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LUCAS HEIGHTS

SHUTDOWN — A REACTOR SHUTDOWN OPTIMIZATION CODE

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J. R. FREDSALL

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ABSTRACT

The Fortran IV digital computer code SHUTDOWN uses a trial and error procedure to find the optimum method of altering the reactor power before shutdown for an outage of a given desired duration. Exact optimum solutions are not found by this method but the solutions that are found can be used to improve reactor operations.

CONTENTS

1. INTRODUCTION

It is sometimes possible to improve the operating efficiency of a reactor that does not have complete xenon-135 override capability by appropriately varying the reactor power just before shutdown. For a reactor having low excess reactivity, outage durations are restricted by the outage xenon transient; often this directly results in a reduction in reactor efficiency. However, since the outage xenon transient is determined by the pre-shutdown power history, it is sometimes possible to vary the power in a way that will produce a more favourable outage xenon transient and a gain in reactor efficiency.

This concept is illustrated in Figure 1. Curve A is the normal abrupt shutdown power reduction and its xenon transient; curve B is a sample time-varied shutdown and its transient. With shutdown method A the startup is delayed past the desired startup time, a, to b. However, with shutdown mode B a startup can be made at a, with a saving of time ΔT. The problem is to find the power reduction mode that gives the most efficient operation.

2. THE SHUTDOWN CODE

The SHUTDOWN code determines the best method for shutting the reactor down for a given set of conditions by examining the xenon transients for all possible paths through a power-time grid super-imposed on the power-history curve. The code can optimize the shutdown in four different ways for a given desired startup time τ :

(1) It can demand startup at exactly τ, and will minimize the loss in MWd incurred during the power alterations.

(2) It can demand startup at exactly τ, and will maximize the time spent within a given range of reactor powers.

(3) It can require that the outage be at least τ, and will minimize loss in MWd incurred from two sources: (i) the loss during the power alterations, and (ii) the MWd loss

from any outage extension beyond τ . The first of these two contributions may be weighted.

(4) It can require that the outage be at least τ, and will minimize the sum of two time contributions: (i) the loss in time spent while the power is outside the desired power band, and (ii) the time lost from any outage extension beyond τ . The first of these two contributions may be weighted.

The several previous attempts to develop a method for determining optimum shutdown modes were hampered by the lack of a direct analytical solution. Consequently the results were rather limited in scope. For instance, the early work described by Kirk (1953) examines only the situation where the reactor power is reduced to zero in two successive step decreases. The advent of modern high speed digital computers has provided the means for calculating optimum shutdown modes in a reasonable length of time. The first attempt to do this is discussed by Ash et al (1959). The method proposed used a dynamic programming technique to find the shutdown mode giving the minimum xenon peak after shutdown. However, aside from the fact that simple minimization of the xenon peak does not necessarily lead to the economically optimum shutdown mode, this method has proved too cumbersome for solution by present day computers. Another approach to the minimization of the xenon peak was tried by Rosztocay (1964) using Pontryagin's Maximum Principle. The power-time grid approach was used for the first time to approximate the optimum shutdown function for the NRU Reactor, (Kerr and Lennox, 1962). The grid analysis was used in the earlier part of the study to determine the general shape of the shutdown function. This treatment was mainly concerned with regulating the outage time available before the reactor was made subcritical by the rising xenon concentration.

The approach used with the SHUTDOWN code is similar to that of Kerr and Lennox in that a power-time grid is employed, but the code makes it possible to determine optimum shutdown modes for a wider variety of conditions than has been attempted before. Its main limitation is that a significant number of calculations must be done (that is, 16,777,216 different power variation functions are available with an 8 x 8 grid) if a near optimum

mode is to be found from the initial grid. Hence the code is designed to refine solutions by examination of finer grids placed in the regions of interest. Another feature is that it can solve for the shutdown method that gives the smallest peak xenon value after shutdown. This feature will be of interest as a check should the dynamic programming method proposed by Ash et al. (1959) ever be used.

3. DISCUSSION

3.1 The General Calculation Method

The calculation method employed in the SHUTDOWN code is simple; a shutdown mode is selected, its outage xenon and reactor reactivity transients are calculated, its associated losses are calculated for the desired outage time, and these losses are compared with the previous best results. This process continues until all paths through the time-power grid have been investigated. For comparison the losses associated with a "sample shutdown" mode (that is, an abrupt shutdown) are also calculated.

3.2 The Power-Time Grid

The initial power-time grid used can be fairly flexible. Up to 20 time intervals can be used, and in each of these intervals up to 20 power levels may be designated. Also, the intervals may be of varying duration, and the number of levels in each interval may vary.

3.3 The Xenon and Iodine Calculations

The equations for calculating the xenon and iodine variations through the power-time grid are fairly simple since the power is varied in steps. The xenon and iodine reactivities at the end of the k-th interval are :

$$X(k+1) = X_e(k) + \left[X(k) - X_e(k)\right] \exp\left[-DE(k)\ T(k)\right] + \frac{\lambda_I}{DE(k) - \lambda_I}\left\{\left[I(k) - I_e(k)\right]\left[\exp\left(-\lambda_I\ T(k)\right) - \exp\left(-DE(k)\ T(k)\right)\right]\right\} \quad \ldots\ldots (1)$$

$$I(k+1) = I_e(k) + \left[I(k) - I_e(k)\right] \exp\left[-\lambda_I\ T(k)\right] \quad \ldots\ldots (2)$$

Here $X_e(k)$ and $I_e(k)$ are the equilibrium xenon and iodine reactivities for the selected power level P(k) in the k-th interval :

$$X_e(k) = \frac{A\,P(k)}{\lambda_x + BP(k)} = \frac{AP(k)}{DE(k)} \quad \ldots\ldots (3)$$

$$I_e(k) = CP(k) \quad \ldots\ldots (4)$$

The above formulae can only rigorously describe the point isotopic concentration of xenon-135 in a fuel element, but it has been found in practice that, with the proper choice of the constants A, B and C, the equations can also be used to describe reactor xenon poisoning transients. These constants can be found if the xenon reactivity is known for two power levels and the effective iodine reactivity is known for one power level. Alternatively, one can use the fact that the ratio of A to C is determined by the reactor fuel composition. This ratio is a function of the fission yields of xenon-135 and iodine-135 and can be expressed as :

$$\lambda_I\,(\gamma_I + \gamma_X)\,/\gamma_I \quad .$$

The value of this ratio is 2.89×10^{-5} sec^{-1} for Pu239 and U233 ($\gamma_X = 0$ for these fuels) and is 3.03×10^{-5} sec^{-1} for U235. (See Reactor Physics Constants, ANL 5800).

3.4 Reactivity Calculation

The reactivity formulation used in the SHUTDOWN code has four portions, a constant base reactivity RB, a prompt linear power coefficient PRC, and two delayed linear power coefficients as follows :

$$R(k) = RB + PRC\left[P(k)\right] + R1(k) + R2(k) \quad \ldots\ldots (5)$$

The delayed contributions are :

$$R1(k) = \left\{D1\left[P(k)\right] - R1(k-1)\right\} \exp\left\{-CR1\ T(k)\right\} + R1(k-1)\ , \quad \ldots\ldots (6)$$

$$R2(k) = \left\{D2\left[P(k)\right] - R2(k-1)\right\} \exp\left\{-CR2\ T(k)\right\} + R2(k-1)\ , \quad \ldots\ldots (7)$$

where D1 and D2 are the power coefficients and CR1 and CR2 are the reactivity decay constants.

An important condition employed in finding the optimum shutdown mode is that the reactor reactivity must not fall below the xenon reactivity during the time covered by the power-time grid, unless the power is zero in the time intervals adjacent to the point of calculation. This condition usually allows the elimination of a significant fraction of the possible paths through the power-time grid, unless the reactor reactivity is relatively large.

3.5 Subroutine TCALC

The subroutine TCALC is used to calculate the time intercepts of the pile reactivity and xenon transients after the reactor is finally at zero power. The near-side intercept, or rising xenon intercept is found in the following manner. First the time scale is adjusted by a time increment ΔT so that the transient starts from zero xenon (Figure 2). (This treatment for the xenon transient is similar to that of Ward (1957)).

Then the intercept is found by an iterative procedure. The first guess for the intercept is the time at which the xenon is maximum. The second iteration intercept value is found by determining the intersection (point 2) of the reactivity level and a line drawn from the origin to the peak of the xenon transient. The third guess is found in a similar manner. (See Figure 3).

The far side intercept is found by iterating on the equation of the zero initial xenon transient (See Figure 2). The equation of this curve is :

$$X = (\text{const})\ \left(e^{-\lambda_X t} - e^{-\lambda_I t}\right) \quad \ldots\ldots (8)$$

or as is used in the subroutine :

$$T2 = \frac{\log}{\lambda_I}\left[\frac{(\text{const})}{(\text{Reactor Reactivity})}\left\{\exp\left[(\lambda_I - \lambda_X)\ T1\right] - 1.0\right\}\right] \quad \ldots\ldots (9)$$

The first guess for the far side intercept is chosen from a simplified representation of the far side of the xenon transient. (See dotted lines in Figure 4).

This approximation allows an explicit estimation of the intercept for any reactivity value.

An alternative method of solution is also included in TCALC. This method uses a read-in table of values for the equation 8 (called the universal shutdown curve by Ward, 1957). As presently used the table consists of the time values for 39 different levels of xenon reactivity. If the intercept proves to be above the 39th level ($X(t)/X_{max} = 0.975$) or below the first level ($X(t)/X_{max} = 0.025$) then recourse is made to the trial and error method discussed previously. Values that can be used for this table are listed in Appendix 2.

Two other features are embodied in this subroutine. First, the xenon reactivity can be reduced by a fraction, corresponding to the loss in poisoning effect with a partial discharge. Secondly, the reactor base reactivity may be changed after shutdown, corresponding to the charging or discharging of spike fuel or poison.

3.6 The Refined Grid Option

Solutions obtained from an examination of the initial power-time grid can be further refined by the SHUTDOWN code. This is accomplished by allowing the power level intervals of the original power-time grid to be subdivided in the regions adjacent to the obtained solution. The code provides for alternative power levels, one above and one below the previous solution. Their spacing is gradually lessened as the calculation proceeds, until the desired accuracy is obtained. This calculation sequence can then be followed by a sequence in which three power levels are offered, the old solution, and values above and below the old solution.

The time intervals in the original power-time grid can also be subdivided. In this case the power levels in the right hand subdivisions of the original time intervals are allowed to vary first, while the power levels in the remainder of the subintervals are held constant at the old

solution. Upon convergence the power levels are allowed to vary in the subintervals that are second from the right, and so on until all of the subintervals have been examined. This sweep through the subintervals is repeated for a designated number of times. Following completion of this operation the subintervals are again subdivided, and the process is repeated until the designated maximum number of subintervals has been examined.

3.7 Example Calculation

Appendix 3 presents the output for a determination of the optimum shutdown mode for the NRU reactor. Actually two desired startup times were examined but only one of the solutions was determined more exactly through the "refined grid" option. This startup time of 1.70 hours was also examined under the same conditions as in Kerr and Lennox (1962); a comparison of the two shutdown modes is given in Figure 5. One can observe that although the two functions shown in Figure 5 both accomplish startup at exactly 1.70 hours down, the one given by Kerr and Lennox loses 1.72 hours more in full power operating time. Thus the function determined by the shutdown code is significantly closer to the optimum.

