*DMP
      TFUEL(1)=TCDGP(1)+DTGP(1)+(TF(1)-TFS(1))*AKWMP+DTGL
      TMNF=TCDGP(1)+DTGP(1)+DTGL
      DTM=DELT/80.
C
      DØ 10    I=2,11
      TNAK(I)=(TN(I)-TN(I-1))*DTM+TNAK(I-1)
      TCDGP(I)=TNAK(I)+(TCG(I)-TN(I))*AKWMP*DMP
      TCLAD(JSTEP,I)=TCDGP(I)
      GMP=G(I)*DMP/0.0067
      DTGP(I)=(TFS(I)-TGS(I))*AKWMP*GMP
      DTGL=(TGS(I)-TCG(I))*AKWMP*DMP
      TFUEL(I)=TCDGP(I)+DTGP(I)+(TF(I)-TFS(I))*AKWMP+DTGL
```

REX CØNTINUED

```
 10 CØNTINUE
C
    AT=TFUEL(1)+TFUEL(11)
    KST=1
    DØ 20    I=2,10
    AT =AT+TFUEL(I)*2.
    TFM=AMAX1(TFM,TFUEL(I))
    IF(TFUEL(I).LT.TFM) GØ TØ 20
    KST=KST+1
 20 CØNTINUE
C
    TPPK(JSTEP)=TFUEL(KST)+(TF(KST)-TFS(KST))*AKWMP
    ATFU(JSTEP)=AT*0.05
    IF(JSTEP.EQ.1)TFMX=TFM
    IF(JSTEP.NE.1)GØ TØ 59
C
    DØ 59 IJ=1,11
    BTNA(IJ)=TNAK(IJ)
    BTCDG(IJ)=TCDGP(IJ)
    BDTGP(IJ)=DTGP(IJ)
    BTFUE(IJ)=TFUEL(IJ)
 59 CØNTINUE
    IF(JSTEP.NE.10)GØ TØ 68
C
    DØ 68 IJ=1,11
    EØTN(IJ)=TNAK(IJ)
    EØTC(IJ)=TCDGP(IJ)
    EØDT(IJ)=DTGP(IJ)
    EØTF(IJ)=TFUEL(IJ)
 68 CØNTINUE
C
    CALL GAG(ØPT,JSTEP,GG,GP,BUX(JSTEP7),DIAFU,AMARG,PHIA)
C FINDS THE GAP BETWEEN CLAD AND FUEL.
    JSTP=JSTEP-1
    IF(ØGP.LT.0)GØ TØ 16
    IF(TIM(JSTEP).LT.ALIF)GØ TØ 99
    IF(GG.NE.GP)GØ TØ 98
 16 CØNTINUE
    TFME=TFM
    RETURN
    END
C
C
C
C
    SUBRØUTINE BHLØSS(ALIFE,ELNØ,ALEN,DIACL,AHLØS,DIAFU,AMO)
C HYDRØGEN LØSS RØUTINE
    DIMENSIØN TC(10)
    CØMMØN PØ,ZAD,EAD,AZR,ALIF,ØGP,GØLD,TFMX,TFME,CBL,CEL,AHL,
&   AKA,AK1,AK2,WHY,BSRCH,TMNF,BTBØL,BTEØL,SADC,TCCE,SADT,TCT,
```

REX CØNTINUED

