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ABSTRACT

The theoretical and numerical data base development of the LARC-1 code is described. Four analytical models of fission product release from an HTGR core during the LOFC accident are developed. Effects of diffusion, adsorption and evaporation of the metallics and precursors are neglected in this first LARC model. Comparison of the analytic models indicates that the constant release-renormalized model is adequate to describe the processes involved.

The numerical data base for release constants, temperature modeling, fission product release rates, coated fuel particle failure fraction and aged coated fuel particle failure fractions is discussed. Analytic fits and graphic displays for these data are given for the Ft. St. Vrain and GASSAR models.

I. INTRODUCTION

In early 1975, a simplified model of fission product release from an HTGR (High-Temperature Gas-Cooled Reactor) core during the LOFC (Loss of Forced Circulation) accident was proposed by John E. Foley.[1] This simplified model was based on the following assumptions:

1. The entire core is at a uniform temperature.
2. All coated particles fail at the same time.
3. Fission products are released only from failed particles (no release from intact particles).

4. The release rate of an isotope from the failed particles is given by the release constant from the SORS report[2].

5. There is no buildup of the isotope from precursor decay.

In December 1975 we began developing the LARC code (Los Alamos Release Calculation) with the goal of calculating analytically the fission product transport of noble gases and metallics in an HTGR during the LOFC accident. We have systematically removed the assumptions of the simplified model. We have also studied the simple analytical models relative to more complex analytical models so as to judge the relative accuracy of the simple models used as a basis for extending the theory.

In this report we review the models developed to the present time, discuss the data base as developed thus far, and illustrate the workings of the LARC code with preliminary results. The current version, LARC-1, neglects the effects of diffusion, adsorption and evaporation of the metallics, and precursors.

The effects of precursors have been solved theoretically. A one-dimensional analytical diffusion model has been derived, but not implemented into this program. These topics will be addressed in subsequent reports.

In Section II we derive and discuss the analytical models: the Simplified Model, the Constant Release-Renormalized Model, the Linear Release Renormalized Model, and the Linear Failure Self-Consistent Model.

In Section III we review and discuss the data base used for the temperature modeling of the core, the fission product release rates for BISO and TRISO fuels from SORS and GASSAR, particle coating failure fraction, and the algorithm for computing the aged fuel failure fraction.

Section IV discusses and compares the results of release calculations for different isotopes. The relative accuracy of the models is compared with the conclusion that the Constant Release-Renormalized Model is justified for further theory extensions, for example for precursors and diffusion processes.

The results presented here are the culmination of about 700 short computer runs. The LARC-1 code runs on either the CDC-7600 in the BATCH mode or on the CDC-6600 in NOS (formally KRONOS) time-sharing system.

We would also like to acknowledge the usage of MACSYMA,* Version 258 (Project MAC's Symbolic Manipulation System for symbolic integration, differentiation, limiting and pattern recognition) that was of great help in the verification of many of the results presented in Appendices A and B.

The programs LARC-1 and PLOTS are discussed and listed in Appendices C and D.

II. ANALYTICAL MODELS

A. Simplified Model Equations - A Review

Using assumptions 1-5, the four Simplified model equations are given by

$$\frac{dN(t)}{dt} = -\Lambda_1(t)N(t), \quad 0 \leq t \leq \tau, \tag{1}$$

$$R(\tau) = \int_0^{\tau} r_1(s)N(s)ds, \tag{2}$$

$$\frac{dN'(t)}{dt} = S(t) - \Lambda^*(t)N'(t), \quad 0 \leq t \leq \tau, \tag{3}$$

$$R'(\tau) = \int_0^{\tau} L(s)N'(s)ds, \tag{4}$$

where

$N(t)$ is the number of atoms of the isotope in the core at time t in the interval $0 \leq t \leq \tau$,

$\Lambda_1(t) = \lambda + r_1(t)$, and λ is the isotope decay constant,

$r_1(t)$ is the release constant for failed particles,

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$R(\tau)$ is the amount of isotope released in the core during the time interval τ,

$N'(t)$ is the number of atoms of the isotope in the containment building at time t,

$R'(\tau)$ is the amount of the isotope released from the containment building during the time interval τ,

$\Lambda^*(t)$ $= \lambda + V(t) + L(t)$ is the total decay constant for the containment building,

$V(t)$ is the containment building cleanup rate,

$L(t)$ is the containment building leakage rate, and

$S(t)$ is the source rate to the containment building from the core.

In the Simplified model we assume that $r_1(t)$, $V(t)$, and $L(t)$ are constant in the time interval $0 \leq t \leq \tau$. We further assume that the source rate can be taken as a constant average, namely

$$S(t) = \frac{R(t)}{t}, \qquad 0 \leq t \leq \tau \tag{5}$$

which is valid if all the time steps are equal and small. In the other models we use

$$S(t) = \frac{dR(t)}{dt}, \tag{6}$$

which avoids that assumption.

The solutions to Eqs. (1-4), using Eq. (5), are given by

$$N(\tau) = N(0)e^{-\Lambda_1\tau}, \tag{7}$$

$$R(\tau) = \frac{r_1 N(0)}{\Lambda_1}(1-e^{-\Lambda_1\tau}), \tag{8}$$

$$N'(\tau) = N'(0)e^{-\Lambda^*\tau} + \frac{R(\tau)}{\tau\Lambda^*}(1 - e^{-\Lambda^*\tau}), \text{ and} \tag{9}$$

$$R'(\tau) = \frac{L}{\Lambda^*} N'(0)(1-e^{-\Lambda^*\tau}) + \frac{LR(\tau)}{\tau\Lambda^{*2}} [e^{-\Lambda^*\tau} - (1+\Lambda^*\tau)] . \quad (10)$$

In order to find the release after a number of time steps $k\tau$, the activity is accumulated according to

$$A(k\tau) = A[(k-1)\tau]e^{-\lambda\tau} + R(\tau) \text{ and} \quad (11)$$

$$A'(k\tau) = A[(k-1)\tau]e^{-\lambda\tau} + R'(\tau) . \quad (12)$$

In addition, the values of $N(\tau)$ and $N'(\tau)$ at the end of a time step become the initial values $N(0)$, $N'(0)$, respectively, for the next time step.

The release rate, $\bar{r}_1$, the leakage rate, $\bar{L}$, and the clean-up rate, $\bar{V}$, are determined by

$$\bar{r}_1 = \frac{1}{2} [r(0) + r(\tau)], \quad (13)$$

$$\bar{L} = \frac{1}{2} [L(0) + L(\tau)], \text{ and} \quad (14)$$

$$\bar{V} = \frac{1}{2} [V(0) + V(\tau)] . \quad (15)$$

Currently we use the values $\bar{L}$ and $\bar{V}$ for all time intervals. The decay constant is an input quantity.

B. Constant Release - Renormalized Model

Whereas in the Simplified model we treated only failed particle release, we now assume a constant release r_i for failed (i=1) and intact (i=2) particles. In addition we calculate the release from BISO and TRISO particles separately and sum the releases using $X_{TOTAL} = a \cdot X_{BISO} + (1-a) \cdot X_{TRISO}$ where a = 0.6 and X is a release, either R or R'. Then the differential equations corresponding to Eqs. (1-4) and (6) are

$$\frac{dN_i(t)}{dt} = -\Lambda_i(t)N_i(t), \tag{16}$$

$$R_i(\tau) = \int_0^\tau r_i(s)N_i(s)ds , \tag{17}$$

$$\frac{dN_i'(t)}{dt} = S_i(t) - \Lambda^* N_i'(t), \tag{18}$$

$$R_i'(\tau) = \int_0^\tau L(s)N_i'(s)ds, \text{ and} \tag{19}$$

$$S_i(t) = \frac{dR_i(t)}{dt} = r_i(t)N_i(t). \tag{20}$$

Integrating Eqs.(16-17), using Eqs.(2) and (13-15) we find

$$N_i(\tau) = e^{-\Lambda_i\tau} N_i(0), \tag{21}$$

$$R_i(\tau) = \frac{\bar{r}_i}{\Lambda_i}(1-e^{-\Lambda_i\tau})N_i(0), \tag{22}$$

$$N_i'(\tau) = \begin{cases} e^{-\Lambda^*\tau} N_i'(0) + \dfrac{\bar{r}_i}{\Lambda^*-\Lambda_i}(e^{-\Lambda_i\tau} - e^{-\Lambda^*\tau})N_i(0) & \text{if } \Lambda^* \neq \Lambda_i, \\ e^{-\Lambda^*\tau} N_i'(0) + \bar{r}_i\tau e^{-\Lambda^*\tau} N_i(0) & \text{if } \Lambda^* = \Lambda_i, \end{cases} \tag{23}$$

$$R_i'(\tau) = \begin{cases} \dfrac{\bar{L}}{\Lambda^*}(1-e^{-\Lambda^*\tau})N_i'(0) + \dfrac{\bar{L}\bar{r}_i}{\Lambda^*-\Lambda_i}\left[\dfrac{1}{\Lambda_i}(1-e^{-\Lambda_i\tau}) - \dfrac{1}{\Lambda^*}(1-e^{-\Lambda^*\tau})\right]N_i(0) & \text{if } \Lambda^* \neq \Lambda_i, \\ \dfrac{\bar{L}}{\Lambda^*}(1-e^{-\Lambda^*\tau})N_i'(0) + \dfrac{\bar{L}\bar{r}_i}{\Lambda^{*2}}\left[1-(1+\Lambda^*\tau)e^{-\Lambda^*\tau}\right]N_i(0) & \text{if } \Lambda^*=\Lambda_i, \end{cases} \tag{24}$$

where $\Lambda_i \equiv \lambda + \bar{r}_i$ and $\Lambda^* = \lambda + \bar{L} + \bar{V}$. Since $\bar{r}_i$ is given as a function of temperature and implicitly as a function of time, the limiting cases $\Lambda^* = \Lambda_i$ are distinctly possible and must be accounted for.