4. CONCLUSIONS

The SHUTDOWN code can be used to approximate the optimum shutdown modes for reactors under a wide range of conditions. The principal limitation of the code is the running time required to analyse large power-time grids. This limitation is aggravated if the reactivity of the reactor is large with respect to the equilibrium xenon reactivity, or if the reactor has a large negative power coefficient. Under these conditions it becomes necessary to depend more on the "grid refining" option which redefines the grids in the regions of interest. This process may distort the solution function in relation to the actual theoretical optimum shutdown mode, but the difference should be small from a reactor operational point of view since the real problem is to improve operation of a reactor, not necessarily to find the exact shape of the optimum shutdown mode.

5. REFERENCES

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Reactor Physics Constants (1963). - ANL 5800, 2nd ed.

Rosztocay, A.R., and Weaver, L.E. (1964). - Optimum reactor shutdown program for minimum xenon building. Nuclear Science and Engineering. 20 : 318-323.

Ward, A.G. (1957). - A universal curve for the prediction of xenon poison after a reactor shutdown. AECL-411.

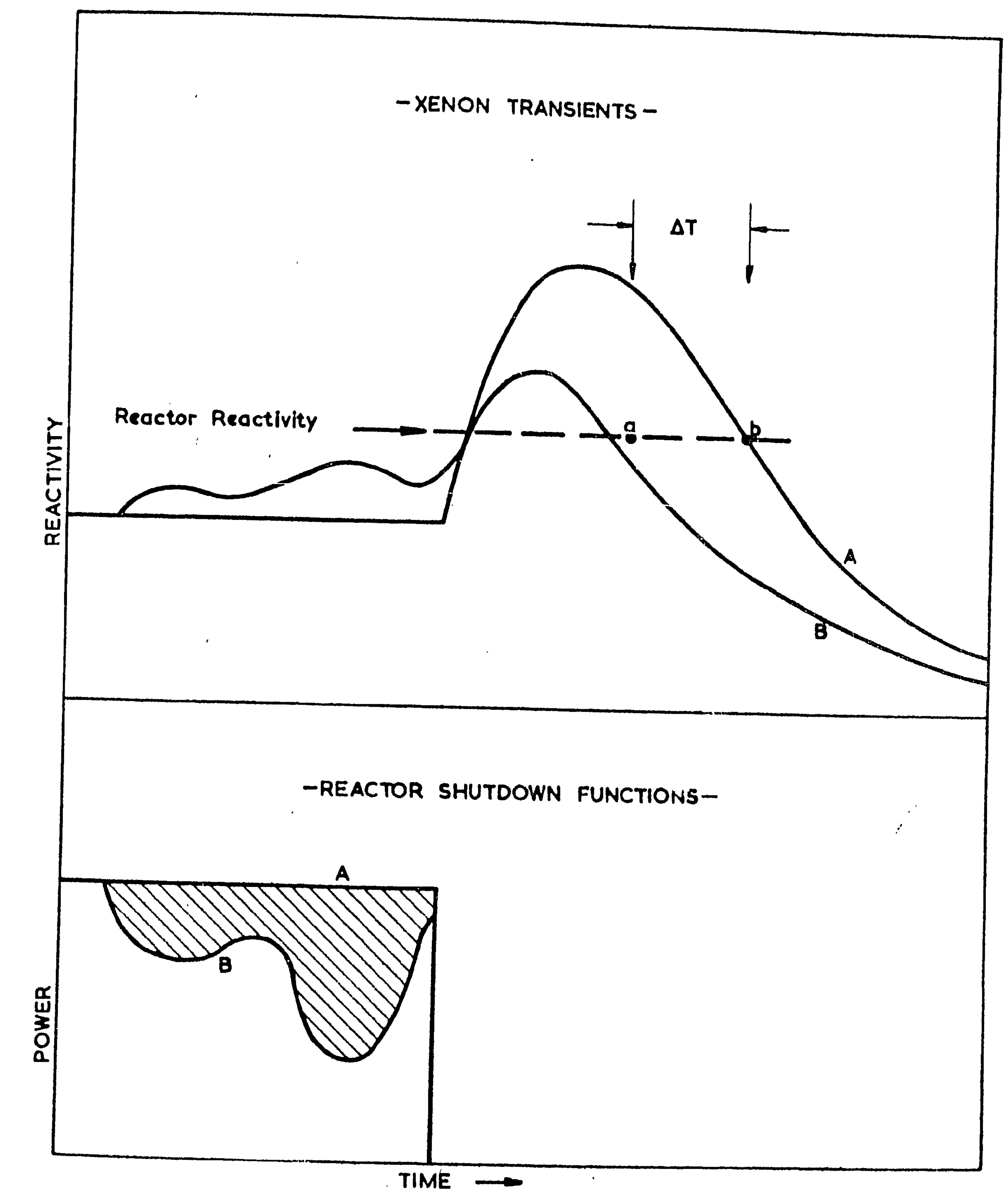

FIGURE I SAVINGS FROM A TIME-VARIED SHUTDOWN

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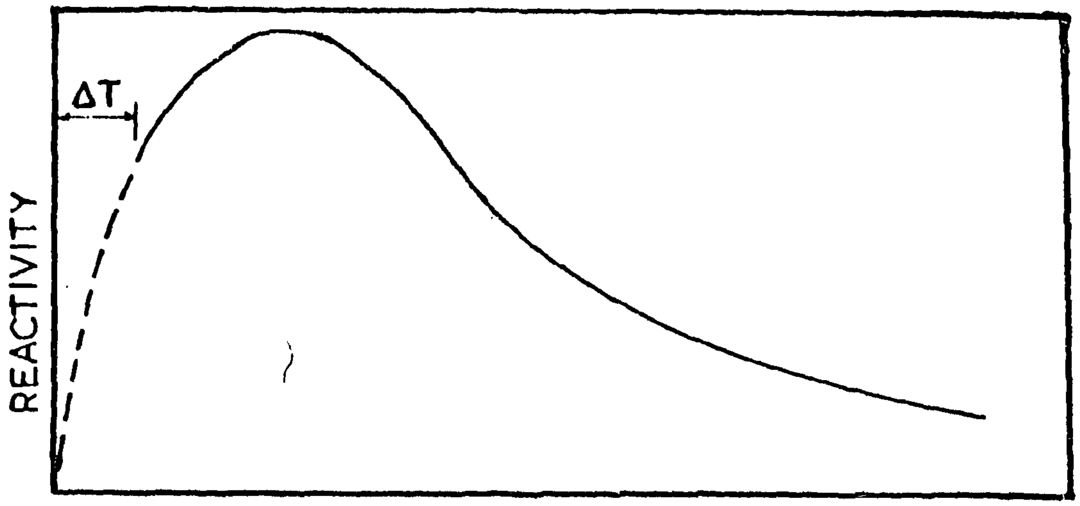