```
&     SADH,TCHE,ZADC,ZADT,ZADH,GTH,AGL,CLTH,CGL,ZØP,CCLD,ACØEF,
&     AEXP,BUZ,PØWINT,TIN,DELT
&     ,TCDGP(11),TIM(25),TFUEL(11),G(11),ATFU(25),ADCE(5),
&     ADT(5),ADHE(5),TBD(5),AM(10),TPPK(25),P(25),BTNA(11),
&     BTCDG(11),BDTGP(11),BTFUE(11),EØTN(11),EØTC(11),EØDT(11),
&     EØTF(11),TNAK(11),DTGP(11),AHZR(25)
&     ,H2L(21),HYL(25),HRCC(25),TSWELL(25),GØØL(23)
&     ,ØSSW(25),BUSW(25),TINZ(25),DELTZ(25),PØWZ(25)
&     ,AM1(25),AM2(25),AM3(25)
&     ,TCLAD(25,11)
&     ,KPT,NJK,JSTP,NSTEPS
C     RAYMØND'S PRESSURE EQUATIØN
      FPRES(X,AT)=EXP(-8.8455+88.9801*X-78.8961*X**2+21.3731*X**3)
&     *EXP((-12.972+9.7707*X-2.4984*X**2)*1.0E04/AT)
 DØ 777 JACK=1,10
 777 AM(JACK)=AM0
      JKD=2
      AKA=AGL*CGL/(GTH*.0254)
      J=1
      ZAD=ZØP
      ZØP=AM(1)
      EAD=AM(2)
      BKD=CCLD/(CLTH*0.0254)
      AHZR(1)=AZR
      AREA=ALEN*3.14159*DIACL*2.54**2*0.1
      WØRH=WHY/.0287
      CCELM=22.4E03*6.3E22*0.7854*16.39*ALEN*DIAFU**2/(1.81*6.023E23)
      CCELM=CCELM/2.
      DØLCC=WØRH/CCELM
      CC=0.0
      DNH=0.0
      AT=ATFU(1)+459.7
      P(1)=FPRES(AZR,AT)
      PØ=P(1)*14.696
      IF(ZAD.GT.199.)GØ TØ 70
      IF(ZAD.GT.99.)GØ TØ 22
      28 CØNTINUE
      ALIF=ALIFE*8766.
      DØ 32 I=1,10
      TC(I)=(TCLAD(J,I)+TCLAD(J,I+1))*.5+459.7
      CC=CC+(AM(I)*BKD*SQRT(P(J))*EXP(-AK1/TC(I))+
&     AKA*P(J)*EXP(-AK2/TC(I)))*AREA*TIM(2)
      32 CØNTINUE
      DNH=CC/CCELM
      CCHR=CC/TIM(2)
      HRCC(1)=CCHR
      CBL=CCHR
      DLØS=DNH*WØRH
      HYL(1)=0
      HYL(2)=DLØS
```

REX CØNTINUED

```
J=2
87 CØNTINUE
IF(TIM(J+1).GT.ALIF)TIM(J+1)=ALIF
AHZR(J)=AHZR(J-1)-CC/CCELM
AZR=AHZR(J)
IF(ØGP.LT.0)ATFU(J)=ATFU(1)
AT=ATFU(J)+459.7
P(J)=FPRES(AZR,AT)
IF(ZAD.GT.199.)GØ TØ 70
IF(ZAD.GT.99.)GØ TØ 22
29 CØNTINUE
TIME=TIM(J+1)-TIM(J)
81 CC=0.
DØ 57 I=1,10
TC(I)=(TCLAD(J,I)+TCLAD(J,I+1))*.5+459.7
CC=CC+(AM(I)*BKD*SQRT(P(J))*EXP(-AK1/TC(I))+
&AKA*P(J)*EXP(-AK2/TC(I)))*AREA*TIME
57 CØNTINUE
DNH=DNH+CC/CCELM
DLØS=DNH*WØRH
HYL(J+1)=DLØS
C
CCHR=CC/TIME
HRCC(J)=CCHR
IF(TIM(J+1).EQ.ALIF)GØ TØ 31
J=J+1
GØ TØ 87
70    CØNTINUE
TMM=0.5*(TIM(J+1)+TIM(J))
AM(1)=SADC*(1-EXP(-TMM/TCCE))+ZADC
AM(2)=SADT*(1-EXP(-TMM/TCT))+ZADT
AM(10)=SADH*(1-EXP(-TMM/TCHE))+ZADH
AM1(J)=AM(1)
AM2(J)=AM(2)
AM3(J)=AM(10)
DØ 76 JIL=3,9
76 AM(JIL)=AM(2)
IF(J.EQ.1)GØ TØ 28
GØ TØ 29
22 CØNTINUE
IF(TBD(JKD).GT.TIM(J+1))GØ TØ 13
JKD=JKD+1
13 TSTP=TBD(JKD)-TBD(JKD-1)
SC=(ADCE(JKD)-ADCE(JKD-1))/TSTP
ST=(ADT(JKD)-ADT(JKD-1))/TSTP
SH=(ADHE(JKD)-ADHE(JKD-1))/TSTP
24 TMKD=0.5*(TIM(J)+TIM(J+1))-TBD(JKD-1)
AM(1)=ADCE(JKD-1)+SC*TMKD
AM(2)=ADT(JKD-1)+ST*TMKD
AM(10)=ADHE(JKD-1)+SH*TMKD
```

REX CØNTINUED