In the Simplified model where we treated the release only from failed particles, using the final value for $N(\tau)$ of a time step as the initial value, $N(0)$, for the next time step was justified. However, from a study of the intact-failed transition (Section D) it became clear that matching the failed fraction (for BISO and TRISO) as a function of time is crucial. The failed fraction is defined as

$$F(t) = \frac{N_1(t)}{N_1(t) + N_2(t)} \quad . \tag{25}$$

Assuming that we know $F(t)$, which we do, then we want to adjust the ratio N_1/N_2 while maintaining the constancy of the sum $N_1 + N_2$. This renormalization of $N_i(\tau)$ at the end of a time step to $N_i(0)$ at the beginning of the next time step is accomplished by the transformation

$$F(\tau)[N_1(\tau) + N_2(\tau)] \rightarrow N_1(0)$$

$$[1 - F(\tau)][N_1(\tau) + N_2(\tau)] \rightarrow N_2(0), \tag{26}$$

for both BISO and TRISO particles using the $F(\tau)$ specific to each type. The failed fraction is a function of temperature which is a function of time and of core volume fraction. Thus $F(t)$ is implicitly a function of time.

The quantities $N_i(t)$, $R_i(\tau)$, $N_i'(t)$, $R_i'(\tau)$ are calculated separately and then summed for BISO and TRISO particles, failed (1) and intact (2) particle coating release, and various core volume fractions.

Although we use the averaging given by Eq. (13) for the $\bar{r}_i$, we also tried time centering $\bar{r}_i$ defined by

$$\bar{r}_i = r_i[T(\tau/2)]. \tag{27}$$

Those results were not in as good agreement as using Eq. (13) in parameter studies involving time steps and core volume fraction.

C. Linear Release - Renormalized Model

In the Constant Release-Renormalized model we assumed that the release rate for failed and intact particles was given by

$$\bar{r}_i = \frac{1}{2}[r_i(0) + r_i(\tau)] \quad i=1,2 , \tag{28}$$

over the time interval τ.

Now we approximate the release function of time over the time interval τ, given by suppressing the subscript i)

$$r(t) = \sum_{k=1} [a_k + b_k(t-t_k)][\theta(t-t_k) - \theta(t-t_{k+1})], \tag{29}$$

where $\theta(x)$ is the Heaviside step-function defined by

$$\theta(x) = \begin{cases} 1, & x > 0 \\ 0, & x \leq 0 \end{cases} . \tag{30}$$

Denoting

$$\begin{aligned} r_k &= r[T(t_k)] \\ \tau &= t_{k+1} - t_k \end{aligned} \tag{31}$$

we solve for the a_k and b_k in Eq. (29) to obtain

$$a_k = r_k \quad \text{and}$$
$$b_k = (r_{k+1} - r_k)/\tau \ . \tag{32}$$

Note that using Eq. (32) in (29), we obtain

$$r(t_k + \frac{1}{2}\tau) = \frac{1}{2}(r_k + r_{k+1}) \ , \tag{33}$$

which is equivalent to Eq. (28).

The same remarks concerning BISO and TRISO particles preceding Eq. (16) in the constant release model apply for the linear release model. The differential equations for the Linear Release-Renormalized model are

$$\frac{dN_i(t)}{dt} = -\Lambda_i(t)N_i(t) \ , \tag{34}$$

$$R_i(\tau) = \int_0^\tau r_i(s)N_i(s)ds \ , \tag{35}$$

$$\frac{dN_i'(t)}{dt} = S_i(t) - \Lambda^* N_i'(t) , \tag{36}$$

$$R_i'(\tau) = \int_0^\tau L(s)N_i(s)ds , \tag{37}$$

$$S_i(t) = \frac{dR_i(t)}{dt} = r_i(t)N_i(t) \ , \tag{38}$$

$$\Lambda_i(t) = \lambda + r_i(t) , \tag{39}$$

$$r_i(s) = a_i + b_i s \ , \quad i = 1,2 \tag{40}$$

where a_i and b_i are determined for i = 1,2 (that is, failed and intact particles) over the time interval τ using Eq. (32) as

$$a_i = r_i(0) \quad \text{and}$$

$$b_i = [r_i(\tau) - r_i(0)]/\tau . \tag{41}$$

After solving Eqs. (34-38) we apply the same renormalization as discussed in the Constant Release-Renormalized model, namely Eq. (26).

The integration of Eqs. (34-38) is straightforward, using the methods developed in Appendices A and B, with the results that

$$N_i(\tau) = e^{-\bar{\Lambda}_i \tau} N_i(0), \tag{42}$$

$$R_i(\tau) = [1-e^{-\bar{\Lambda}_i \tau} - \lambda P_o(\Lambda_i, \beta, \tau)] N_i(0), \tag{43}$$

$$N'_i(\tau) = e^{-\Lambda^* \tau} N'_i(0) + [(\bar{V} + \bar{L}) P_o(\Lambda_i - \Lambda^*, \beta, \tau) + 1 - e^{-(\Lambda_i - \Lambda^*)\tau}] e^{-\Lambda^* \tau} N_i(0), \tag{44}$$

$$R'_i(\tau) = \frac{\bar{L}}{\Lambda^*} (1-e^{-\Lambda^* \tau}) N'_i(0) + \frac{\bar{L}}{\Lambda^*} [1-e^{-\Lambda^* \tau} - \lambda P_o(\Lambda_i, \beta, \tau) + (\bar{V}+\bar{L}) e^{-\Lambda^* \tau} P_o(\Lambda_i - \Lambda^*, \beta, \tau)] N_i(0), \tag{45}$$

where

$$\bar{\Lambda}_i = \lambda + a_i + \frac{b_i \tau}{2},$$

$$\Lambda_i = \lambda + a_i, \tag{46}$$

$$\beta = \frac{b_i}{2},$$

and

$$P_k(\gamma, \beta, \tau) = \int_o^\tau ds\, s^k\, e^{-\gamma s - \beta s^2} = (-\frac{\partial}{\partial \gamma})^k P_o(\gamma, \beta, \tau) \tag{47}$$

with

$$P_o(\gamma,\beta,\tau) = \frac{1}{2}\sqrt{\frac{\pi}{\beta}}\ e^{\gamma^2/4\beta}\ [\mathrm{erf}(\sqrt{\beta}\tau + \frac{\gamma}{2\sqrt{\beta}}) - \mathrm{erf}\ (\frac{\gamma}{2\sqrt{\beta}})]\ . \quad (48)$$

Various limiting forms of $P_o(\gamma,\beta,\tau)$ are derived in Appendix A where it is shown that

$$P_o(0,\beta,\tau) = \frac{1}{2}\sqrt{\frac{\pi}{\beta}}\ \mathrm{erf}\ (\sqrt{\beta}\tau)\ \text{if}\ \gamma = 0,\ \beta \neq 0 \quad (49)$$

$$P_o(\gamma,0,\tau) = \frac{1}{\gamma}(1-e^{-\gamma\tau}) \quad \text{if}\ \gamma \neq 0,\ \beta = 0 \quad (50)$$

and

$$P_o(0,0,\tau) = \tau \quad \text{if}\ \gamma = \beta = 0\ . \quad (51)$$

Also involved in the integration of Eqs. (34-38), and derived in Appendices A and B, are the integrals

$$P_1(\gamma,\beta,\tau) = \int_o^\tau ds\ s\ e^{-\gamma s-\beta s^2} = -\frac{\gamma}{2\beta}P_o(\gamma,\beta,\tau) + \frac{1}{2\beta}(1-e^{-\gamma\tau-\beta\tau^2}), \quad (52)$$

$$\int_o^\tau ds\ e^{-\Lambda^* s}\ P_o(\gamma,\beta,s) = \frac{1}{\Lambda^*}[P_o(\Lambda^* + \gamma,\beta,\tau) - e^{-\Lambda^*\tau}P_o(\gamma,\beta,\tau)], \quad (53)$$

and

$$\int_0^\tau ds\, e^{-\Lambda^* s} P_1(\gamma,\beta,s) = \frac{1}{2\beta\Lambda^*} [-(\Lambda^* + \gamma) P_o(\Lambda^* + \gamma,\beta,\tau)$$

$$+ \gamma e^{-\Lambda^*\tau} P_o(\gamma,\beta,\tau) + 1 - e^{-\Lambda^*\tau}] . \quad (54)$$