FIGURE 2 TIME SCALE ADJUSTMENT OF THE XENON TRANSIENT FOLLOWING COMPLETE SHUTDOWN

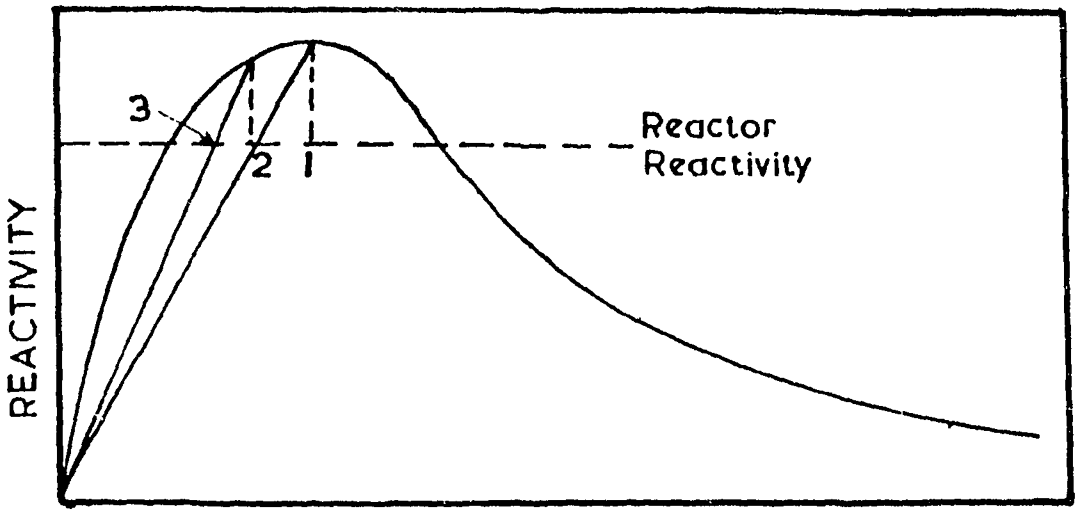

FIGURE 3 SCHEME FOR FINDING NEAR SIDE INTERCEPT OF XENON TRANSIENT

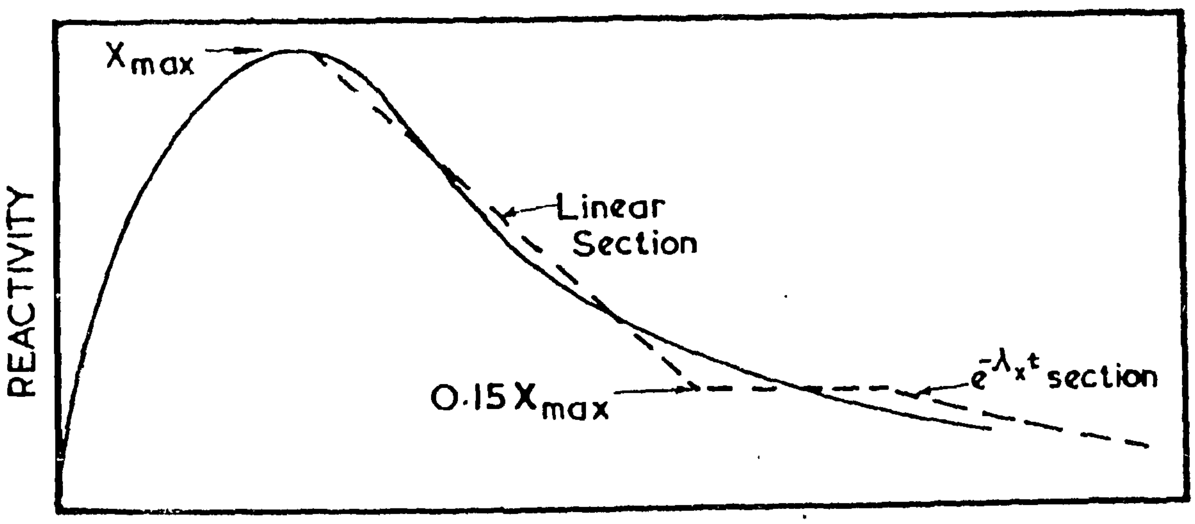

FIGURE 4 SCHEME FOR FINDING INITIAL GUESS OF FAR SIDE INTERCEPT OF XENON TRANSIENT

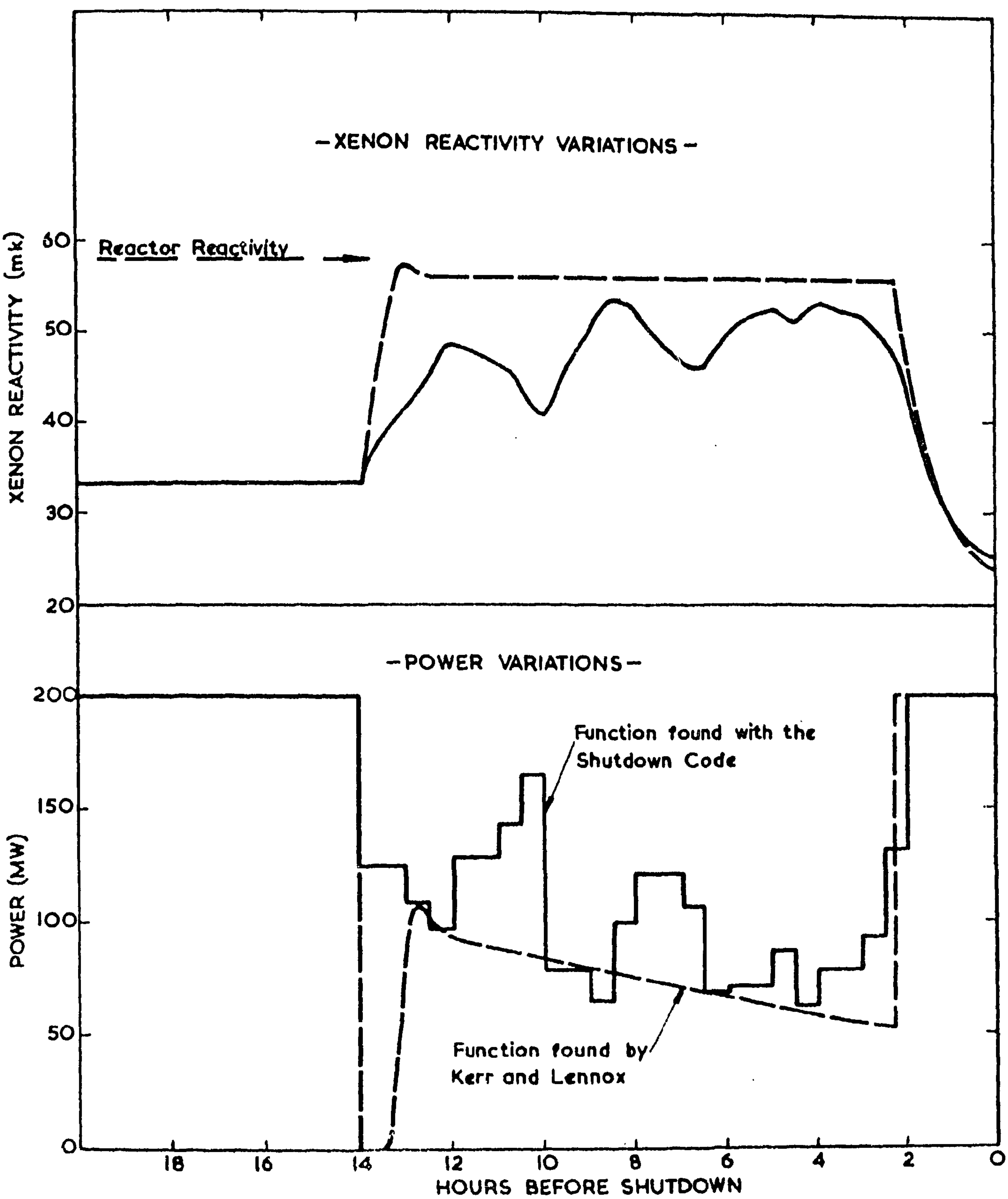

FIGURE 5 SHUTDOWN FUNCTIONS FOR NRU STARTUP AFTER 1·70 HOURS

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APPENDIX I.

INPUT FOR SHUTDOWN

Card	Variable Name	Format	Explanation
1*	CY	10.5	The I-135 decay constant in hr^{-1}.
	CZ	10.5	The Xe-135 decay constant in hr^{-1}.
	ARF	10.5	If ARF $\leq$ 0 then the universal shutdown curve will be read from the next 39 cards. ARF > 0 when no table is given.
2-40*	TSUBN(I)	10.5	The near side values of the universal shutdown curve.
	TSUBF(I)	10.5	The far side values of the universal shutdown curve.
41	NT	I2	The number of time intervals in the initial power-time grid.
	NSDD	I2	The number of desired startup times (τ's) to be analysed.
	NOPT	I1	If NOPT = 1 then outage is at least τ. If NOPT = 2 then outage is exactly τ. If NOPT = 3 the solution will be found which gives the minimum of the maximum xenon after shutdown.
	MOPT	I1	If MOPT = 1 then optimization is on MWd. If MOPT = 2 then optimization is on the time spent with the power within a fraction (FRACT) of a given power level (WCALC).
	NHIOPT	I1	If NHIOPT $\leq$ 0 then the maximum power level in each time interval will be given and cards 53 and 54 must be given. If NHOPT > 0 then the maximum power level through the grid is taken as WCALC.

* These cards are read only at the start of the Data cards.

A P P E N D I X I (continued)

Card	Variable Name	Format	Explanation
	NRITE	I1	If NRITE > 0 then full output will be printed. If NRITE ≤ 0 then full output will not be printed.
	FRACT	F4.2	See MOPT.
	WEIGHT	F4.2	This is the weight to be applied to the losses (e.g. MWd) incurred before shutdown relative to the losses after shutdown.
	NTOPT	I1	If NTOPT > 0 the tabulated universal xenon curve (see cards 2-40) will be used to calculate the times of zero net reactivity after shutdown. If NTOPT ≤ 0 then the iterative method explained in the text is used.
	KOPT	I2	The number of "Refined Grid Calculations".
	TITLE	A53	Case identification.
42	A	F10.5	Xenon and iodine equation constants.
	B	F10.5	See Equations 3 and 4 in text.
	C	F10.5	
	D1	F10.5	The first delayed linear power coefficient.
	CR1	F10.5	The decay constant corresponding to D1.
	D2	F10.5	See D1.
	CR2	F10.5	See CR1.
43	PRC	F10.5	The prompt linear power coefficient.
	WCALC	F10.5	The power level used for calculating losses in the power-time grid.
	RB	F10.5	The reactor base reactivity.
	ZF1	F10.5	The fraction of xenon and iodine reactivity discharged after shutdown.

A P P E N D I X I (continued)

Card	Variable Name	Format	Explanation
	DELTAR	F10.5	The reactivity added after shutdown.
	TLIMIT	F10.5	The convergence limit for calculations of the zero net reactivity points after shutdown. (in hours, say 0.01).
44	WSD	F10.5	If WSD ≠ 0 then ZSDI, YSDI, R1I, R21, and WLOSSI will be calculated assuming WSD is the equilibrium power level.
	ZSDI**	F10.5	The xenon at shutdown for the reference shutdown method.
	YSDI**	F10.5	The iodine at shutdown --------- etc.
	R1I**	F10.5	The value of R1 at shutdown -------- etc.
	R2I**	F10.5	The value of R2 at shutdown -------- etc.
	WLOSSI**	F10.5	The loss incurred during the power reduction for the reference shutdown method. WLOSSI = 0.0 if WSD ≠ 0 .
45	WSTART	F10.5	If WSTART ≠ 0 Z(1), Y(1), R1(1), and R2(1) will be calculated assuming WSTART is the equilibrium power level.
	Z(1)	F10.5	The initial conditions at the start of the power-time grid. These are ignored if WSTART ≠ 0.
	Y(1)	F10.5	
	R1(1)	F1.5	
	R2(1)		
46	N(1)-N(20)	I3	The number of power levels in each interval of the power-time grid.
47 48	SDD(1) - SDD(20)	F5.2	The startup times to be analysed (in hours)
49 50	T(1)-T(20)	F5.2	The duration of the time intervals in the power-time grid (in hours).

** These values are not used if WSD ≠ 0

A P P E N D I X I (continued)

Card	Variable Name	Format	Explanation
51 52	WLO(1) - WLO(20)	F5.2	The lowest power level in each interval in the power-time grid.
53 54	WHI(1) - WHI(20)	F5.2	The highest power level in each interval of the power-time grid. Cards 53 and 54 should not be used if NHIOPT > 0.
55	NTSPL	I2	The number of times the intervals in the power-time grid are to be split in half.
	NPSPL	I2	The number of times the spacing between the current solution power level and the alternative power levels is reduced by the factor DEM.
	NTIMES	I2	The maximum number of calculational sweeps through the subdivided time intervals before another time split is made.
	NREP	I2	NREP $\leq$ NPSPL. The number of times three alternative power levels are offered (the centre one being the current solution) starting with the finest power subdivision. These calculations are made after the calculations with two alternative levels are completed.
	DEM	F4.3	The fraction by which the spacing between the current solution and the alternative power levels is diminished at each power split.
	NSUT(1) - NSUT (KOPT)	I2, 1X	The numbers of the startup times (in the order of cards 47 and 48) that are to have refined grid calculations.

A P P E N D I X 2

UNIVERSAL SHUTDOWN CURVE

Ward (1957) was the first to realise that all xenon transients following reactor shutdown follow the function

$$X(t) = e^{-\lambda_X t} - e^{-\lambda_I t} .$$

Actually this function only truly describes the xenon transient starting from the condition of having zero xenon. However, by appropriate shifts in the time axis this function can be used for transients starting from non-zero xenon.

This function can be used by the subroutine TCALC in two forms:

(1) as given by the equation, and
(2) as given in a table.

Four sets of the tabulated values are given below. Each set corresponds to various pairs of the I - 135 and Xe - 135 decay constants that are currently in use. The tables were derived with the use of the program GARBAGE in conjunction with the subroutine TCALC. The values are accurate to $\pm$ 0.001 hr.

λ_I = 0.10404 hr^{-1}
λ_x = 0.07524 hr^{-1}

($\lambda_I = 2.89 \times 10^{-5} sec^{-1}$, $\lambda_x = 2.09 \times 10^{-5} sec^{-1}$)

0.10401	75.76132
0.21001	65.98784
0.31809	60.16509
0.42831	55.96991
0.54082	52.66979
0.65570	49.93624
0.77308	47.59592
0.89310	45.54284
1.01579	43.70904
1.14143	42.04763
1.27015	40.52573
1.40211	39.11945
1.53751	37.80796
1.67642	36.57779
1.81930	35.41629
1.96631	34.31481
2.11776	33.26504
2.27396	32.26033
2.43499	31.29449
2.60169	30.36357
2.77436	29.46282
2.95350	28.58841
3.13933	27.73733
3.33316	26.90530
3.53553	26.09011
3.74694	25.28713
3.96923	24.49730
4.20301	23.71506
4.45060	22.93809
4.71327	22.16307
4.99436	21.38633
5.29623	20.60355
5.62373	19.80946
6.38240	18.15773
5.98287	18.99714
6.83520	17.27572
7.36477	16.32958
8.01484	15.27284
8.90248	13.98899

λ_I = 0.10345 hr^{-1}
λ_x = 0.07534 hr^{-1}

(Half lives = 6.7 hr and 9.2 hr)

0.10428	75.86292
0.21054	66.08582
0.31890	60.25978
0.42940	56.06162
0.54219	52.75881
0.6573[illegible]	50.02286
0.77505	47.68025
0.89537	45.62502
1.01837	43.78919
1.14433	42.12585
1.27337	40.60203
1.40566	39.19413
1.54140	37.88122
1.68065	36.64900
1.82389	35.48596
1.97128	34.38292
2.12310	33.33162
2.27968	32.32541
2.44111	31.35860
2.60823	30.42581
2.78132	29.52364
2.96090	28.64830
3.14719	27.79529
3.34149	26.96188
3.54436	26.14544
3.75628	25.34132
3.97911	24.54984
4.21346	23.76627
4.46165	22.98794
4.72495	22.21154
5.00671	21.43338
5.30930	20.64916
5.63758	19.85358
5.99757	19.03972
6.39803	18.19868
6.85190	17.31494
7.38269	16.36691
8.03426	15.30803
8.92392	14.02150