```
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 CØNTINUE
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     SUBRØUTINE 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,TIN,DELT
34700& ,TCDGP(11),TIM(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),TINZ(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     ID=I
34880     BTP=FBETA(P(I))
34890     IF(BTP.LE.TPPK(I))GØ TØ 17
34900  14 CØNTINUE
34910  26 TFEL=TPPK(JSTP)
34920     IF(BTEØL.LE.TFEL)GØ TØ 9
34930     GØ TØ 2
34940   5 PRINT 22,TIM(1),BTBØL,TPPK(1)
```

REX CØNTINUED

```
      GØ TØ 6
 17 PRINT 22,TIM(ID),BTP,TPPK(ID)
      GØ TØ 26
 9 PRINT 22,TIM(JSTP),BTEØL,TPPK(JSTP)
      GØ TØ 2
 22 FØRMAT( "CAUTIØN!!  BETA PHASE FUEL HAS ØCCURRED AT TIME",
& F8.1," HØURS."/"BETA FUEL TEMPERATURE IS ",F8.2,/"BUT PEAK
& FUEL TEMPERATURE IS ",F8.2/)
  2 RETURN
      END
C
C
C
 SUBRØUTINE XPLØDE(TINX,DELTX,TMX,BUM,PØWX,RHØ,TIMEND,BØLRHØ
&     ,FPK,UBUKK,SMK,BUMØM1,BUMØM2,PPBUK
&     ,FRAC1,FRAC2,TDEFK,XENØNK,HRDK,PDEFK,SMKO
&     )
C
 CØMMØN PØ,ZAD,EAD,AZR,ALIF,ØGP,GØLD,TFMX,TFME,CBL,CEL,AHL,
&     AKA,AK1,AK2,WHY,BSRCH,TMNF,BTBØL,BTEØL,SADC,TCCE,SADT,TCT,
&     SADH,TCHE,ZADC,ZADT,ZADH,GTH,AGL,CLTH,CGL,ZØP,CCLD,ACØEF,
&     AEXP,BUZ,PØWINT,TIN,DELT
&     ,TCDGP(11),TIM(25),TFUEL(11),G(11),ATFU(25),ADCE(5),
&     ADT(5),ADHE(5),TBD(5),AM(10),TPPK(25),P(25),BTNA(11),
&     BTCDG(11),BDTGP(11),BTFUE(11),EØTN(11),EØTC(11),EØDT(11),
&     EØTF(11),TNAK(11),DTGP(11),AHZR(25)
&     ,H2L(21),HYL(25),HRCC(25),TSWELL(25),GØØL(23)
&     ,ØSSW(25),BUSW(25),TINZ(25),DELTZ(25),PØWZ(25)
&     ,AM1(25),AM2(25),AM3(25)
&     ,TCLAD(25,11)
&     ,KPT,NJK,JSTP,NSTEPS
C
 DIMENSIØN FP(21),UBU(21),SM(21),PPBU(21),TBAR(21),
&     TDEF(21),XENØN(21),HRD(21),PDEF(21),RLØSS(21),RHØ(21)
&     ,TMX(21),DELTX(21),BUM(21),PØWX(21),TINX(21)
&     ,ØHR(21),XMT(21)
C
      DØ 1 I=1,21
      FP(I)=BUM(I)*FPK
      UBU(I)=BUM(I)*UBUKK
      SM(I)=SMKO*(1.-EXP(BUM(I)/SMK))
      PPBU(I)=PPBUK*(FRAC1*EXP(-BUM(I)*219.05*BUMØM1)+
&     FRAC2*EXP(-BUM(I)*219.05*BUMØM2))
      TBAR(I)=TINX(I)+DELTX(I)/2
      TDEF(I)=TBAR(I)*TDEFK
      XENØN(I)=PØWX(I)*XENØNK
      HRD(I)=PØWX(I)*HRDK
      PDEF(I)=PØWX(I)*PDEFK
      RLØSS(I)=FP(I)+UBU(I)+SM(I)+H2L(I)+PPBU(I)+TDEF(I)+
&     XENØN(I)+HRD(I)+PDEF(I)
```

REX   CØNTINUED