Using Eqs.(48-51), the various limiting forms may be written explicitly as

$\gamma = \Lambda_i - \Lambda^*,\ \beta \neq 0$:

$$N_i'(\tau) = e^{-\Lambda^*\tau} N_i'(0) + e^{-\Lambda^*\tau}[a_i P_o(0,\beta,\tau) + 1 - e^{-\beta\tau^2}] N_i(0) \quad (55)$$

$$R_i'(\tau) = \bar{L}\ \{\frac{1-e^{-\Lambda^*\tau}}{\Lambda^*} N_i'(0) + \frac{1}{\Lambda^*} [(a_i - \Lambda^*) P_o(\Lambda^*,\beta,\tau)$$

$$- a_i P_o(0,\beta,\tau) + 1 - e^{-\Lambda^*\tau}] N_i(0)\} . \quad (56)$$

$\gamma = \Lambda_i - \Lambda^* \neq 0,\ \beta = 0$:

$$N_i'(\tau) = e^{-\Lambda^*\tau} N_i'(0) + \frac{a_i}{\bar{\Lambda}_i} [1 - e^{-(\Lambda_i - \Lambda^*)\tau}]\ e^{-\Lambda^*\tau} N_i(0) \quad (57)$$

$$R_i'(\tau) = \bar{L} \left\{\frac{1-e^{-\Lambda^*\tau}}{\Lambda^*} N_i'(0) + \frac{a_i}{\bar{\Lambda}_i}\left[\frac{1}{\Lambda^*} (1-e^{-\Lambda^*\tau}) - \frac{1}{\Lambda_i} (1-e^{-\Lambda_i\tau})\right] N_i(0)\right\} . \quad (58)$$

$\gamma = \Lambda_i - \Lambda^* = 0,\ \beta = 0$:

$$N_i'(\tau) = e^{-\Lambda^*\tau} N_i'(0) + a_i \tau e^{-\Lambda^*\tau} N_i(0) \quad (59)$$

$$R_i'(\tau) = \bar{L} \{ \frac{1-e^{-\Lambda^* \tau}}{\Lambda^*} N_i'(0) + \frac{a_i}{\Lambda^{*2}} [1-(1+\Lambda^*\tau)e^{-\Lambda^*\tau}] N_i(0) \}. \quad (60)$$

In the $\beta = 0$ limit, $a_i \to \bar{r}_i$ using Eq. (41), and Eq. (57) and Eq. (59) for $N_i'(\tau)$ and Eq. (58) and Eq. (60) for $R_i'(\tau)$ are seen to be identical with Eq. (23) and Eq. (24), respectively, for the Constant Release model described previously, as they should.

In terms of numerical evaluation it suffices to use the limiting forms for $P_o(\gamma,\beta,\tau)$ given in Eqs. (48-51) in Eqs. (42-45) since there are no singularities.

D. Intact - Failed Self-Consistent Fuel Transition

In order to investigate the accuracy of the simple renormalized intact-failed models, we now develop a self-consistent model for reference comparisons. We assume that the release rate, r(t), the containment building clean-up system removal rate, V(t), and the containment building leak rate, L(t), are constant over the time interval τ. We assume that the failed fraction, F(t), is a linear function of time over the time interval τ.

The transition of intact to failed fuel, including decay and release from failed (Eq.61) and intact (Eq.62) fuel particles can be represented by

$$\frac{dN_1}{dt} = -(\lambda+\bar{r}_1)N_1 + \dot{G}N_2 \quad \text{(failed)}, \quad (61)$$

$$\frac{dN_2}{dt} = -(\lambda+\bar{r}_2)N_2 - \dot{G}N_2 \quad \text{(intact)}, \quad (62)$$

where λ is the isotope decay constant and the $\bar{r}_i$ are the release constants. We assume that the release constants are averaged over the time interval τ and are given by

$$\bar{r}_i \equiv \frac{1}{2}\,[r_i(0) + r_i(\tau)], \quad i = 1,2 . \tag{63}$$

The transition rate, $\dot{G}$, in Eqs. (61) and (62), is determined from the definition of the failed fraction

$$F(t) \equiv \frac{N_1(t)}{N_1(t) + N_2(t)} . \tag{64}$$

Differentiating ($\dot{} \equiv \frac{d}{dt}$) Eq. (64), we obtain

$$\dot{F}(t) = [1 - F(t)]\,\frac{\dot{N}_1(t)}{N_1(t) + N_2(t)} - F(t)\,\frac{\dot{N}_2(t)}{N_1(t) + N_2(t)} , \tag{65}$$

where we have used Eq.(64). Defining

$$\Lambda_i = \lambda + \bar{r}_i , \; i = 1,2 \tag{66}$$

and substituting Eqs (61) and (62) for $\dot{N}_1(t)$ and $\dot{N}_2(t)$ into Eq. (65), we find

$$\dot{F}(t) = F(t)\;[1-F(t)](\Lambda_2-\Lambda_1) + [1-F(t)]\dot{G} . \tag{67}$$

Solving for $\dot{G}(t)$ we obtain

$$\dot{G}(t) = \frac{\dot{F}(t)}{1-F(t)} + (\Lambda_1-\Lambda_2)F(t) . \tag{68}$$

Assuming that the failed fraction, F(t), is approximated as a linear function in the time interval τ,

$$F(t) = a + bt , \; 0 \leq F(t) \leq 1 \tag{69}$$

then

$$a = F(0)$$

$$b = \frac{F(\tau) - F(0)}{\tau} \tag{70}$$

and Eqs. (61) and (62) can be integrated, using Eq. (68) to give

$$N_1(\tau) = \sum_{k=o}^{3} A_k M_k(\tau)$$

and (71)

$$N_2(\tau) = \sum_{k=4}^{5} A_k M_k(\tau),$$

where the functions $M_k(\tau)$ are defined as

$$M_o(\tau) = e^{-\Lambda_1 \tau},$$

$$M_k(\tau) = e^{-\Lambda_1 \tau} \int_o^{\tau} ds\, s^{k-1}\, e^{\alpha s - \beta s^2}, \quad 1 \leq k \leq 3,$$

$$M_4(\tau) = e^{-\gamma\tau - \beta\tau^2}, \text{ and}$$

$$M_5(\tau) = \tau e^{-\gamma\tau - \beta\tau^2}. \tag{72}$$

The constants (in the time interval τ) α, β, γ, and A_k are given by

$$\alpha = (\Lambda_1 - \Lambda_2)(1-a),$$

$$\beta = (\Lambda_1 - \Lambda_2)\, b/2,$$

$$\gamma = \Lambda_1 a + \Lambda_2(1-a) = \Lambda_1 - \alpha, \tag{73}$$

and

$$A_o = N_1(0) ,$$

$$A_1 = [b + (\Lambda_1-\Lambda_2)(1-a)] \frac{N_2(0)}{1-a} ,$$

$$A_2 = (\Lambda_1-\Lambda_2)[b(1-a)-ab] \frac{N_2(0)}{1-a} , \tag{74}$$

$$A_3 = -(\Lambda_1-\Lambda_2) \frac{b^2 N_2(0)}{1-a} ,$$

$$A_4 = N_2(0) , \text{ and}$$

$$A_5 = - \frac{bN_2(0)}{1-a} .$$

The release from intact and failed particles is given by

$$R_i(\tau) = \int_o^\tau ds\ r_i\ N_i(s) ,\ i = 1,2 \tag{75}$$

or

$$R_1(\tau) = \sum_{R=o}^{3} B_k\ \hat{P}_k\ (\tau)$$

$$R_2(\tau) = \sum_{R=4}^{5} B_k\ \hat{P}_k(\tau) , \tag{76}$$

where the functions $\hat{P}_k(\tau)$ are defined by

$$\hat{P}_k(\tau) = \int_o^\tau ds\ M_k(s) \tag{77}$$

and the constants B_k are related to the A_k's by

$$B_k = \bar{r}_1\ A_k \quad 0 \le k \le 3$$

$$B_k = \bar{r}_2\ A_k \quad k = 4,5 . \tag{78}$$

The functions $M_k(\tau)$ and $\hat{P}_k(\tau)$ are derived explicitly in Appendix A. They are all expressible in terms of exponentials and combinations of exponentials with error functions. If we define the function $P_o(\gamma,\beta,\tau)$, c.f. Eq. (A-8), by

$$P_o(\gamma,\beta,\tau) = \int_o^\tau ds\ e^{-\gamma s-\beta s^2}$$

$$= \frac{1}{2}\sqrt{\frac{\pi}{\beta}}\ e^{\gamma^2/2\beta}\left[\text{erf}\left(\sqrt{\beta}\tau + \frac{\gamma}{2\sqrt{\beta}}\right) - \text{erf}\left(\frac{\gamma}{2\sqrt{\beta}}\right)\right], \qquad (79)$$

then by integration and differentiation [with respect to the parameters of $P_o(\gamma,\beta,\tau)$], the $M_k(\tau)$ functions for $\beta \neq 0$ are given by

$$M_o(\Lambda_1,\tau) = e^{-\Lambda_1\tau},$$

$$M_1(\Lambda_1,\alpha,\beta,\tau) = e^{-\Lambda_1\tau}\ P_o(-\alpha,\beta,\tau),$$