λ_I = 0.10440 hr^{-1}
λ_x = 0.07560 hr^{-1}

($\lambda_I = 2.9 \times 10^{-5} sec^{-1}$, $\lambda_x = 2.1 \times 10^{-5} sec^{-1}$)

0.10359	75.43829
0.20916	65.70827
0.31680	59.91120
0.42658	55.73440
0.53863	52.44868
0.65305	49.72705
0.76996	47.39687
0.88949	45.35266
1.01168	43.52677
1.13682	41.87258
1.26502	40.35699
1.39644	38.95692
1.53130	37.65109
1.66964	36.42571
1.81195	35.26955
1.95837	34.17276
2.10920	33.12746
2.26476	32.12652
2.42514	31.16521
2.59118	30.23824
2.76314	29.34131
2.94155	28.47060
3.12663	27.62265
3.31967	26.79474
3.52123	25.98273
3.73178	25.18490
3.95316	24.39643
4.18600	23.61723
4.43258	22.84402
4.69419	22.07221
4.97413	21.29869
5.27477	20.51917
5.60094	19.72837
5.95862	18.91944
6.35651	18.08285
6.80748	17.20518
7.33488	16.26295
7.98230	15.21061
8.86631	13.93215

λ_I = 0.1034 hr^{-1}
λ_x = 0.0753 hr^{-1}

0.10433	75.90184
0.21065	66.11966
0.31906	60.29060
0.42962	56.09027
0.54247	52.78575
0.65770	50.04839
0.77544	47.70457
0.89582	45.64828
1.01888	43.81151
1.14491	42.14730
1.27401	40.62309
1.40637	39.21329
1.54248	37.90046
1.68150	36.66763
1.82481	35.50400
1.97227	34.40040
2.12417	33.34856
2.28083	32.34184
2.44235	31.37453
2.60955	30.44173
2.78273	29.53911
2.96240	28.66283
3.14878	27.80938
3.34318	26.97554
3.54615	26.15898
3.75818	25.35410
3.98112	24.56227
4.21559	23.77832
4.46390	22.99959
4.72734	22.22280
5.00924	21.44425
5.31199	20.65963
5.64043	19.86364
6.00060	19.04936
6.40127	18.20790
6.85536	17.32370
7.38643	16.37519
8.03833	15.31577
8.92843	14.02858

```
$IBJOB          DECK
$IBFTC GARBAG
C   GARBAGE A TIME INTERCEPT CALC
       COMMON MANYNE,MANYFA,TSUBN(40),TSUBF(40),TLIMIT,NTOPT,NOPT
       DIMENSION TNEAR(100),TFAR(100),MANF(100),MANN(100)
     1 FORMAT(I2,8X,3F10.5)
     2 FORMAT(2F10.5)
       NTOPT=0
       NOPT=1
       CALL TYMIN (5HCLOCK)
    50 READ(5,1)M,CY,CZ,TLIMIT
       WRITE(7,2)CY,CZ
       WRITE(6,3)CY,CZ
       TMAXI=ALOG(CY/CZ)/(CY-CZ)
       AAA=CZ*EXP(CY*TMAXI)/(CY-CZ)
       Y=AAA*(CY-CZ)/CY
       SM=M
       S=1.0/SM
       R=S
       MA=M-1
       DO 10 N=1,MA
      0CALL TCALC(Y,0.0,CY,CZ,0.0,0.0,TMAXI,AAA,R,0.0,0.0,0.0,1.0,
      1TNEAR(N),TFAR(N),NNEAR,NFAR,XMAXI)
       R=S+R
       MANN(N)=MANYNE
       MANF(N)=MANYFA
       WRITE(7,2) TNEAR(N),TFAR(N)
       WRITE(6,4)TNEAR(N),TFAR(N),MANN(N),MANF(N)
     3 FORMAT(2F10.5,20H    NNEAR      NFAR    )
     4 FORMAT(2F10.5,3X,I5,5X,I5)
    10 CONTINUE
       CALL TYMOUT (5HCLOCK)
       GO TO 50
       END
```

APPENDIX 3.

OUTPUT FOR SHUTDOWN

Normal Output

The first page of output displays the input data; the actual output data begins on the second page. An explanation of terms is given below:

The first two lines	A statement of the type of problem solved.
NCALCS	The number of possible paths through the input grid.
NTRANS	The number of times the subroutine TCALC was used.
Ave. NNEAR and Ave. NFAR	The average number of iterations required to reach convergence in TCALC.
Initial Iodine and Xenon	The values of xenon and iodine for the reference shutdown.
TIME LOSS	The loss for the reference shutdown.
XMAXI	The maximum xenon concentration following the reference shutdown.
NFAR AND FAR INTERCEPTS	The times of zero net reactivity following the reference shutdown.
NNEARI AND NFARI	The number of iterations in TCALC for the reference shutdown solution.

The next group of data shows the losses that would be associated with each desired startup time if the reference shutdown were used. SDD = Desired Startup Time. TSUI = Time of Actual Startup. SDLOSSI = The Losses from not being able to Startup When Desired. SDNETI = "Time Loss" + "Weight" x SDLOSSI.

The next group of data shows the results of the shutdown optimization using the input power-time grid. The terms are explained below.

SDD	Desired startup time.
TSU	Time of startup.
WLOSS	The loss incurred by varying the power.
SDLOSS	The loss incurred after shutdown.
SDNET	WLOSS + SDLOSS
YSD, ZSD, RSD	The iodine, xenon and reactor reactivity values at zero power.
XMAX	The maximum xenon after shutdown.
TNEAR and TFAR	The times of zero net reactivity after shutdown.

Two alternative messages can be written in this section. One "Sample Shutdown is Best" shows that the reference shutdown method is better than any of the possibilities offered by the power-time grid. The other "No Shutdown Mode will Work" is possible only when NOPT = 2; that is, that a startup at exactly the time desired is demanded. In this case it is possible that no shutdown method - including the sample - will work.

The optimum power level variations are listed next. Following these are the corresponding reactor reactivity, xenon and iodine values at the end of each time interval. The last value "REJECTS" is the number of times selected shutdown modes have been rejected because of insufficient reactor reactivity.

If refined grid calculations are asked for, additional output appears. The first line reiterates the values designated in card 55. Then follows the output for each successive time split in the power-time grid. Every time an improvement in the shutdown function is found the new solution is printed out along with the corresponding values of SDNET and XMAX (the maximum xenon value after zero power is reached). The series of integers shown is the number of power options allowed in each subinterval of the power time grid. For example, the numbers 1 2 show that each time interval has been split once and that currently two power options are allowed in the right hand half of each of the original time intervals. After the calculations have been completed for each level of time split, then a print-out of the pertinent data for the current

solution is given.

Another feature of the code, and one that could be improved on, is related to the convergence limits in the subroutine TCALC. At present if 25 iterations or more are required to find zero net reactivity times after shutdown, then the corresponding path through the grid is rejected and a print-out is given of the level indices for each time interval (an index of 1 means the lowest power level is being examined, etc.). It would be an improvement to allow this limit of 25 iterations to be an input variable.

```
NRU AT 58MK
7  2 1 1 1 1 1.00 1.00 1  1    NRU AT 58MK
17.92000    0.50300 168.30000  -0.        -0.        -0.        -0.
-0.         2.00000  58.00000  -0.        -0.        0.01000
 2.00000   33.14529 336.60000  -0.        -0.        0.
 2.00000   33.14529 336.60000  -0.        -0.
  5    5    5    5    5    5    5   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0   -0
 1.70000    2.00000  -0.        -0.        -0.        -0.        -0.        -0.        -0.        -0.
-0.         -0.       -0.        -0.        -0.        -0.        -0.        -0.        -0.        -0.
 2.00000    2.00000   2.00000   2.00000    2.00000    2.00000    2.00000    -0.        -0.        -0.
-0.         -0.       -0.        -0.        -0.        -0.        -0.        -0.        -0.        -0.
-0.         -0.       -0.        -0.        -0.        -0.        -0.        -0.        -0.        -0.
-0.         -0.       -0.        -0.        -0.        -0.        -0.        -0.        -0.        -0.
 2.00000    2.00000   2.00000   2.00000    2.00000    2.00000    2.00000    0.         0.         0.
 0.         0.        0.        0.         0.         0.         0.         0.         0.         0.
```

THIS IS A MWD OPTIMIZATION

OUTAGE AT LEAST SDD PROBLEM

SAMPLE SHUTDOWN DATA

NCALCS = 78125. NTRANS = 2950. AVE. NNEAR = 1.0 AVE. NFAR = 1.0

INITIAL IODINE = 336.600 INITIAL XENON = 33.145 TIME LOSS = 0. XMAXI= 158.581

NEAR INTERCEPT = 0.832 FAR INTERCEPT = 34.995 NNEARI = 1 NFARI = 1

SDD	TSUI	SDLOSSI	SDNETI
1.700	34.995	33.295	33.295
2.000	34.995	32.995	32.995

OPTIMUM SHUTDOWN MODE RESULTS

SDD	TSU	WLOSS	SDLOSS	SDNET	YSD	ZSD	RSD	XMAX	TNEAR	TFAR
1.700	1.700	6.500	0.	6.500	226.531	25.727	58.000	108.303	1.777	28.088
2.000	25.497	8.000	23.497	31.497	179.369	57.919	58.000	104.496	0.007	25.497

OPTIMUM POWER LEVEL VARIATIONS

SDD	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
1.70	1.000	1.000	1.000	1.000	1.000	0.500	2.000	0.	0.	0.
2.00	1.000	1.000	1.000	1.000	1.000	0.500	0.500	0.	0.	0.

REACTIVITY MATRIX 1,10

1.70	58.000	58.000	58.000	58.000	58.000	58.000	58.000	0.	0.	0.
2.00	58.000	58.000	58.000	58.000	58.000	58.000	58.000	0.	0.	0.

XENON MATRIX 1,10

1.70	33.145	49.938	51.807	49.619	46.673	43.911	55.525	0.	0.	0.
2.00	33.145	49.938	51.807	49.619	46.673	43.911	55.525	0.	0.	0.

IODINE MATRIX 1,10

1.70	336.600	305.159	279.591	258.800	241.893	228.144	201.244	0.	0.	0.
2.00	336.600	305.159	279.591	258.800	241.893	228.144	201.244	0.	0.	0.