```
    RHØ(I)=BØLRHØ-RLØSS(I)
 1 CØNTINUE
NLØC=0
    VALUE=0.
LIFE=1+NSTEPS
C
DØ 5 I=1,21
I12=22-I
    ØHR(I)=RHØ(I12)
5 XMT(I)=TMX(I12)
TIMEND=FUNCT1(ØHR,XMT,LIFE,VALUE,NLØC,2)
    TIMEND=TIMEND/8766.
C
    IF(KPT.LT.0) GØ TØ 78
    PRINT 77, TIMEND
77 FØRMAT("EØL (YRS)",3X,F10.3)
    PRINT 20,
    DØ 2 I=1,21
2 PRINT 10, FP(I),UBU(I),SM(I),PPBU(I),H2L(I),TDEF(I),XENØN(I),
&   HRD(I),PDEF(I),RLØSS(I),RHØ(I)
10 FØRMAT(11F6.2)
20 FØRMAT(
&   "   FP    UBU    SM    PPØI    H2L
&    TDEF  XENØN  HRD  PDEF RLØSS   RHØ")
78 CØNTINUE
    RETURN
    END
C
C
C
    SUBRØUTINE GAG(ØPT,JSTEP,GG,GP,BU,DIAFU,AMARG,PHIA)
C CALCULATES GAP AND ØTHER FUEL SWELLING CHARACTERISTICS
CØMMØN PØ,ZAD,EAD,AZR,ALIF,ØGP,GØLD,TFMX,TFME,CBL,CEL,AHL,
&   AKA,AK1,AK2,WHY,BSRCH,TMNF,BTBØL,BTEØL,SADC,TCCE,SADT,TCT,
&   SADH,TCHE,ZADC,ZADT,ZADH,GTH,AGL,CLTH,CGL,ZØP,CCLD,ACØEF,
&   AEXP,BUZ,PØWINT,TIN,DELT
&   ,TCDGP(11),TIM(25),TFUEL(11),G(11),ATFU(25),ADCE(5),
&   ADT(5),ADHE(5),TBD(5),AM(10),TPPK(25),P(25),BTNA(11),
&   BTCDG(11),BDTGP(11),BTFUE(11),EØTN(11),EØTC(11),EØDT(11),
&   EØTF(11),TNAK(11),DTGP(11),AHZR(25)
&   ,H2L(21),HYL(25),HRCC(25),TSWELL(25),GØØL(23)
&   ,ØSSW(25),BUSW(25),TINZ(25),DELTZ(25),PØWZ(25)
& ,AM1(25),AM2(25),AM3(25)
& ,TCLAD(25,11)
& ,KPT,NJK,JSTP,NSTEPS
C
    DIMENSIØN AØF(11),PHIA(11)
    ALAM=5000.
    GMX=0.
    ØSSW(1)=0
```

REX CØNTINUED