$$M_2(\Lambda_1,\alpha,\beta,\tau) = \frac{e^{-\Lambda_1\tau}}{2\beta}\left[\alpha P_o(-\alpha,\beta,\tau) + 1 - e^{\alpha\tau-\beta\tau^2}\right],$$

$$M_3(\Lambda_1,\alpha,\beta,\tau) = \frac{e^{-\Lambda_1\tau}}{4\beta^2}\left[\begin{array}{l}(\alpha^2+2\beta)P_o(-\alpha,\beta,\tau) + \alpha(1-e^{\alpha\tau-\beta\tau^2}) \\ -(\alpha-2\beta\tau)e^{\alpha\tau-\beta\tau^2}\end{array}\right],$$

$$M_4(\gamma,\beta,\tau) = e^{-\gamma\tau-\beta\tau^2},$$

and

$$M_5(\gamma,\beta,\tau) = \tau e^{-\gamma\tau-\beta\tau^2}. \qquad (80)$$

The functions $M_2(\tau)$ and $M_3(\tau)$ are expressible as

$$M_2(\Lambda_1,\alpha,\beta,\tau) = \frac{M_o(\Lambda_1,\tau) - M_4(\Lambda_1-\alpha,\beta,\tau) + \alpha M_1(\Lambda_1,\alpha,\beta,\tau)}{2\beta} \qquad (81)$$

and

$$M_3(\Lambda_1,\alpha,\beta,\tau) = \frac{M_1(\Lambda_1,\alpha,\beta,\tau) - M_5(\Lambda_1-\alpha,\beta,\tau) + \alpha M_2(\Lambda_1,\alpha,\beta,\tau)}{2\beta} \quad . \qquad (82)$$

The limiting forms are given in Appendix A. In particular we note that the integrals for $M_2(\tau)$ and $M_3(\tau)$ in the $\beta = 0$ limit are finite and independent of β. The contribution from $A_k M_k(\tau)$, $k = 2,3$, is therefore zero since A_2 and A_3 have a factor of β in them.

Similarly, integration of Eq. (77), using Eq. (80), as derived in Appendix A, yields for the $\hat{P}_k(\tau)$ functions the results

$$\hat{P}_o(\Lambda_1,\tau) = \frac{1}{\Lambda_1}(1-e^{-\Lambda_1\tau}) ,$$

$$\hat{P}_1(\Lambda_1,\alpha,\beta,\tau) = \frac{1}{\Lambda_1}[P_o(\Lambda_1-\alpha,\beta,\tau)-e^{-\Lambda_1\tau} P_o(-\alpha,\beta,\tau)] ,$$

$$\hat{P}_2(\Lambda_1,\alpha,\beta,\tau) = \frac{1}{2\beta\Lambda_1}\left[\begin{matrix}(\Lambda_1-\alpha)P_o(\Lambda_1-\alpha,\beta,\tau)+\alpha e^{-\Lambda_1\tau} P_o(-\alpha,\beta,\tau) \\ -(1-e^{-\Lambda_1\tau})\end{matrix}\right] ,$$

$$\hat{P}_3(\Lambda_1,\alpha,\beta,\tau) = \frac{1}{4\beta^2}\left\{\begin{matrix}-\frac{[2\beta+(\Lambda_1-\alpha)^2]}{\Lambda_1} P_o(\Lambda_1-\alpha,\beta,\tau) + \frac{(-2\beta+\Lambda_1^2)}{\Lambda_1} e^{-\Lambda_1\tau} \times \\ P_o(-\alpha,\beta,\tau)+(1-e^{-\beta\tau^2-(\Lambda_1-\alpha)\tau}) - \frac{\alpha}{\Lambda_1}(1-e^{-\Lambda_1\tau})\end{matrix}\right\} ,$$

$$\hat{P}_4(\gamma,\beta,\tau) = P_o(\gamma,\beta,\tau) , \quad \text{and}$$

$$\hat{P}_5(\gamma,\beta,\tau) = -\frac{\gamma}{2\beta} P_o(\gamma,\beta,\tau) + \frac{1}{2\beta}(1-e^{-\gamma\tau-\beta\tau^2}) , \qquad (83)$$

where the limiting forms for $\hat{P}_k(\tau)$ are given in Appendix A.

The functions $\hat{P}_k(\tau)$ are expressible as

$$\hat{P}_o(\Lambda_1,\tau) = \frac{1-M_o(\Lambda_1,\tau)}{\Lambda_1} ,$$

$$\hat{P}_1(\Lambda_1,\alpha,\beta,\tau) = \frac{\hat{P}_4(\Lambda_1-\alpha,\beta,\tau) - M_1(\Lambda_1,\alpha,\beta,\tau)}{\Lambda_1} ,$$

$$\hat{P}_2(\Lambda_1,\alpha,\beta,\tau) = \frac{\hat{P}_o(\Lambda_1,\tau) - \hat{P}_4(\Lambda_1-\alpha,\beta,\tau) + \alpha\hat{P}_1(\Lambda_1,\alpha,\beta,\tau)}{2\beta} ,$$

$$\hat{P}_3(\Lambda_1,\alpha,\beta,\tau) = \frac{\hat{P}_1(\Lambda_1,\alpha,\beta,\tau) - \hat{P}_5(\Lambda_1-\alpha,\beta,\tau) + \alpha P_2(\Lambda_1,\alpha,\beta,\tau)}{2\beta} ,$$

$$\hat{P}_4(\gamma,\beta,\tau) = P_o(\gamma,\beta,\tau) \text{ , and}$$

$$\hat{P}_5(\gamma,\beta,\tau) = \frac{1 - \gamma\hat{P}_4(\gamma,\beta,\tau) - M_4(\gamma,\beta,\tau)}{2\beta} . \tag{84}$$

In particular we note that the integrals for $\hat{P}_2(\tau)$, $\hat{P}_3(\tau)$, and $\hat{P}_5(\tau)$ in the $\beta = 0$ limit are finite and independent of β. The contribution from $A_k\hat{P}_k(\tau)$ for $k = 2,3$, and 5 therefore vanishes for $\beta = 0$. The other limiting forms are automatically accounted for using Eq. (84) and the limiting forms for $P_o(\gamma,\beta,\tau)$ given in Appendix A.

The number of isotope particles, $N_i^{'}(t)$, from failed or intact particles released in the containment building is governed by

$$\frac{dN_i^{'}}{dt} = S_i(t) - \Lambda^{*}N_i^{'}(t) , \tag{85}$$

where the source, $S_i(t)$, is taken as the release rate from failed or intact particles,

$$S_i(t) = \frac{dR_i}{dt} = r_iN_i(t) . \tag{86}$$

The decay constant, Λ^*, is defined as

$$\Lambda^* = \lambda + \bar{V} + \bar{L} , \tag{87}$$

where $V(\tau)$ represents the containment building cleanup system removal rate and $L(\tau)$ represents the containment building leakage rate. We assume averaged values over the time interval τ and define

$$\bar{V} \equiv \frac{1}{2} [V(0) + V(\tau)] \quad \text{and}$$
$$\bar{L} \equiv \frac{1}{2} [L(0) + L(\tau)] . \tag{88}$$

The release from the containment building is given by

$$R_i'(\tau) = \int_0^\tau ds\ L(s) N_i'(s) . \tag{89}$$

Integrating Eqs. (85) and (89), using Eq. (86), we may express the solutions in the form

$$N_i'(\tau) = e^{-\Lambda^*\tau} N_i'(0) + \bar{r}_i e^{-\Lambda^*\tau} \int_0^\tau ds\ e^{\Lambda^* s} N_i(s)$$

and (90)

$$R_i'(\tau) = \bar{L} \left[\frac{(1-e^{-\Lambda^*\tau})}{\Lambda^*} N_i'(0) + \bar{r}_i \int_0^\tau ds\ e^{-\Lambda^* s} \int_0^s ds'\, e^{\Lambda^* s'} N_i(s') \right] ,$$

where $\bar{r}_i$, Λ^*, and $\bar{L}$ are given by Eqs.(63), (87), and (88), respectively.

Substituting Eq. (71) and (78) into Eq. (90), we may express the solutions as

$$N_1'(\tau) = e^{-\Lambda^*\tau} N_1'(0) + e^{-\Lambda^*\tau} \sum_{R=0}^{3} B_k Q_k(\tau) ,$$

(91)

$$N_2'(\tau) = e^{-\Lambda^*\tau} N_2'(0) + e^{-\Lambda^*\tau} \sum_{R=4}^{5} B_k Q_k(\tau) ,$$

and

$$\frac{R_1'(\tau)}{L} = \frac{1-e^{-\Lambda^*\tau}}{\Lambda^*} N_1'(0) + \sum_{k=0}^{3} B_k V_k(\tau) ,$$

(92)

$$\frac{R_2'(\tau)}{L} = \frac{1-e^{-\Lambda^*\tau}}{\Lambda^*} N_2'(0) + \sum_{k=4}^{5} B_k V_k(\tau) ,$$

where the functions $Q_k(\tau)$ and $V_k(\tau)$ are defined by

$$Q_k(\tau) = \int_0^\tau ds\ e^{\Lambda^* s} M_k(s) ,$$

(93)

$$V_k(\tau) = \int_0^\tau ds\ e^{-\Lambda^* s} Q_k(s) .$$

The $Q_k(\tau)$ and $V_k(\tau)$ functions are derived explicitly in Appendix B.