REJECTS= 2581.

```
        REFINED GRID CALCULATIONS

        NTSPL= 2  NPSPL= 4  NTIMES= 2  NREP= 1  DEM=.500  NSUT= 1

           2
  1.2500        1.2500       0.7500       1.2500       0.7500       0.7500       2.0000

        SDNET=   6.00000     XMAX= 111.33214

           2

           2

           2

           2

           3
  1.2500        1.2812       0.7812       1.2187       0.7187       0.7813       2.0000

        SDNET=   5.96875     XMAX= 111.49081

           3
TYMOUT CALLCLOCK 0404.8

        NT=  7

        SDD      TSU      WLOSS    SDLOSS     SDNET    YSD      ZSD      RSD      XMAX     TNEAR    TFAR

        1.700    1.700    5.969    0.         5.969    233.982  25.765   58.000   111.491  1.700    28.662

        POWER LEVELS
  1.2500        1.2812       0.7812       1.2187       0.7187       0.7813       2.0000

        REACTIVITIES
 58.0000       58.0000      58.0000      58.0000      58.0000      58.0000      58.0000

        XE135 LEVELS
 33.1453       44.4958      44.2974      55.0390      43.4807      51.5626      49.9745

         I135 LEVELS
336.6000      313.0189     294.8258     264.3107     253.2520     228.5386     210.4071

           1   2

           1   2
  1.2500        1.1250       1.2812       1.4062       0.7812       0.6562       1.2187       1.0937       0.7187       0.8437
  0.7813        0.9063       2.0000       2.0000

        SDNET=   5.96875     XMAX= 111.87310

           1   2

           1   2

           1   2
  1.2500        1.0937       1.2812       1.4375       0.7812       0.6562       1.2187       1.0625       0.7187       0.8750
  0.7813        0.9375       2.0000       2.0000

        SDNET=   5.95312     XMAX= 112.07866

           1   3

           2   1

           2   1

           2   1

           2   1

           3   1

           1   2

           1   2

           1   2

           1   2

           1   3

           2   1

           2   1

           2   1

           2   1

           3   1
TYMOUT CALLCLOCK 1120.2

        NT= 14

        SDD      TSU      WLOSS    SDLOSS     SDNET    YSD      ZSD      RSD      XMAX     TNEAR    TFAR

        1.700    1.700    5.953    0.         5.953    235.670  25.483   58.000   112.079  1.700    28.779

        POWER LEVELS
  1.2500        1.0937       1.2812       1.4375       0.7812       0.6562       1.2187       1.0625       0.7187       0.8750
  0.7813        0.9375       2.0000       2.0000

        REACTIVITIES
 58.0000       58.0000      58.0000      58.0000      58.0000      58.0000      58.0000      58.0000      58.0000      58.0000
 58.0000       58.0000      58.0000      58.0000

        XE135 LEVELS
 33.1453       41.3213      46.8572      45.7801      42.3263      50.4777      56.9049      48.4383      46.3000      50.5252
 49.2632       49.5556      46.1902      30.1859

         I135 LEVELS
336.6000      324.2004     310.4357     301.1230     295.3084     279.2153     262.6365     256.9860     249.3074     236.6999
```

```
227.9141     218.4414     212.4825     224.6751

      1     1     1     2
 1.2500      1.2500      1.0937      0.8437      1.2812      1.2812      1.4375      1.6875      0.7812      0.7812
 0.6562      0.9062      1.2187      1.2187      1.0625      0.8125      0.7187      0.7187      0.8750      0.6250
 0.7813      0.7813      0.9375      1.1875      2.0000      2.0000      2.0000      2.0000

    SDNET=    5.95312     XMAX= 112.11704

      1     1     1     2

      1     1     1     2

      1     1     1     2
 1.2500      1.2500      1.0937      0.9062      1.2812      1.2812      1.4375      1.6250      0.7812      0.7812
 0.6562      0.9687      1.2187      1.2187      1.0625      0.7500      0.7187      0.7187      0.8750      0.6875
 0.7813      0.7813      0.9375      1.2500      2.0000      2.0000      2.0000      2.0000

    SDNET=    5.92187     XMAX= 112.40268

      1     1     1     2

      1     1     1     2

      1     1     1     3
 1.2500      1.2500      1.0937      0.9375      1.2812      1.2812      1.4375      1.6250      0.7812      0.7812
 0.6562      1.0000      1.2187      1.2187      1.0625      0.7187      0.7187      0.7187      0.8750      0.6562
 0.7813      0.7813      0.9375      1.2813      2.0000      2.0000      2.0000      2.0000

    SDNET=    5.91406     XMAX= 112.43671

      1     1     1     3
 1.2500      1.2500      1.0937      0.9687      1.2812      1.2812      1.4375      1.6562      0.7812      0.7812
 0.6562      1.0000      1.2187      1.2187      1.0625      0.6875      0.7187      0.7187      0.8750      0.6250
 0.7813      0.7813      0.9375      1.3125      2.0000      2.0000      2.0000      2.0000

    SDNET=    5.90625     XMAX= 112.46100

      1     1     1     3

      1     1     2     1

      1     1     2     1

      1     1     2     1

      1     1     2     1

      1     1     3     1

      1     2     1     1

      1     2     1     1

      1     2     1     1

      1     2     1     1

          1     3     1     1

          2     1     1     1

          2     1     1     1

          2     1     1     1

          2     1     1     1

          3     1     1     1

          1     1     1     2

          1     1     1     2

          1     1     1     2

          1     1     1     2

          1     1     1     3

          1     1     2     1

          1     1     2     1

          1     1     2     1

          1     1     2     1

          1     1     3     1

          1     2     1     1

          1     2     1     1

          1     2     1     1

          1     2     1     1

          1     3     1     1

          2     1     1     1

          2     1     1     1

          2     1     1     1

          2     1     1     1

          3     1     1     1
 TYPOUT CALLCLOCK 3195.8

       NT= 28

       SDD       TSU       WLOSS     SDLOSS     SDNET     YSD       ZSD       RSD       XMAX      TNEAR     TFAR

       1.700     1.700     5.906     0.         5.906     236.772   25.296    58.000    112.461   1.700     28.855
```

POWER LEVELS

1.2500	1.2500	1.0937	0.9687	1.2812	1.2812	1.4375	1.6562	0.7812	0.7812
0.6562	1.0000	1.2187	1.2187	1.0625	0.6875	0.7187	0.7187	0.8750	0.6250
0.7813	0.7813	0.9375	1.3125	2.0000	2.0000	2.0000	2.0000		

REACTIVITIES

58.0000	58.0000	58.0000	58.0000	58.0000	58.0000	58.0000	58.0000	58.0000	58.0000
58.0000	58.0000	58.0000	58.0000	58.0000	58.0000	58.0000	58.0000	58.0000	58.0000
58.0000	58.0000	58.0000	58.0000	58.0000	58.0000	58.0000	58.0000		

XE135 LEVELS

33.1453	38.1038	41.3213	44.6948	48.0619	47.1375	46.2929	44.0914	40.6704	45.8181
49.5185	53.4868	52.3499	48.9523	46.4126	45.9580	49.1660	51.1012	52.3647	51.3416
53.1444	52.5185	51.8102	49.3468	43.6898	34.5191	29.4185	26.6762		

I135 LEVELS

336.6000	330.2400	324.2004	317.1402	309.3757	304.6524	300.1671	297.2328	296.3014	287.9969
280.1108	271.5620	266.3591	263.2732	260.3429	256.2352	249.1544	242.6955	236.5620	232.0625
225.6697	220.9241	216.4175	213.4631	213.8375	220.0230	225.8969	231.4748		

APPENDIX 4.