```
      BUSW(1)=0
      GØØL(1)=GG*1000.
      J=JSTEP
      JK=J+1
      DØ 82 JC=1,11
   82 G(JC)=GG
      IF(ØGP.LT.0)GØ TØ 10
      IF(JSTEP.GT.1)GØ TØ 20
      DØ 22 JA=1,11
   22 AØF(JA)=0.
   20 IF(TIM(JK).GT.ALIF)TIM(JK)=ALIF
      AXPJ=(1.-EXP(-(TIM(JK)-TIM(J))/ALAM))
      DØ 69 K=1,11
      AT=TFUEL(K)+459.7
      AØFF=ACØEF*EXP(AEXP/AT)
      DDV=(AØFF-AØF(K))*AXPJ
      IF(ØPT.GT.0)GØ TØ 7
      IF(K.NE.7)GØ TØ 7
      PRINT, AØFF,AØF(K)
    7 CØNTINUE
      IF(DDV.LE.0.)DDV=0.
      AØF(K)=AØF(K)+DDV
      ABU=BU*PHIA(K)*1.45
      BNUP=3.21*ABU
      IF(K.EQ.8) BUSW(J+1)=BNUP*DIAFU*5./2.8
      GR=(BNUP+AØF(K))*DIAFU*0.01/2.8
      G(K)=GG-GR/2.
      GRR=GR/2.
      GMX=AMAX1(GMX,GRR)
      IF(GRR.LT.GG)GØ TØ 81
      G(K)=0.
   81 CØNTINUE
   69 CØNTINUE
      TSWELL(J)=TFUEL(8)
      ØSSW(JK)=AØF(8)*DIAFU*5./2.8
      IF(ØPT.GT.0)GØ TØ 11
      PRINT 57,(G(K),K=2,11)
   57 FØRMAT( 10F7.4)
   11 CØNTINUE
      IF(TIM(JK).LT.ALIF)GØ TØ 10
      IF(ØGP.LT.1)GØ TØ 10
      RG=GMX+AMARG
      DIF=ABS(GG-RG)
      IF(DIF.LT.0.00001)GØ TØ 10
      GP=RG
   10 JSTEP=JK
      GØLD=(GG-GMX)*1000.
      GØØL(JK)=GØLD
      RETURN
      END
```

REX CØNTINUED

```
36450 SUBRØUTINE FINDGA(GØØL,LØØG,TIM,MIT,LUMP,GAPTIM,GAPØ)
36460C GØØL(LUMP) IS THE X-ARRAY; TIM IS THE Y-ARRAY. SINCE GØØL
36470C IS IN DESCENDING ØRDER, HAVE TØ INVERT IT TØ LØØG (ALSØ INVERT
36480C TIM TØ MIT). GAPTIM IS THE CALCULATED TIME AT WHICH GAP=GAPØ.
36490 REAL GØØL(LUMP),LØØG(LUMP),TIM(LUMP),MIT(LUMP)
36500 DØ 1 I=1,LUMP
36510 J=LUMP-I+1
36520 LØØG(J)=GØØL(I)
36530 1 MIT(J)=TIM(I)
36540 NLØC=0
36550 GAPTIM=FUNCT1(LØØG,MIT,LUMP,GAPØ,NLØC,2)
36560 GAPTIM=GAPTIM/8766.
36570 RETURN
36580 END
```

BNDHZR

```
      SUBRØUTINE BNDHZR(BBZR,AZZ,ATFUEL,TMMMF)
 CØMMØN DUMDUM(933),IBUM(4)
      FBP(Y)=1.434E-10*EXP(.01806*Y)
      FPRES(X,AT)=EXP(-8.8455+88.8901*X-78.8961*X**2+21.3731*X**3)
&     *EXP((-12.972+9.7707*X-2.4984*X**2)*1.0E04/AT)
      ADD=.1
      AZZR=AZZ
    3 CØNTINUE
      AT=ATFUEL+459.7
      P1=FPRES(AZZR,AT)
      IF(AZZR.GT.1.7)GØ TØ 6
      BZR=AZZR+ADD
      GØ TØ 7
    6 BZR=AZZR-ADD
    7 P2=FPRES(BZR,AT)
      A=(AZZR-BZR)/(ALØG(P1)-ALØG(P2))
      B=AZZR-A*ALØG(P1)
      BP=FBP(TMMMF)
      BHZR=AZZR
      AZZR=A*ALØG(BP)+B
      DIF=BHZR-AZZR
      IF(DIF.LT.0.0)DIF=-DIF
      IF(DIF.LT.0.001)GØ TØ 4
      ADD=ADD*.2
      GØ TØ 3
    4 AZZ=AZZR
      RETURN
      END
```

INTRP2