For the general case of $Q_k(\tau)$ we obtain the results that

$$Q_o(\Lambda^*,\Lambda_1,\tau) = \frac{1}{\Lambda_1-\Lambda^*} [1-e^{-(\Lambda_1-\Lambda^*)\tau}] ,$$

$$Q_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{1}{\Lambda_1-\Lambda^*}\left[P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau) - e^{-(\Lambda_1-\Lambda^*)\tau} P_o(-\alpha,\beta,\tau)\right],$$

$$Q_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{1}{2\beta(\Lambda_1-\Lambda^*)}\left[\begin{array}{l}(\Lambda_1-\Lambda^*-\alpha)P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau) \\ + \alpha e^{-(\Lambda_1-\Lambda^*)\tau} P_o(-\alpha,\beta,\tau) \\ -(1-e^{-(\Lambda_1-\Lambda^*)\tau}\end{array}\right],$$

$$Q_3(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{1}{4\beta^2}\left\{\begin{array}{l}\frac{[2\beta+(\Lambda_1-\Lambda^*-\alpha)^2]}{\Lambda_1-\Lambda^*} P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau) \\ - \frac{(2\beta+\alpha^2)}{\Lambda_1-\Lambda^*} e^{-(\Lambda_1-\Lambda^*)\tau} P_o(-\alpha,\beta,\tau) \\ -[1-e^{-\beta\tau^2-(\Lambda_1-\Lambda^*-\alpha)\tau}] \\ + \frac{\alpha}{\Lambda_1-\Lambda^*}[1-e^{-(\Lambda_1-\Lambda^*)\tau}]\end{array}\right\},$$

$$Q_4(\Lambda^*,\gamma,\beta,\tau) = P_o(\gamma-\Lambda^*,\beta,\tau)\text{ , and}$$

$$Q_5(\Lambda^*,\gamma,\beta,\tau) = P_1(\gamma-\Lambda^*,\beta,\tau)\ . \qquad (94)$$

$P_1(\gamma,\beta,\tau)$ is defined in Appendix A.

The expressions for $Q_2(\tau)$, $Q_3(\tau)$ can be expressed in a functionally simpler manner as

$$Q_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{Q_o(\Lambda^*,\Lambda_1,\tau) - Q_4(\Lambda^*,\Lambda_1-\alpha,\beta,\tau) + \alpha Q_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau)}{2\beta}$$

$$Q_3(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{Q_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) - Q_5(\Lambda^*,\Lambda_1-\alpha,\beta,\tau) + \alpha Q_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau)}{2\beta} . \tag{95}$$

Again, the integrals for $Q_2(\tau)$, $Q_3(\tau)$, and $Q_5(\tau)$ in the $\beta = 0$ limit are finite and independent of β. The contribution from $B_k\ Q_k(\tau)$ for $k = 2,3$, and 5 therefore vanishes for $\beta = 0$ since those B_k have a factor β in them. The other limiting forms are handled correctly using the limiting forms for $P_o(\gamma,\beta,\tau)$, $P_1(\gamma,\beta,\tau)$ and $Q_o(\tau)$ given in Appendices A and B.

For the general case of $V_k(\tau)$ we obtain the results that

$$V_o(\Lambda^*,\Lambda_1,\tau) = \frac{1}{\Lambda_1-\Lambda^*}\left[\frac{1}{\Lambda^*}(1-e^{-\Lambda^*\tau}) - \frac{1}{\Lambda_1}(1-e^{-\Lambda_1\tau})\right] ,$$

$$V_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{1}{\Lambda_1\Lambda^*} P_o(\Lambda_1-\alpha,\beta,\tau) - \frac{1}{\Lambda_1-\Lambda^*}\left[\frac{e^{-\Lambda^*\tau}}{\Lambda^*} P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau) - \frac{e^{-\Lambda_1\tau}}{\Lambda_1} P_o(-\alpha,\beta,\tau)\right] ,$$

$$V_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = + \frac{(\Lambda_1-\Lambda^*-\alpha)}{2\beta(\Lambda_1-\Lambda^*)} \frac{1}{\Lambda^*} [P_o(\Lambda_1-\alpha,\beta,\tau) - e^{-\Lambda^*\tau} P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau)]$$

$$+ \frac{\alpha}{2\beta(\Lambda_1-\Lambda^*)} \frac{1}{\Lambda_1-\Lambda^*} [P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau)$$

$$-e^{(\Lambda_1-\Lambda^*)\tau} P_o(-\alpha,\beta,\tau)]$$

$$- \frac{1}{2\beta(\Lambda_1-\Lambda^*)} [\frac{1}{\Lambda^*} (1-e^{-\Lambda^*\tau}) - \frac{1}{\Lambda_1} (1-e^{-\Lambda_1\tau})] ,$$

$$V_3(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{1}{4\beta^2} [\frac{2\beta+(\Lambda_1-\Lambda^*-\alpha)^2}{\Lambda^*(\Lambda_1-\Lambda^*)} - \frac{(2\beta+\alpha^2)}{\Lambda_1(\Lambda_1-\Lambda^*)} + 1] P_o(\Lambda_1-\alpha,\beta,\tau)$$

$$+ \frac{1}{4\beta^2} \frac{2\beta+\alpha^2}{\Lambda_1(\Lambda_1-\Lambda^*)} e^{-\Lambda_1\tau} P_o(-\alpha,\beta,\tau)$$

$$- \frac{1}{4\beta^2} \frac{2\beta+(\Lambda_1-\Lambda^*-\alpha)^2}{\Lambda^*(\Lambda_1-\Lambda^*)} e^{-\Lambda^*\tau} P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau)$$

$$- \frac{1}{4\beta^2} \frac{1}{\Lambda^*} (1-e^{-\Lambda^*\tau})$$

$$+ \frac{1}{4\beta^2} \frac{\alpha}{\Lambda_1-\Lambda^*} [\frac{1}{\Lambda^*} (1-e^{-\Lambda^*\tau}) - \frac{1}{\Lambda_1} (1-e^{-\Lambda_1\tau})] ,$$

$$V_4(\Lambda^*,\gamma,\beta,\tau) = \frac{1}{\Lambda^*}\,[P_o(\gamma,\beta,\tau) - e^{-\Lambda^*\tau}P_o(\gamma-\Lambda^*,\beta,\tau)], \text{ and}$$

$$V_5(\Lambda^*,\gamma,\beta,\tau) = -\frac{\gamma}{2\beta\Lambda^*}P_o(\gamma,\beta,\tau) + \frac{\gamma-\Lambda^*}{2\beta\Lambda^*}\;e^{-\Lambda^*\tau}\;P_o(\gamma-\Lambda^*,\beta,\tau)$$

$$+ \frac{1}{2\beta\Lambda^*}\,(1-e^{-\Lambda^*\tau}) \;. \tag{96}$$

The expressions for $V_1(\tau)$, $V_2(\tau)$, $V_3(\tau)$, $V_4(\tau)$ and $V_5(\tau)$ can be expressed in a functionally simpler manner as

$$V_1(\Lambda^*,\Lambda_1,\tau) = \frac{V_4(\Lambda^*,\Lambda_1-\alpha,\beta,\tau) - e^{-\Lambda^*\tau}Q_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau)}{\Lambda_1},$$

$$V_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{V_o(\Lambda^*,\Lambda_1,\tau) - V_4(\Lambda^*,\Lambda_1-\alpha,\beta,\tau) + \alpha V_1(\Lambda^*,\Lambda_1,\tau)}{2\beta},$$

$$V_3(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{V_1(\Lambda^*,\Lambda_1,\tau) - V_5(\Lambda^*,\Lambda_1-\alpha,\beta,\tau) + \alpha V_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau)}{2\beta},$$

$$V_4(\Lambda^*,\gamma,\beta,\tau) = \frac{P_o(\gamma,\beta,\tau) - e^{-\Lambda^*\tau}\;Q_4(\Lambda^*,\gamma,\beta,\tau)}{\Lambda^*}, \text{ and}$$

$$V_5(\Lambda^*,\gamma,\beta,\tau) = \frac{\hat{P}_o(\Lambda^*,\tau) - \gamma V_4(\Lambda^*,\gamma,\beta,\tau) - e^{-\Lambda^*\tau}\;Q_4(\Lambda^*,\gamma,\beta,\tau)}{2\beta}, \tag{97}$$

where we have used the identity $\gamma = \Lambda_1 - \alpha$ from Eq. (73).

Finally we remark that the integrals for $V_2(\tau)$, $V_3(\tau)$ and $V_5(\tau)$ given in Eq. (97) in the $\beta = 0$ limit are finite and independent of β. The contribution from $B_k V_k(\tau)$ for $k = 2,3,5$ therefore vanishes for $\beta = 0$ since those B_k have a factor β in them. The other limiting forms are handled correctly using the limiting forms for $P_o(\gamma,\beta,\tau)$ and $V_o(\Lambda^*,\Lambda_1,\tau)$ given in Appendices A and B.

As we shall see in Section IV, comparison of these four models indicates that the Constant Release-Renormalized model is adequate for the calculation of the release to the coolant and from the containment building.