SHUTDOWN CODE LISTING IN FORTRAN IV

```
$IBFTC E06SHD
       COMMON MANYNE,MANYFA,TSUBN(40),TSUBF(40),TLIMIT,NTOPT,NOPT
      0DIMENSION T(100),W(20,100),NP(100),Y(101),Z(101),R(101),M(20),
      1YE(20,100),ZE(20,100),DE(20,100),P(101),NPSOL(100,20),SDLOSS(20),
      2WLOSS(20),SDNET(20),YSD(20),ZSD(20),SDD(20),TSU(20),TNEAR(20),
      3TFAR(20),WHI(100),WLO(100),TITLE( 9),WSOL(100,20),XMAX(20),
      4N(100),TSUI(20),SDLOSI(20),SDNETI(20),RSD(20),R1(101),ZEM(100,20),
      5REM(100,20),YEM(100,20),R2(101),NOM(100),NSUT(20),SOL(20),WR(100),
      6TI(20),NOMT(20),WRT(20),WHIT(20),WLOT(20),WOLD(100),ROLD(100),
      7ZOLD(100),YOLD(100)
 1000 FORMAT(2I2,4I1,2F4.2,I1,I2,8A6,A5)
 1001 FORMAT(7F10.5)
 1002 FORMAT(20I3)
 1003 FORMAT(14F5.2)
 2000 FORMAT(1H0,11X,2(1I2,1X),4(1I1,1X),2(1F4.2,1X),I1,1X,I2,1X,8A6,
      1A5)
 2001 FORMAT(1H0,10X,7F10.5)
 2002 FORMAT(1H0,10X,20I5)
 2003 FORMAT(1H0,10X,10F10.5/11X,10F10.5)
 2004 FORMAT(1H0,10X,10HTHIS IS A ,2A6,14HOPTIMIZATION, ,4A6,
      19HD PROBLEM)
 2005 FORMAT(1H0/10X,20HSAMPLE SHUTDOWN DATA)
 2006 FORMAT(1H0,10X,17HINITIAL IODINE = ,F8.3,4X,16HINITIAL XENON = ,
      1F8.3,4X,12HTIME LOSS = ,F8.3,4X,6HXMAXI=,F8.3)
 2007 FORMAT(1H0,10X,17HNEAR INTERCEPT = ,F8.3,4X,16HFAR INTERCEPT = ,
      1F8.3,4X,9HNNEARI = ,I5,4X,8HNFARI = ,I5)
 2008 FORMAT(1H0,10X,29HOPTIMUM SHUTDOWN MODE RESULTS)
 2009 FORMAT(1H0,10X,102HSDD        TSU       WLOSS     SDLOSS     SDNET
      1  YSD        ZSD        RSD        XMAX       TNEAR      TFAR)
 2010 FORMAT(1H0,6X,11(1X,F8.3,1X))
 2011 FORMAT(1H0,8X,F8.3,26H   SAMPLE SHUTDOWN IS BEST)
 2012 FORMAT(1H0,8X,F8.3,29H   NO SHUTDOWN MODE WILL WORK)
 2013 FORMAT(1H0,10X,30HOPTIMUM POWER LEVEL VARIATIONS)
 2014 FORMAT(1H0,4X,110HSDD        W1         W2         W3         W4
      1   W5         W6         W7         W8         W9         W10        )
 2015 FORMAT(1H0,3X,F5.2,2X,10(1X,F8.3,1X))
 2016 FORMAT(1H0,4X,110HSDD        W11        W12        W13        W14
      1  W15        W16        W17        W18        W19        W20        )
 2017 FORMAT(1H0,10X,9HNCALCS = ,F10.0,2X,9HNTRANS = ,F10.0,2X,13HAVE. N
      1NEAR = ,F4.1,2X,12HAVE. NFAR = ,F4.1)
 2018 FORMAT(1H0,10X,39H    SDD        TSUI       SDLOSSI    SDNETI)
 2019 FORMAT(1H0,11X,F8.3,3X,F8.3,3X,F8.3,3X,F8.3)
 2025 FORMAT(1H0,10X,22HREACTIVITY MATRIX 1,10)
 2026 FORMAT(1H0,10X,23HREACTIVITY MATRIX 10,20)
 2027 FORMAT(1H0,10X,17HXENON MATRIX 1,10)
 2028 FORMAT(1H0,10X,18HXENON MATRIX 10,20)
 2029 FORMAT(1H0,10X,18HIODINE MATRIX 1,10)
 2030 FORMAT(1H0,10X,19HIODINE MATRIX 10,20)
 2031 FORMAT(1H0,10X,40HNON CONVERGENCE NEAR SIDE NP GIVEN BELOW)
 2032 FORMAT(1H0,10X,39HNON CONVERGENCE FAR SIDE NP GIVEN BELOW)
 2033 FORMAT(1H0,10X,20I3)
 2034 FORMAT(2F10.5)
 2035 FORMAT(1H0,10X,8HREJECTS=,F10.0)
 2045 FORMAT(1H1,10X,8A6,A5)
 2046 FORMAT (3F10.5)
C DEFINITION OF FUNCTIONS
      0RXENF(YE,ZE,Y,Z,D,T,CY) = ZE +(Z-ZE)*EXP (-D*T)+
      1CY*(Y-YE)*(EXP (-CY*T)-EXP (-D*T))/(D-CY)
       REACF(YE,Y,CY,T)= YE+(Y-YE)*EXP (-CY*T)
       CALL TYMIN(5HCLOCK)
```

```
      READ(5,2046) CY,CZ ,ARF
      IF(ARF)9001,9001,3000
 9001 DO 7002 I=2,40
 7002 READ(5,2034)TSUBN(I),TSUBF(I)
      TSUBN(1)=0.0
      TSUBF(1)=0.0
 3000 DO 3575 I=1,20
      XMAX(I)=0.
      M(I)=0
      SDLOSS(I)=0.
      WLOSS(I)=0.
      SDNET(I)=0.
      YSD(I)=0.
      ZSD(I)=0.
      TSU(I)=0.
      TNEAR(I)=0.
      TFAR(I)=0.
      N(I)=0
      TSUI(I)=0.
      SDLOSI(I)=0.
      SDNETI(I)=0.
      RSD(I)=0.
      NSUT(I)=0
      SOL(I)=0.
      DO 3576 J=1,100
      T(J)=0.
      W(I,J)=0.
      NP(J)=0
      Y(J)=0.
      Z(J)=0.
      R(J)=0.
      YE(I,J)=0
      ZE(I,J)=0.
      DE(I,J)=0.
      P(J)=0.
      NPSOL(J,I)=0
      WHI(J)=0.
      WLO(J)=0.
      WSOL(J,I)=0.
      R1(J)=0.
      R2(J)=0.
      ZEM(J,I)=0.
      REM(J,I)=0.
      YEM(J,I)=0.
      NOM(J)=0
      WR(J)=0.
 3576 CONTINUE
 3575 CONTINUE
      KT=0
      DEM=0.
      CALL TYMOUT(5HCLOCK)
     0READ (5,1000)          NT,NSDD,NOPT,MOPT,NHIOPT,NRITE,FRACT,
     1WEIGHT,NTOPT,KOPT,TITLE
      READ (5,1001)          A,B,C,D1,CR1,D2,CR2
      READ (5,1001)          PRC,WCALC,RB,ZF1,DELTAR,TLIMIT
      READ (5,1001)          WSD,ZSDI,YSDI,R1I,R2I,WLOSSI
      READ (5,1001)          WSTART,Z(1),Y(1),R1(1),R2(1)
      READ(5,1002)(N(I),I=1,20)
      READ(5,1003) (SDD(I),I=1,20)
      READ(5,1003) (T(I),I=1,20)
```

```
      READ(5,1003) (WLO(I),I=1,20)
      IF(NHIOPT)571,571,572
  571 READ(5,1003) (WHI(I),I=1,20)
C CALCULATION OF W(I,J)                                                 A
  572 CALCS=1.0
      WRITE(6,2045)TITLE
      REJECT=0.
      TRANS = 0.0
      IF(NOPT-2)3660,3660,3661
 3661 NSDD=1
 3660 DO 100 J2 = 1,NT                                                   B
      NP(J2) = 0
      IF(N(J2) - 1) 101,101,102                                          C
  101 W(1,J2) = WLO(J2)                                                  D
      GO TO 104
  102 IF(NHIOPT)501,501,500
  500 WHI(J2) = WCALC
  501 ARG1=N(J2) - 1
      WR(J2)=(WHI(J2)-WLO(J2))/ARG1
      NJ = N(J2)                                                         F
      DO 103 J3 = 1,NJ                                                   G
      ARG2=J3 -1
  103 W(J3,J2) = WLO(J2) + WR(J2)*ARG2
  104 DC=N(J2)
      CALCS = CALCS*DC
  100 CONTINUE
C SECONDARY PARAMETERS                                                 010
      ZF=1.0-ZF1
      IF (WSD) 2,2,1                                                   011
    1 YSDI=C*WSD                                                       012
      ZSDI= A*WSD/(CZ+ B * WSD)                                        013
      R1I = D1*WSD
      R2I = D2*WSD
      WLOSSI = 0.0                                                     014
    2 TMAXI =ALOG ( CY/CZ) / (CY-CZ)
      RSDI = RB + R1I+R2I
      AAA = CZ * EXP  (CY*TMAXI) / (CY-CZ)
     0CALL TCALC(YSDI,ZSDI,CY,CZ,CR1,CR2,TMAXI,AAA,RB,R1I,R2I,DELTAR,ZF,
     1TNEARI,TFARI,NNEARI,NFARI,XMAXI)
      IF(MANYNE-25)194,194,190
  194 IF(MANYFA-25)195,195,191
  195 IF(WSTART)18,18,17
   17 Y(1) = C*WSTART                                                  019
      Z(1) = A*WSTART / (CZ + B*WSTART)                                020
      R1(1) = D1 * WSTART
      R2(1) = D2 * WSTART
   18 DO 23 I = 1, NT                                                  022
      NP(I) = 1
      II = N(I)                                                        023
      DO 24 J = 1 , II                                                 024
      YE(J,I) = C* W(J,I)                                              025
      DE(J,I) = CZ + B * W(J,I)                                        026
      ZE(J,I) = A * W(J,I) / DE(J,I)                                   028
   24 CONTINUE                                                         029
      DO 70 I1 = 1,NSDD                                                030
   70 NPSOL(I,I1) = 0                                                  031
   23 CONTINUE                                                         032
      R(1) = RB + R1(1)+R2(1)+PRC*WSTART
C INITIAL VALUES
      ANEAR = 0.0
```

```
      AFAR = 0.0
      ANNEAR=0.0
      ANFAR=0.0
      IF(KT)7510,7510,7511
 7510 DO 19 IN =1,20
      SDLOSS(IN )=0.0
      WLOSS(IN )=0.0
      SDNET(IN )=WLOSSI
      YSD(IN )=YSDI
      ZSD(IN )=ZSDI
      RSD(IN )=RSDI
      XMAX(IN )=XMAXI
      TNEAR(IN )=TNEARI
      TFAR(IN )=TFARI
      M(IN )=1
      SDLOSI(IN )=0.0
      SDNETI(IN )=WLOSSI
      TSUI(IN )=SDD(IN )
      TSU(IN )=SDD(IN )
   19 CONTINUE
 7511 DO 50 ND=1,NSDD
      GO TO (90,91,50),NOPT
   90 IF(TFARI-SDD(ND))50,50,54
   54 IF(TNEARI-SDD(ND))55,50,50
   55 SDLOSI(ND)=TFARI-SDD(ND)
      TSUI(ND)=TFARI
      TSU(ND)=TFARI
      SDNET(ND)=WLOSSI+TFARI-SDD(ND)
      SDNETI(ND)=SDNET(ND)
      GO TO 50
   91 IF(TFARI-SDD(ND))50,50,97
   97 IF(TNEARI-SDD(ND))93,50,50
   93 SDNETI(ND)=0.0
      TSUI(ND)=0.0
      M(ND)=2
   50 CONTINUE
C CALCULATION OF ZERO POWER VALUES                                    117
      W(1,NT+1) = 1.0
      NP(NT+1) = 1
   92 JJ = 1                                                          118
   41 DO 26 K = JJ,NT                                                 119
      NPK = NP(K)                                                     120
      P(K) = W(NPK,K)                                                 121
      NPD = NP(K+1)
      P(K+1) = W(NPD,K+1)