```
      FUNCTIØN FUNCT2(X1,X2,Z,NP1,NP2,LP1,XP1,XP2,IS,IC)
C
C     FEBRUARY 4, 1972
C     TWØ-DIMENSIØNAL LAGRANGIAN INTERPØLATIØN RØUTINE
C     X1 = FIRST ABSCISSA ARRAY
C          (MUST BE IN ASCENDING ØRDER IN ARRAY)
C     X2 = SECØND ABSCISSA ARRAY
C          (MUST BE IN ASCENDING ØRDER IN ARRAY)
C     Z  = TWØ-DIMENSIØNAL ØRDINATE ARRAY
C     NP1= LENGTH ØF X1 ARRAY
C     NP2= LENGTH ØF X2 ARRAY
C     LP1= TØTAL FIRST DIMENSIØNAL STØRAGE FØR Z ARRAY
```

INTRP2 CØNTINUED

```
C      XP1= VALUE ØF FIRST ABSCISSA FØR INTERPØLATIØN
C      XP2= VALUE ØF SECØND ABSCISSA FØR INTERPØLATIØN
C      IS   REMEMBERS PLACE IN TABLE (MUST BE SET EQUAL
C           TØ ZERØ BEFØRE FIRST CALL TØ FUNCTIØN)
C      IC   CØNTRØLS INTERPØLATIØN METHØD:
C         = 1 FØR LINEAR INTERPØLATIØN
C         = 2 FØR LAGRANGIAN INTERPØLATIØN
C      FUNCT2 SET TØ CØRRESPØNDING ØRDINATE VALUE
C      (FUNCT2 WILL EXTRAPØLATE)
C
       DIMENSIØN X1(1),X2(1),Z(LP1,NP2),Y(20)
       DIMENSIØN ED(3),XA(3),YA(3)
       EQUIVALENCE (ED(1),XA(1))
       NINT=3
       IS1=0
       IF(NP1.GE.3 .AND. IC.GE.2) GØ TØ 15
C      LINEAR INTERPØLATIØN
       NN=1
       I=0
       IF(NP1.LE.1) GØ TØ 38
       NINT=2
    15 NN=MAX0(2,NP1+2-NINT)
       XP=XP1
       NN1=2
       IF(IS.LE.1 .ØR.IS.GE.NP1) GØ TØ 102
C      TEST WHICH DIRECTIØN TØ SEARCH - MUST FIND THE SMALLEST
C      X1 GREATER THAN XP, BUT WITH I GREATER THAN 1 AND LESS
C      THAN NP1 (ØR EQUAL TØ NP1 FØR LINEAR INTERPØLATIØN)
   211 NN1=IS
       IF(XP.LT.X1(NN1)) GØ TØ 101
C      SEARCH UPWARD IN TABLE
   102 DØ 20 I=NN1,NN
       IF(XP.LE.X1(I)) GØ TØ 10
    20 CØNTINUE
       I=NN
       GØ TØ 10
C      SEARCH DØWNWARD IN TABLE
   101 DØ 21 J=2,NN1
       I=NN1-J+1
       IF(XP.GT.X1(I)) GØ TØ 11
    21 CØNTINUE
       I=1
    11 I=I+1
    10 SPAN=1.0E-06*XP
       NN=0
       DØ 12 J=1,NINT
       NN1=I+J-2
       ED(J)=XP-X1(NN1)
    12 IF(ABS(ED(J)).LE.SPAN) NN=NN1
       IF(NN.EQ.0) GØ TØ 90
```

INTRP2 CØNTINUED