III. CALCULATIONAL DATA BASE

The calculational data base for LARC-1 is composed of the following: (a) Temperature modeling, (b) Fission product release rates, (c) Particle coating fuel failure fractions, and (d) Aged particle coating fuel fracture fraction. Each of these is discussed in detail including the form and parameters used in the analytic fits as well as the graphic representations generated from the fits.

A. Temperature Modeling

The temperature modeling of LARC-1 is represented as a function of core volume fraction (x) and time (t). Four different models are available at present.

The first three models are based on data obtained from SORS,[2] CORCON,[3] and AYER.[4,5] These models involve three different calculations of the maximum and average temperature as a function of the time from the beginning of an LOFC. The temperature shape as a function of core volume fraction was obtained graphically from GASSAR.[6] A simple scaling law is used to construct T(x,t) from T(t) and T(x).

The fourth model is obtained from an inversion of the data made available from recent AYER calculations.[7] The core volume fraction at time t with temperature above T is transformed into T(x,t).

1. Temperature vs Core Volume Fraction

The fuel temperature, T(x), vs the core volume fraction x, or "fraction of the fuel volume above indicated temperature at rated power" is given graphically in the GASSAR report.[6] That graph was read and interpolated for a number of core volume fraction points, given in Table I.

TABLE I

GASSAR DATA T(x) vs x

x	T(x) K
0	1699.82
0.01	1588.71
0.03333	1479.26
0.06666	1402.59
0.1	1347.59
0.2	1255.37
0.3	1205.37
0.4	1173.41
0.5	1147.04
0.6	1127.59
0.7	1104.26
0.8	1079.08
0.9	1044.26
1.0	922.04

Originally a simple analytic polynominal fit to the data was used. That technique had an accuracy of about 1% in T(x), but did not have dT/dx continuous across fit boundaries, of which there were several.

However, with the implementation of a general one-dimensional spline method,[8-10] the accuracy of the fits is maintained, dT/dx is smooth, and d^2T/dx^2 is continuous.

The average temperature $\overline{T}$ is used in scaling and is determined from numerical integration of the spline representation as

$$\overline{T} = \int_0^1 T(x)dx = 1174.4 \text{ K} \cdot \qquad (98)$$

A graphic display of the spline representation of T(x) is given in Fig. 1.

2. SORS Data

The maximum and average temperature, $T_{MAX}(t)$ and $T_{AVG}(t)$, are displayed graphically in Fig. 6-2 of the SORS report[2] for a 3000 MW(t) reactor for lumped fuel/graphite temperature vs time. That graph was read and interpolated for $T_{MAX}(t)$ and $T_{AVG}(t)$ at a number of time points given in Table II.

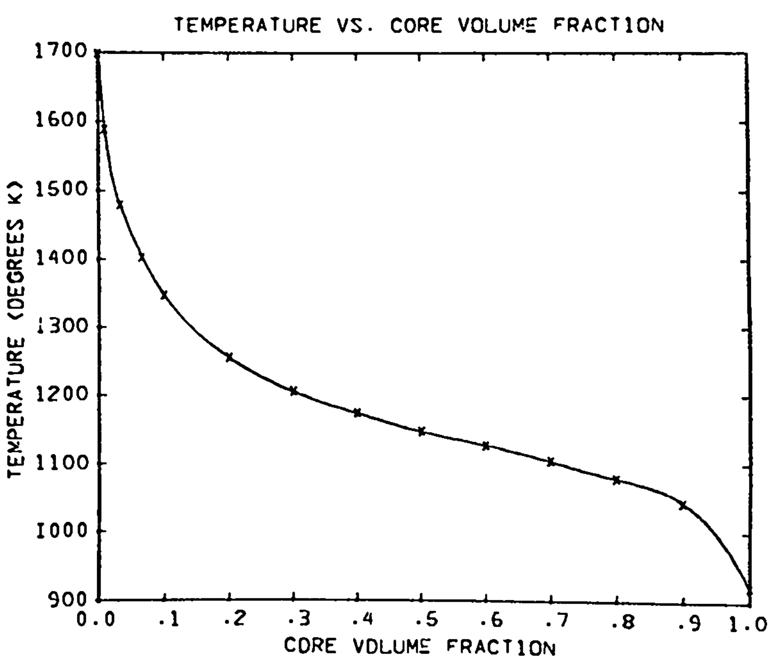


Fig. 1. Temperature vs core volume fraction.

TABLE II

SORS TEMPERATURE DATA

t(h)	T_{MAX}(K)	t(h)	T_{AVG}(K)
0	1227.59	0	1088.71
1.3	1644.26	1.1	1366.48
2.3	1922.04	2.5	1644.26
3.5	2199.82	4.2	1922.04
5	2477.59	6.3	2199.82
6.92	2755.37	10.0	2477.59
9.42	3033.15	14.8	2755.37
12.3	3310.93	22.5	3033.15
17.3	3588.71	34.6	3310.93
26.5	3922.04	40.0	3374.42
40.0	3922.04	50.0	3459.08

We note that the SORS data as given in Ref. (2) does not have a maximum temperature exceeding the graphite sublimation temperature (3925 K).

The results of the spline representation[9] of the data of Table II are displayed in Fig. 2.

3. CORCON Data

The maximum and average temperature, $T_{MAX}(t)$ and $T_{AVG}(t)$, are given in Table 6-4 of the CORCON report.[3] This data is reproduced in LARC-1 units in Table III.

The results of the spline representation of the data of Table III are displayed in Fig. 3.

We note that in Fig. 3 there is a depression of the $T_{MAX}(t)$ and $T_{AVG}(t)$ curves in the time range $1 < t < 5$ h of the

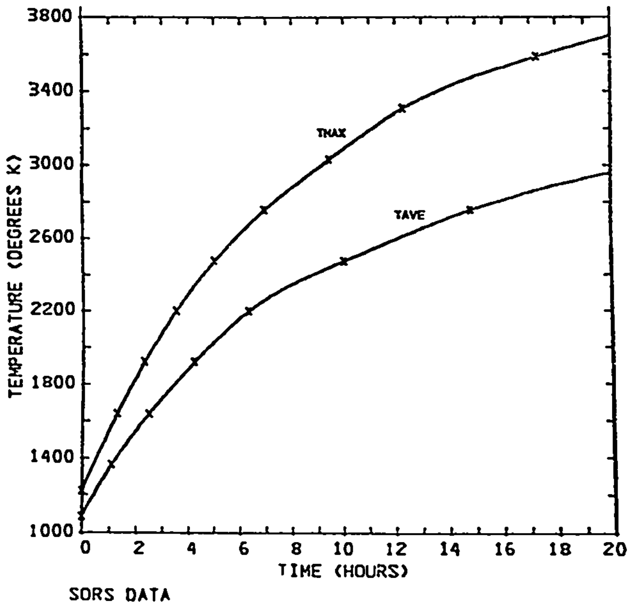


Fig. 2. Temperature vs time after LOFC, SORS graphic data.

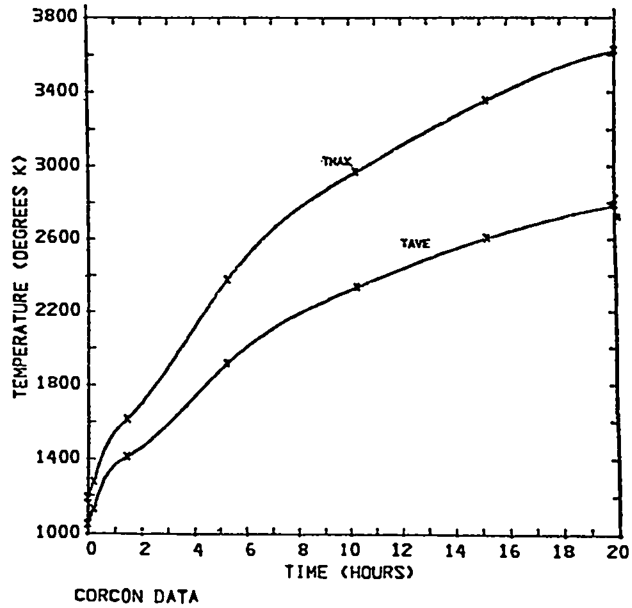


Fig. 3. Temperature vs time after LOFC, CORCON tabular data.

TABLE III

CORCON TEMPERATURE DATA

t(h)	T_{MAX}(K)	T_{AVG}(K)
0	1192.59	1052.59
0.0083	1192.59	1052.59
0.2167	1280.37	1134.82
1.45	1618.15	1413.71
5.25	2379.26	1920.37
10.25	2969.82	2338.71
15.25	3358.71	2608.71
20.25	3630.37	2793.71
25.25	3665.37	2938.15
30.25	3665.37	3026.48

CORCON data relative to the SORS data shape, Fig. 2. In general, after t = 1 h the CORCON data has lower temperatures, with differences upwards of 150 K, than SORS for both $T_{MAX}(t)$ and $T_{AVG}(t)$.

4. AYER Data

The maximum and average temperatures, $T_{MAX}(t)$ and $T_{AVG}(t)$ are reproduced in Table IV from AYER data.[4,5]

The results of the spline representation of the data of Table IV are displayed in Fig. 4.