      R1(K+1) = (D1*P(K)-R1(K))*(1.0-EXP (-CR1*T(K)))+R1(K)
      R2(K+1) = (D2*P(K)-R2(K))*(1.0-EXP (-CR2*T(K)))+R2(K)
      Y(K+1) = REACF(YE(NPK,K), Y(K), CY, T(K))                       122
      R(K+1) = RB + PRC*P(K) + R1(K+1) + R2(K+1)
      Z(K+1) = RXENF(YE(NPK,K),ZE(NPK,K),Y(K),Z(K),DE(NPK,K),T(K),CY)
      IF(R(K+1) - Z(K+1))581,26,26                                    125
  581 NERROR = K
      IF(P(K))590,590,8099
  590 IF(P(K+1))26,26,8099
 8099 REJECT=REJECT+1.0
      GO TO 27
   26 CONTINUE
      CALL TCALC(Y(NT+1),Z(NT+1),CY,CZ,CR1,CR2,TMAXI,AAA,RB,R1(NT+1),
     1R2(NT+1),DELTAR,ZF,TNEA,TFA,NNEAR,NFAR,XMAXA)
      IF(MANYNE - 25) 180,180,190
```

```
  180 IF(MANYFA - 25)181,181,191
  181 TRANS = TRANS + 1.0
      EAR=NNEAR
      FAR=NFAR
      ANEAR = ANEAR + EAR/CALCS
      AFAR = AFAR + FAR/CALCS
C CALCULATION OF WLOS, SDLOS, SDNE                                    128
      WLOS = 0.0                                                      129
      DO 153 K1 = 1,NT
      GO TO (29,150),MOPT
  150 A1= FRACT*WCALC
      IF (P(K1) -A1) 151,153,153
  151 WLOS = WLOS + T(K1)*WEIGHT
      GO TO 153
   29 WLOS = WLOS + ((WCALC - P(K1))*T(K1)*WEIGHT)/WCALC              131
  153 CONTINUE
      GO TO(60,61,3501),NOPT
C CALCULATION OF WLOS, SDLOS, SDNE  FOR NOPT = 1                      133
   60 DO 28 KK = 1,NSDD                                               134
   31 IF (TFA - SDD(KK)) 33,33,34                                     139
   33 SDLOS = 0.0                                                     140
      TS = SDD(KK)                                                    141
      GO TO 32                                                        142
   34 IF (TNEA - SDD(KK)) 35,36,36                                    143
   36 SDLOS = 0.0                                                     144
      TS = SDD(KK)                                                    145
      GO TO 32                                                        146
   35 SDLOS = TFA - SDD(KK)                                           147
      TS = TFA                                                        148
   32 SDNE = WLOS + SDLOS                                             149
      IF(SDNET(KK) - SDNE) 28,28,38                                   150
   38 SDNET(KK) = SDNE                                                151
      WLOSS(KK) = WLOS                                                152
      SDLOSS(KK) = SDLOS                                              153
      TNEAR(KK) = TNEA                                                154
      TFAR(KK) = TFA                                                  155
      YSD(KK) = Y(NT + 1)                                             156
      ZSD(KK) = Z(NT +1)                                              157
      XMAX(KK)=XMAXA
      RSD(KK) = RB + R1(NT+1) + R2(NT+1)
      TSU(KK) = TS                                                    158
      M(KK) = 0
      DO 99 M9= 1,NT                                                  159
      NPSOL(M9,KK) = NP(M9)                                           160
      REM(M9,KK) = R(M9)
      ZEM(M9,KK) = Z(M9)
      YEM(M9,KK) = Y(M9)
   99 CONTINUE                                                        161
   28 CONTINUE                                                        162
C CHOOSE NEW NP                                                       163
 9000 NERROR = NT
   27 DO 39 KQ = 1, NERROR                                            164
      JQ = NERROR - KQ + 1                                            165
      NP(JQ) = NP(JQ) + 1                                             166
      IF(NP(JQ) - N(JQ)) 40,40,42                                     167
   40 IF(JQ-1)600,600,601
  600 JJ = 1
      GO TO 602
  601 JJ=JQ-1
  602 NER = JQ+1
```

```
      DO 580 M5 = NER,NT
      NP(M5) = 1
  580 CONTINUE
      GO TO 41
   42 IF(JQ - 1) 43,43,44
   44 NP(JQ) = 1
   39 CONTINUE
C CALCULATION OF WLOS, SDLOS, SDNE FOR NOPT = 2
   61 DO 62 JI = 1, NSDD
   67 IF (TFA - SDD(JI)) 66,66,64
   64 IF (TNEA - SDD(JI)) 62,66,66
   66 TS = SDD(JI)
      SDNE = WLOS
      IF(M(JI)-1)165,165,68
  165 IF(SDNET(JI)-SDNE)62,62,68
   68 SDNET(JI) = SDNE
      M(JI) = 0
      WLOSS(JI) = WLOS
      TNEAR(JI) =TNEA
      TFAR(JI) = TFA
      XMAX(JI)=XMAXA
      YSD(JI) = Y(NT + 1)
      ZSD(JI) = Z(NT + 1)
      RSD(JI) = RB + R1(NT+1)+R2(NT+1)
      TSU(JI) = TS
      DO 69 K3 = 1,NT
      NPSOL(K3,JI) = NP(K3)
      REM(K3,JI) = R(K3)
      ZEM(K3,JI) = Z(K3)
      YEM(K3,JI) = Y(K3)
   69 CONTINUE
   62 CONTINUE
      NERROR = NT
      GO TO 27
  190 WRITE (6,2031)
      GO TO 192
  191 WRITE (6,2032)
  192 WRITE (6,2033)          (NP(L50),L50=1,20)
      GO TO 9000
C CALCULATION FOR NOPT=3
 3501 IF(XMAX(1)-XMAXA)9000,9000,3504
 3504 XMAX(1)=XMAXA
      M(1)=0
      WLOSS(1)=WLOS
      TNEAR(1)=TNEA
      TFAR(1)=TFA
      YSD(1)=Y(NT+1)
      ZSD(1)=Z(NT+1)
      RSD(1)=RB+R1(NT+1)+R2(NT+1)
      DO 3505 I=1,NT
      NPSOL(I,1)=NP(I)
      REM(I,1)=R(I)
      ZEM(I,1)=Z(I)
      YEM(I,1)=Y(I)
 3505 CONTINUE
      GO TO 9000
C SOLUTION MATRIX
   43 IF(KT)210,210,211
  210 DO 900 J6 =1,NSDD
      DO 901 J7 = 1,NT
```

```
      M19=NPSOL(J7,J6)
      WSOL(J7,J6)=W(M19,J7)
  901 CONTINUE
  900 CONTINUE
      ANNEAR = ANEAR*CALCS/TRANS
      ANFAR = AFAR*CALCS/TRANS
     0WRITE (6,2000)          NT,NSDD,NOPT,MOPT,NHIOPT,NRITE,FRACT,
     1WEIGHT,NTOPT,KOPT,TITLE
      WRITE (6,2001)          A,B,C,D1,CR1,D2,CR2
      WRITE (6,2001)          PRC,WCALC,RB,ZF1,DELTAR,TLIMIT
      WRITE (6,2001)          WSD,ZSDI,YSDI,R1I,R2I,WLOSSI
      WRITE (6,2001)          WSTART,Z(1),Y(1),R1(1),R2(1)
      WRITE(6,2002) (N(I),I=1,20)
      WRITE(6,2003) (SDD(I),I=1,20)
      WRITE(6,2003) (T(I),I=1,20)
      WRITE(6,2003) (WLO(I),I=1,20)
      WRITE(6,2003) (WHI(I),I=1,20)
      GO TO(3650,3651),MOPT
 3650 WRITE(6,2049)
 2049 FORMAT(1H1,10X,26HTHIS IS A MAD OPTIMIZATION)
      GO TO 3652
 3651 WRITE(6,2050)
 20500FORMAT(1H1,10X,49HTHIS IS A TIME ABOVE (FRACT)X(WCALC) OPTIMIZATIO
     1N)
 3652 GO TO (3653,3654,3655),NOPT
 3653 WRITE(6,2051)
 2051 FORMAT(1H0,10X,27HOUTAGE AT LEAST SDD PROBLEM)
      GO TO 3656
 3654 WRITE(6,2052)
 2052 FORMAT(1H0,10X,30HSTARTUP AT EXACTLY SDD PROBLEM)
      GO TO 3656
 3655 WRITE(6,2053)
 2053 FORMAT(1H0,10X,28HMINIMIZATION OF XMAX PROBLEM)
 3656 WRITE (6,2005)
      WRITE (6,2017)           CALCS,TRANS,ANNEAR,ANFAR
      WRITE (6,2006)          YSDI,ZSDI,WLOSSI,XMAXI
      WRITE (6,2007)             TNEARI, TFARI, NNEARI, NFARI
      WRITE (6,2018)
      DO 555 IR = 1,NSDD
      WRITE (6,2019)          SDD(IR),TSUI(IR),SDLOSI(IR),SDNETI(IR)
  555 CONTINUE
      WRITE (6,2008)
      WRITE (6,2009)
      DO 5000 N16=1,NSDD
      IF(M(N16)-1) 5001,5002,5003
 50010WRITE (6,2010)          SDD(N16),TSU(N16),WLOSS(N16),SDLOSS(N16),
     1SDNET(N16),YSD(N16),ZSD(N16),RSD(N16),XMAX(N16),TNEAR(N16),TFAR(N1
     26)
      GO TO 5000
 5002 WRITE (6,2011)          SDD(N16)
      GO TO 5000
 5003 WRITE (6,2012)          SDD(N16)
 5000 CONTINUE
      WRITE (6,2013)
      WRITE (6,2014)
      DO 5005 J8=1,NSDD
      WRITE (6,2015)          SDD(J8),(WSOL(J9,J8),J9=1,10)
 5005 CONTINUE
      IF(NT - 10)5050,5050,5051
 5051 WRITE (6,2016)
```

```
      DO 5010 K8=1,NSDD
      WRITE (6,2015)                      SDD(K8),(WSOL(K9,K8),K9=11,20)
 5010 CONTINUE
 5050 IF(NRITE)5016,5016,5017
 5017 WRITE (6,2025)
      DO 6000 L8 = 1,NSDD
      WRITE (6,2015)                      SDD(L8),(REM(L9,L8),L9=1,10)
 6000 CONTINUE
      IF(NT-10)5018,5018,5019
 5019 WRITE (6,2026)
      DO 6001 L10= 1,NSDD
      WRITE (6,2015)                      SDD(L10),(REM(L11,L10),L11= 10,20)
 6001 CONTINUE
 5018 WRITE (6,2027)
      DO 6002 L12 = 1,NSDD
      WRITE (6,2015)                      SDD(L12),(ZEM(L13,L12),L13 = 1,10)
 6002 CONTINUE
      IF(NT-10)5052,5052,5053
 5053 WRITE (6,2028)
      DO 6003 L14=1,NSDD
      WRITE (6,2015)                      SDD(L14),(ZEM(L15,L14),L15 = 10,20)
 6003 CONTINUE
 5052 WRITE (6,2029)
      DO 6004 L16 = 1,NSDD
      WRITE (6,2015)                      SDD(L16),(YEM(L17,L16),L17=1,10)
 6004 CONTINUE
      IF(NT-10)5016,5016,5055
 5055 WRITE (6,2030)
      DO 6005 L18 = 1,NSDD
      WRITE (6,2015)                      SDD(L18),(YEM(L19,L18),L19 = 10,20)
 6005 CONTINUE
 5016 WRITE(6,2035) REJECT
      IF(KOPT)3000,3000,200