```
   38 DØ 40 K=1,NP2
   40 Y(K)=Z(NN,K)
      FUNCT2=FUNCT1(X2,Y,NP2,XP2,IS1,IC)
      GØ TØ 80
   90 DØ 93 J=1,NINT
      NN1=I+J-2
      DØ 92 K=1,NP2
   92 Y(K)=Z(NN1,K)
      YA(J)=FUNCT1(X2,Y,NP2,XP2,IS1,IC)
   93 XA(J)=X1(NN1)
      NN1=3
      IF(NINT.LT.3) NN1=2
      IS1=0
      FUNCT2=FUNCT1(XA,YA,NN1,XP,IS1,IC)
   80 IS=I
      RETURN
      END
      FUNCTIØN FUNCT1(X,Y,NP,XPI,IS,IC)
C
C     FEBRUARY 4, 1972
C     THREE PØINT LANGRANGIAN INTERPØLATIØN
C                    ØR
C     TWØ PØINT LINEAR INTERPØLATIØN
C     X  = ABSCISSA ARRAY
C          (MUST BE IN ASCENDING ØRDER IN ARRAY)
C     Y  = ØRDINATE ARRAY
C     NP = LENGTH ØF X & Y ARRAYS
C     XPI= VALUE ØF ABSCISSA FØR INTERPØLATIØN
C     IS   REMEMBERS PLACE IN TABLE (MUST BE SET TØ
C          ZERØ BEFØRE FIRST CALL TØ FUNCTIØN)
C     IC   CØNTRØLS INTERPØLATIØN METHØD:
C        = 1 FØR LINEAR INTERPØLATIØN
C        = 2 FØR LAGRANGIAN INTERPØLATIØN
C     FUNCT1 SET TØ CØRRESPØNDING ØRDINATE VALUE
C     (FUNCT1 WILL EXTRAPØLATE)
C
      DIMENSIØN X(1), Y(1), ED(3)
      EQUIVALENCE (ED(1),E1), (ED(2),E2), (ED(3),E3)
      NINT=3
      IF(NP.GE.3 .AND. IC.GE.2) GØ TØ 15
C     LINEAR INTERPØLATIØN
      NN=1
      I=0
      IF(NP.LE.1) GØ TØ 38
      NINT=2
   15 NN=MAX0(2,NP+2-NINT)
      XP=XPI
      NN1=2
      IF(IS.LE.1 .ØR. IS.GE.NP) GØ TØ 102
C     TEST WHICH DIRECTIØN TØ SEARCH - MUST FIND THE SMALLEST
```

INTRP2 CØNTINUED

```
C      X GREATER THAN XP, BUT WITH I GREATER THAN 1 AND LESS
C      THAN NP (ØR EQUAL TØ NP FØR LINEAR INTERPØLATIØN)
  211 NN1=IS
      IF(XP.LT.X(NN1)) GØ TØ 101
C     SEARCH UPWARD IN TABLE
  102 DØ 20 I=NN1,NN
      IF(XP.LE.X(I)) GØ TØ 10
   20 CØNTINUE
      I=NN
      GØ TØ 10
C     SEARCH DØWNWARD IN TABLE
  101 DØ 21 J=2,NN1
      I=NN1-J+1
      IF(XP.GT.X(I)) GØ TØ 11
   21 CØNTINUE
      I=1
   11 I=I+1
C     INTERPØLATE FØR FUNCT1 IN Y-TABLE CØRRESPØNDING TØ
C     XP IN X-TABLE USING THREE PØINT LAGRANGIAN
C     INTERPØLATIØN SCHEME
   10 SPAN=1.0E-06*XP
      NN=0
      DØ 12 J=1,NINT
      NN1=I+J-2
      ED(J)=XP-X(NN1)
   12 IF(ABS(ED(J)).LE.SPAN) NN=NN1
      IF(NN.EQ.0) GØ TØ 90
   38 FUNCT1=Y(NN)
      GØ TØ 80
   90 E12=X(I-1)-X(I)
      IF(NINT.EQ.3) GØ TØ 360
      FUNCT1=Y(I)-(Y(I)-Y(I-1))*E2/E12
      GØ TØ 80
  360 E13=X(I-1)-X(I+1)
      E23=X(I)-X(I+1)
   36 FUNCT1=Y(I-1)*E2*E3/(E12*E13)
&           -Y(I)   *E1*E3/(E12*E23)
&           +Y(I+1)*E1*E2/(E13*E23)
   80 IS=I
      RETURN
      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,
```

SI

```
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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