We note that for this data $T_{MAX}(t)$ attains and exceeds the graphite sublimation temperature at 17 h.

Comparing the AYER to SORS temperature histories we note that $T_{MAX}(t)_{AYER} < T_{MAX}(t)_{SORS}$ for $0 < t < 15$ h and $T_{AVG}(t)_{AYER} < T_{AVG}(t)_{SORS}$ for $0 < t < 20$ h, with temperature differences of the order of 50-200 K. After 15 h, $T_{MAX}(t)_{AYER} > T_{MAX}(t)_{SORS}$ until $t \sim 20$ h when the 2 models are equal.

Comparing the AYER and CORCON temperature histories we note that $T_{MAX}(t)_{AYER} < T_{MAX}(t)_{CORCON}$ for $0 < t < 10.5$ h with a maximum difference of approximately 100 K. For $10.5 < t < 20$ h, $T_{MAX}(t)_{AYER} > T_{MAX}(t)_{CORCON}$ with a maximum difference of almost 200 K occurring at 17 h. $T_{AVG}(t)$, on the other hand, for AYER and CORCON data differ by less than 50 K over the range $0 < t < 20$ h. AYER is first lower than CORCON ($0 < t < 1.8$ h), then higher ($1.8 < t < 4.5$ h), then lower ($4.5 < 5 < 15$ h), and, finally higher ($15 < t < 20$ h).

5. Computation of T(x,t) for Models 1, 2, and 3

Using the temperature vs core volume fraction data, by spline interpolation we find $T(x)$ for any x in the range $0 \leq x \leq 1$. The average temperature is given by $\overline{T} = 1174.4$ K from Eq. (98).

From the spline representations of $T_{MAX}(t)$ and $T_{AVG}(t)$ we find these quantities at any time t by spline interpolation.

In order to determine $T(x,t)$ we use a simple scaling law given by

$$T(x,t) = \frac{T_{MAX}(t) - T_{AVG}(t)}{T(0) - \overline{T}} [T(x) - \overline{T}] + T_{AVG}(0) \quad . \qquad (99)$$

TABLE IV

AYER TEMPERATURE DATA

t(h)	T_{MAX}(K)	T_{AVG}(K)
0.2	1199	1167
0.4	1278	1219
0.5	1315	1243
1.0	1461	1338
1.5	1589	1421
2.0	1704	1496
2.5	1810	1566
3.0	1908	1631
3.5	2002	1692
4.0	2091	1749
4.5	2176	1804
5.0	2257	1856
5.5	2335	1906
6.0	2411	1954
6.5	2483	1999
7.0	2554	2044
8.0	2687	2126
9.0	2815	2204
10.	2936	2278
11.	3053	2347
12.	3165	2414
13.	3273	2477
14.	3376	2538
15.	3475	2596
16.	3570	2653
17.	3663	2707
18.	3636	2756
19.	3664	2801
20.	3665	2840

This form scales the maximum to average difference of the T(x) curve to match the maximum to average difference of a model at time t.

The function T(x,t) and the isotherms are displayed for $0 < x < 1$, $0 \leq t \leq 20$ h in Fig. 5-10 for the SORS (Model 1), CORCON (Model 2) and AYER (Model 3) data.

6. AYER Fu-Cort Data

Data was available for $x = x(T,t)$ from recent results of the AYER code[4,7] in which the core volume was divided into 112 elements. Reinterpreting this data as the function T(x,t) and supplying additional interpolated points, we constructed the tabular values for T(x,t) given in Table V.

Performing a two-dimensional spline fit we calculate T(x,t) for any (x,t) in the range $0 \leq x \leq 1$, $0 < t < 20$ h by spline interpolation.

The T(x,t) and isotherms are displayed for Model 4 in Figs. 11 and 12.

Comparing Model 4 to Models 1-3 for the temperature field T(x,t), Figs. 5,7,9, and 11, we note that Model 4 maintains a larger fraction of the core ($x = 1$) at a lower temperature than the other models. Models 1-3, on the other hand exhibit a rise and then a decrease in the temperature as a function of time near $x = 1$. Maintaining any significant fraction of the core at a uniformly low temperature during a LOFC would seem to need further justification. As we shall see later, it results in a considerable reduction in the release to the coolant for $t > 9$ h.

B. Fission Product Release Rates

The graphic data for fission product release rates as a function of temperature (T) in the SORS[2] and GASSAR[12] reports has been fitted to Arrhenius relations of the form

$$r(T) = \alpha e^{-\beta/T} \tag{100}$$

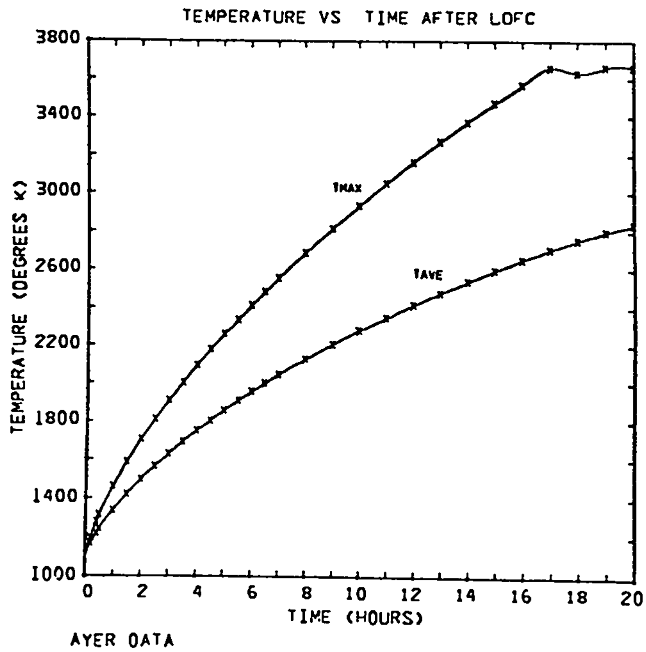
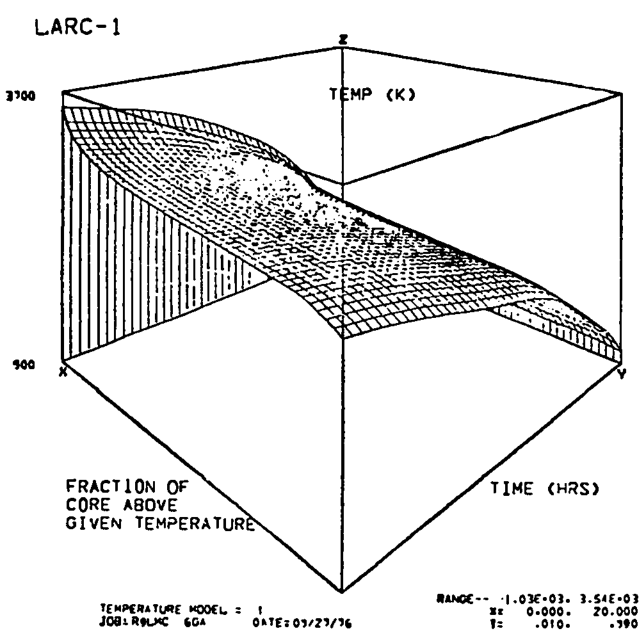


Fig. 4. Temperature vs time after LOFC, AYER tabular data.



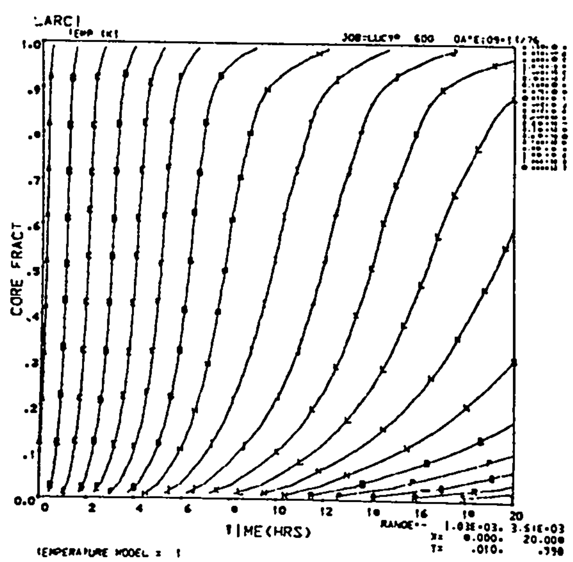


Fig. 5. Temperature model 1 vs time (x) and core volume fraction (y).

Fig. 6. Contours of temperature model 1 vs time (x) and core volume fraction (y).