  200 READ(5,2036)NTSPL,NPSPL,NTIMES,NREP,DEM,(NSUT(I),I=1,KOPT)
 2036 FORMAT(4I2,F4.3,20(I2,1X))
      DO 201 J=1,KOPT
      IF(NSUT(J)-NSDD)201,201,202
  202 WRITE(6,2037)
 2037 FORMAT(1H0,10X,47HASKED FOR REFINED CALC OF FICTITIOUS SDD..IDIOT)
      GO TO 3000
  201 CONTINUE
      WRITE(6,2048)
 2048 FORMAT(1H1,10X,25HREFINED GRID CALCULATIONS)
      WRITE(6,2077)NTSPL,NPSPL,NTIMES,NREP,DEM,(NSUT(I),I=1,KOPT)
 2077 FORMAT(1H0,10X,6HNTSPL=,I2,2X,6HNPSPL=,I2,2X,7HNTIMES=,
     1I2,2X,5HNREP=,I2,2X,4HDEM=,F4.3,2X,5HNSUT=,20(I2,1X))
      DO 212 I=1,20
      NOMT(I)=N(I)
      TI(I)=T(I)
      WRT(I)=WR(I)
      WHIT(I)=WHI(I)
      WLOT(I)=WLO(I)
  212 SOL(I)=SDNET(I)
      DAMNT=NTSPL
      DAMNP=NPSPL
      XMAZ=XMAX(1)
      NIT=NT
      KR=0
C CHOOSE SDD
  234 KR=KR+1
      IF(KR-KOPT)230,230,3000
  230 KT=NSUT(KR)
      DO 3500 I=1,20
      NOM(I)=NOMT(I)
      T(I)=TI(I)
      WR(I)=WRT(I)
      WHI(I)=WHIT(I)
      WLO(I)=WLOT(I)
      WOLD(I)=WSOL(I,KT)
      ROLD(I)=REM(I,KT)
      ZOLD(I)=ZEM(I,KT)
      YOLD(I)=YEM(I,KT)
 3500 CONTINUE
      AB1=TSU(KT)
      AB2=WLOSS(KT)
      AB3=SDLOSS(KT)
      AB4=YSD(KT)
      AB5=ZSD(KT)
      AB6=RSD(KT)
      AB7=XMAX(KT)
      AB8=TNEAR(KT)
      AB9=TFAR(KT)
      XMAZ=XMAX(KT)
      SOL(KT)=SDNET(KT)
      NT=NIT
C CHOOSE TIME SPLIT
      MRS=1
      CTLS=-1.0
  227 CTLS=CTLS+1.0
      NTI=0
      GO TO (237,380),MRS
  380 CALL TYMOUT(5HCLOCK)
      WRITE(6,2038)NT
 2038 FORMAT(1H0,10X,3HNT=,I3)
      WRITE(6,2009)
      WRITE(6,2010)SDD(KT),AB1,AB2,AB3,SDNET(KT),AB4,AB5,AB6,AB7,AB8,AB9
      WRITE(6,2039)
      WRITE(6,2055)(WOLD(I),I=1,NT)
      IF(NRITE)237,260,260
 2039 FORMAT(1H0,10X,12HPOWER LEVELS)
  260 WRITE(6,2040)
      WRITE(6,2055)(ROLD(I),I=1,NT)
 2040 FORMAT(1H0,10X,12HREACTIVITIES)
      WRITE(6,2041)
      WRITE(6,2055)(ZOLD(I),I=1,NT)
 2041 FORMAT(1H0,10X,12HXE135 LEVELS)
      WRITE(6,2042)
      WRITE(6,2055)(YOLD(I),I=1,NT)
 2042 FORMAT(1H0,10X,12H I135 LEVELS)
 2055 FORMAT(10F13.4)
  237 IF(CTLS-DAMNT)235,235,234
  235 NDU = CTLS
      MRS=2
      NODO=2**NDU
      IF(NDU)238,238,239
  239 DO 216 I=1,NT
      J=2*(NT-I)+1
      I2=NT-I+1
      WOLD(J)=WOLD(I2)
      ROLD(J)=ROLD(I2)
```

```
      ZOLD(J)=ZOLD(I2)
      YOLD(J)=YOLD(I2)
      WR(J)=WR(I2)
      T(J)=T(I2)*0.5
      WHI(J)=WHI(I2)
      WLO(J)=WLO(I2)
      NOM(J)=NOM(I2)
      WR(J+1)=WR(J)
      T(J+1)=T(J)
      WOLD(J+1)=WOLD(J)
      ROLD(J+1)=ROLD(J)
      ZOLD(J+1)=ZOLD(J)
      YOLD(J+1)=YOLD(J)
      WHI(J+1)=WHI(J)
      WLO(J+1)=WLO(J)
      NOM(J+1)=NOM(J)
  216 CONTINUE
  238 NT=(NIT)*(NODO)
      MAN=1
C CHOOSE TIME INTERVALS TO BE VARIED
      NDO=NODO+1
  233 NDO =NDO-1
      NO=1
      IF(NDO)281,281,245
  281 NTI=NTI+1
      IF(CTLS)227,227,284
  284 IF(NTI-NTIMES)290,227,227
  290 GO TO(227,7506),MAN
 7506 NDO=NODO
  245 DO 240 I = 1,NT
      N(I)=1
      W(1,I)=WOLD(I)
  240 CONTINUE
C CHOOSE POWER LEVEL SPLIT
      CPLS=0.0
  250 CPLS=CPLS+1.0
 2398 IF(CPLS-DAMNP)217,217,233
C CHOOSE POWER LEVELS
  217 NTOT=0
      NTO=0
      GO TO (362,371),NO
  362 DO215 I=NDO,NT,NODO
      IF(NOM(I)-1)215,215,241
  241 W(2,I)=WOLD(I)+WR(I)*DEM**CPLS
      W(1,I)=WOLD(I)-WR(I)*DEM**CPLS
      N(I)=2
      N(I+1)=1
      IF(W(2,I)-WHI(I))218,218,219
  219 W(2,I)=WHI(I)
      NTO=NTO+1
      GO TO 215
  218 IF(W(1,I)-WLO(I))222,215,215
  222 W(1,I)=WLO(I)
      NTOT=NTOT+1
  215 CONTINUE
      WRITE(6,2002)(N(I),I=1,NODO)
      IF(NTOT-NT)226,224,224
  226 IF(NTO-NT)18,225,225
C SAVINGS TEST
  211 GO TO(3550,3550,3551),NOPT
```

```
 3551 IF(XMAX(1)-XMAZ)3552,359,359
 3552 XMAZ=XMAX(1)
      GO TO 214
 3550 IF(SOL(KT)-SDNET(KT))359,359,214
  214 SOL(KT)=SDNET(KT)
      DO 251 I=1,NT
      NPG=NPSOL(I,KT)
      WOLD(I)=W(NPG,I)
      AB1=TSU(KT)
      AB2=WLOSS(KT)
      AB3=SDLOSS(KT)
      AB4=YSD(KT)
      AB5=ZSD(KT)
      AB6=RSD(KT)
      AB7=XMAX(KT)
      AB8=TNEAR(KT)
      AB9=TFAR(KT)
      XMAZ=XMAX(KT)
      ROLD(I)=REM(I,KT)
      ZOLD(I)=ZEM(I,KT)
      YOLD(I)=YEM(I,KT)
  251 CONTINUE
      MAN=2
      WRITE(6,2055)(WOLD(I),I=1,NT)
      WRITE(6,2080)SOL(KT),XMAZ
 2080 FORMAT(1H0,10X,6HSDNET=,F10.5,5X,5HXMAX=,F10.5)
      GO TO 217
  224 WRITE(6,2043)
 2043 FORMAT(1H0,10X,21HCALC HAS BOTTOMED OUT)
      GO TO 234
  225 WRITE(6,2044)
 2044 FORMAT(1H0,10X,19HCALC HAS TOPPED OUT)
      GO TO 234
  359 IF(CPLS-DAMNP)250,365,365
  365 GO TO (352,233),NO
  352 NO=2
      CPLS=NPSPL-NREP+1
      IF(NREP)233,233,371
  371 DO 360 I=NDO,NT,NODO
      IF(NOM(I)-1)360,360,361
  361 W(3,I)=WOLD(I)+WR(I)*DEM**CPLS
      W(2,I)=WOLD(I)
      W(1,I)=WOLD(I)-WR(I)*DEM**CPLS
      N(I)=3
      N(I+1)=1
      IF(W(3,I)-WHI(I))353,353,354
  354 W(3,I)=WHI(I)
      GO TO 360
  353 IF(W(1,I)-WLO(I))355,360,360
  355 W(1,I)=WLO(I)
  360 CONTINUE
      WRITE(6,2002)(N(I),I=1,NODO)
      GO TO 18
      END
```

```
$IBFTC TCALC
C SUBROUTINE TCALC
      0SUBROUTINE TCALC(YI,ZI,CY,CZ,CR1,CR2,TMAXI,AAA,RB,R1,R2,DELTAR,ZF,
      1TNEAR,TFAR,NNEAR,NFAR,XMAX1)
       COMMON MANYNE,MANYFA,TSUBN(40),TSUBF(40),TLIMIT,NTOPT,NOPT
       MANYNE = 0
       MANYFA = 0
       NNEAR=0
       NFAR=0
       TMAX =ALOG ((CZ/CY)* (1.0+(1.0-(CZ/CY)) * (ZI/YI)))/ (CZ-CY)
       DELTAT = TMAXI - TMAX
       XMAX =(EXP (-CY*TMAX))* (CY*YI)/ CZ
       IF(TMAX)8026,8026,8027
 8026  XMAX1=ZI
       GO TO 8025
 8027  XMAX1=XMAX
 8025  RMAX = (RB + DELTAR + R1*EXP (-CR1*TMAX) +R2*EXP (-CR2*TMAX))/ZF
       REL = RMAX/XMAX
       GO TO (250,250,14),NOPT
  250  IF(1.0-REL)3,3,4
    3  TNEAR = 0.0
       TFAR = 0.0
       GO TO 14
    4  IF (NTOPT)8001,8001,8022
 8022  IF(REL-0.975)8000,8001,8001
 8000  KMAX=REL*40.+1.0
       KM=KMAX
      0RV1=(RB+DELTAR+R1*EXP(-CR1*(TSUBN(KM  )-DELTAT))+
      1R2*EXP(-CR2*(TSUBN(KM  )-DELTAT)))/(ZF*XMAX)
 80020RV2=(RB+DELTAR+R1*EXP(-CR1*(TSUBN(KM+1)-DELTAT))+
      1R2*EXP(-CR2*(TSUBN(KM+1)-DELTAT)))/(ZF*XMAX)
       NNEAR=NNEAR+1
 8009  V=KM
       VAL1=(V-1.0)/40.
       VAL2=V/40.
       RNET1=RV1-VAL1
       RNET2=RV2-VAL2
       IF(RNET2)8003,8004,8005
 8004  TNEAR=TSUBN(KM+1)-DELTAT
       IF(TNEAR)8023,8010,8010
 8023  TNEAR=0.0
       GO TO 8010
 8003  IF(RNET1)8008,8007,8006
 8007  TNEAR=TSUBN(KM  )-DELTAT
       GO TO 8010
 8006  TNEAR=TSUBN(KM)+(TSUBN(KM+1)-TSUBN(KM))*RNET1*40.-DELTAT
       GO TO 8010
 8005  KM=KM+1
       RV1=RV2
       GO TO 8002
 8008  KM=KM-1
       RV2=RV1
      0RV1=(RB+DELTAR+R1*EXP(-CR1*(TSUBN(KM  )-DELTAT))+
      1R2*EXP(-CR2*(TSUBN(KM  )-DELTAT)))/(ZF*XMAX)
       GO TO 8009
 8010  IF(REL-0.025)9,9,8012
 8012  KM=KMAX
      0RV1=(RB+DELTAR+R1*EXP(-CR1*(TSUBF(KM  )-DELTAT))+
      1R2*EXP(-CR2*(TSUBF(KM  )-DELTAT)))/(ZF*XMAX)
 80130RV2=(RB+DELTAR+R1*EXP(-CR1*(TSUBF(KM+1)-DELTAT))+
      1R2*EXP(-CR2*(TSUBF(KM+1)-DELTAT)))/(ZF*XMAX)
       NFAR=NFAR+1
 8021  V=KM
       VAL1=(V-1.0)/40.
       VAL2= V/40.
       RNET1=RV1-VAL1
       RNET2=RV2-VAL2
       IF(RNET2)8014,8015,8016
 8015  TFAR=TSUBF(KM+1)-DELTAT
       GO TO 14
 8014  IF(RNET1)8017,8018,8019
 8018  TFAR=TSUBF(KM  )-DELTAT
       IF(TFAR)8024,14,14
 8024  TFAR=0.0
       GO TO 14
 8019  TFAR =TSUBF(KM)+(TSUBF(KM+1)-TSUBF(KM))*RNET1*40.-DELTAT
       GO TO 14
 8016  KM=KM+1
       RV1=RV2
       GO TO 8013
 8017  KM=KM-1
       IF(KM-2)9,8020,8020
 8020  RV2=RV1
      0RV1=(RB+DELTAR+R1*EXP(-CR1*(TSUBF(KM  )-DELTAT))+
      1R2*EXP(-CR2*(TSUBF(KM  )-DELTAT)))/(ZF*XMAX)
       GO TO 8021
 8001  TN1 = TMAXI
       X1 = 1.0
     50TN2 = TN1*(RB+DELTAR+R1*EXP (CR1*(DELTAT-TN1))+R2*EXP (CR2*
      1(DELTAT-TN1)))/(ZF*XMAX*X1)
       X2 = AAA*(EXP ( -CZ*TN2) -EXP (-CY*TN2))
       MANYNE = MANYNE + 1
       IF(MANYNE - 25) 175,175,14
  175  R = ABS (TN1 - TN2)
       IF(TLIMIT-R)6,6,7
    6  X1 =X2
       NNEAR = NNEAR + 1
       TN1 = TN2
       GO TO 5
    7  TNEAR = TN2 + TMAX - TMAXI
       IF(TNEAR) 8,8,9
    8  TNEAR = 0.0
    9  RELX=(RB+DELTAR)/(ZF*XMAX)
       IF(RELX-0.15)172,170,170
  172  TF1=(ALOG(3.62/RELX)+11.2)/CZ
       GO TO 10
  170  TF1=51.2-40.0*RELX
   100XREL = (RB+DELTAR+R1*EXP (CR1*(DELTAT-TF1))+R2*
      1EXP (CR2*(DELTAT-TF1)))/(ZF*XMAX)
       TF2 =ALOG ((AAA/XREL)*(EXP ((CY-CZ)*TF1) - 1.0))/CY
       MANYFA = MANYFA + 1
       IF(MANYFA - 25)177,177,14
  177  S = ABS (TF1 - TF2)
       IF(TLIMIT-S)11,11,12
   11  TF1 = TF2
       NFAR = NFAR + 1
       GO TO 10
   12  TFAR = TF2 + TMAX - TMAXI
       IF(TFAR) 13,13,14
   13  TFAR = 0.0
   14  RETURN
       END
```