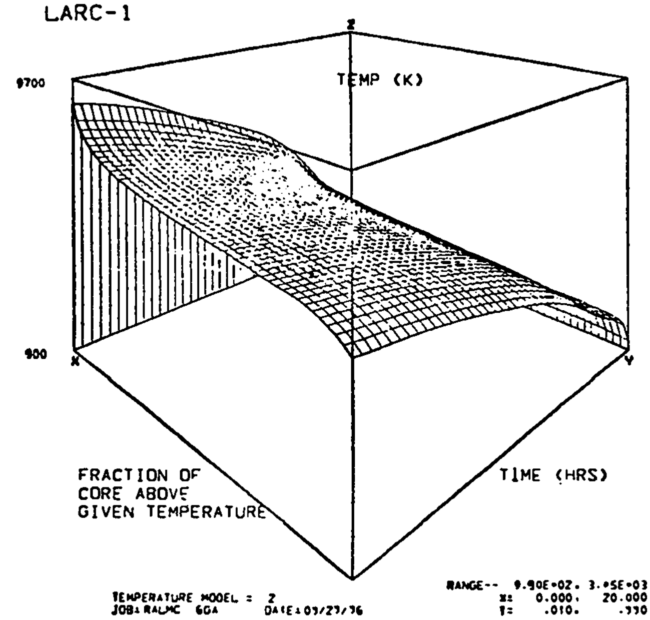


Fig. 7. Temperature model 2 vs time (x) and core volume fraction (y).

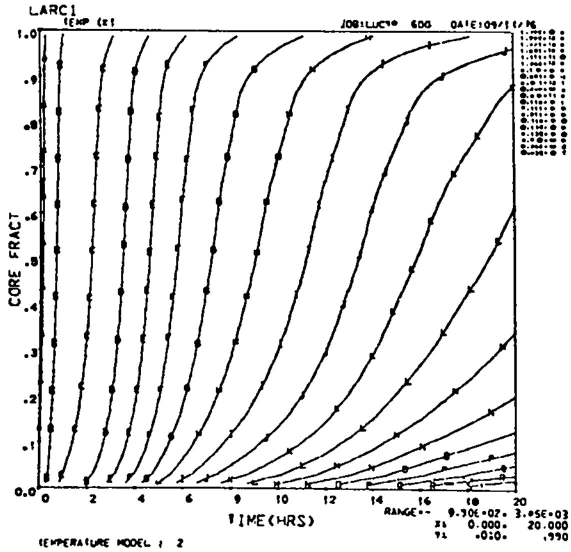


Fig. 8. Contours of temperature model 2 vs time (x) and core volume fraction (y).

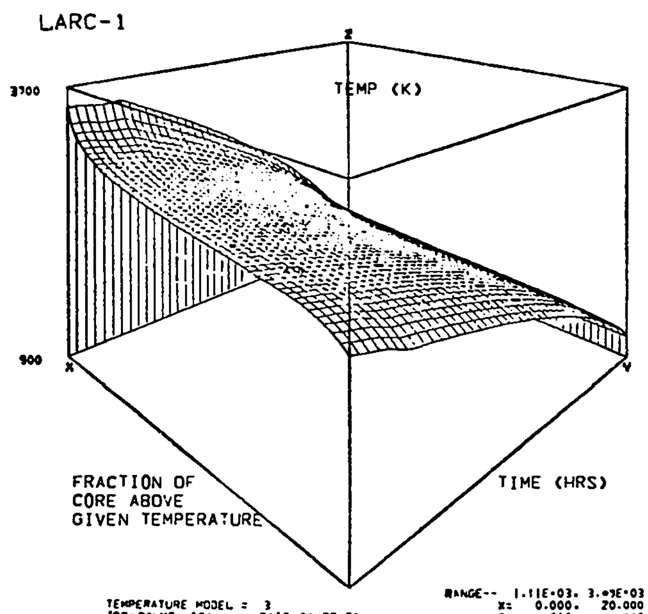


Fig. 9. Temperature model 3 vs time (x) and core volume fraction (y).

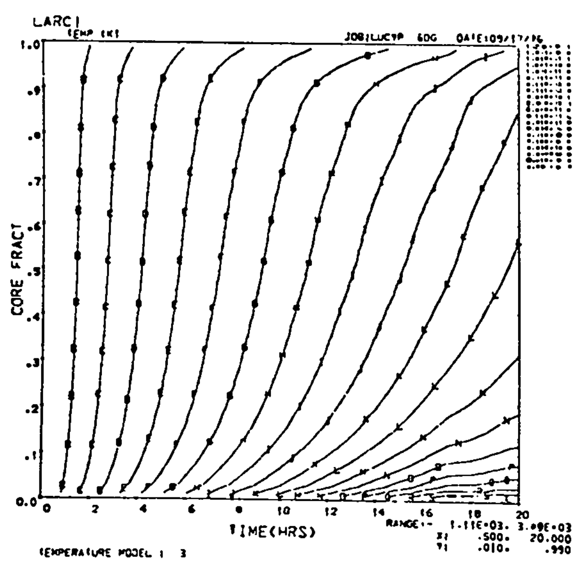


Fig. 10. Contours of temperature model 3 vs time (x) and core volume fraction (y).

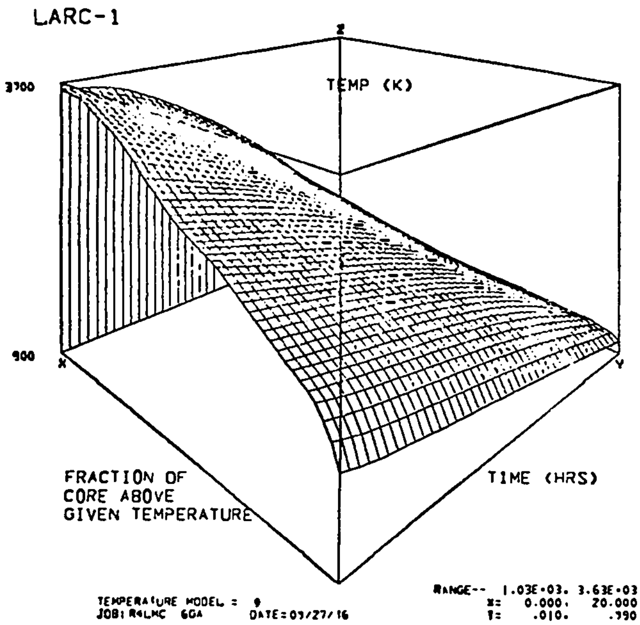


Fig. 11. Temperature model 4 vs time (x) and core volume fraction (y).

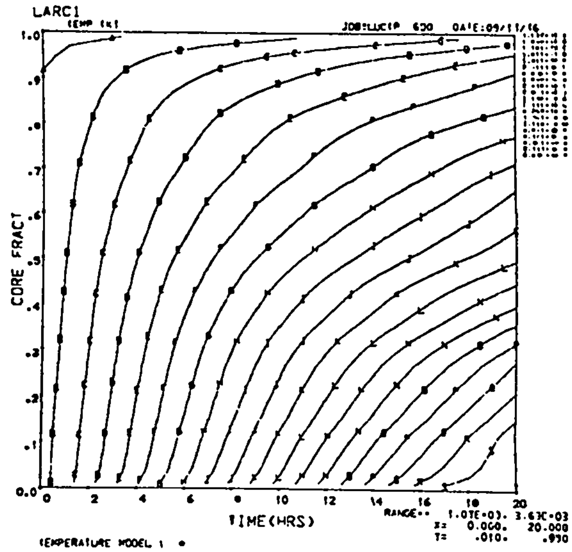


Fig. 12. Contours of temperature model 4 vs time (x) and core volume fraction (y).

for intact and failed particle coatings. The isotopes have been arranged in the 10 groupings as used by SORS, and listed in Table VI.

In the SORS data, the effects of BISO and TRISO particles have been "added for a conservative estimate."[2] In the GASSAR data, BISO and TRISO release rates are distinguished in some instances.

The fitted parameters for the SORS and GASSAR data are given in Tables VII and VIII, where the parameters are further subdivided as intact or failed. In the case of GASSAR parameters a subscript B (BISO) or T (TRISO) on the group index further distinguishes the release rate parameters.

The release rates using the parameters of Table VI-VIII are displayed graphically in Figs. 13-15. The SORS data is denoted as the Ft. St. Vrain fuel model.

TABLE V

TEMPERATURE VS TIME AND CORE FRACTION INDEX I, $I = \frac{\text{CORE FRACTION}}{112} + 1$
(Interpolated Fu-Cort Data)

I	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h
1	1455	1694	1895	2073	2236	2387	2526	2657	2782	2901	3016	3126	3232	3333	3431	3525	3616	3624	3630	3634
2	1454	1666	1861	2041	2206	2359	2501	2634	2760	2881	2996	3106	3211	3310	3402	3485	3553	3590	3613	3633
3	1452	1651	1841	2019	2184	2338	2481	2615	2743	2863	2979	3088	3192	3289	3378	3456	3519	3565	3600	3631
4	1450	1642	1828	2003	2168	2321	2465	2600	2727	2848	2963	3073	3176	3272	3358	3434	3497	3548	3590	3629
5	1448	1636	1819	1992	2155	2308	2452	2586	2714	2834	2949	3058	3161	3256	3342	3417	3481	3535	3582	3626
6	1446	1632	1811	1983	2145	2297	2440	2574	2701	2822	2936	3045	3147	3242	3327	3403	3468	3525	3575	3623
7	1444	1627	1805	1975	2136	2288	2430	2564	2690	2810	2924	3032	3134	3228	3314	3390	3457	3515	3569	3620
8	1442	1624	1800	1969	2128	2279	2420	2553	2680	2799	2913	3020	3121	3215	3301	3378	3446	3507	3563	3617
9	1440	1620	1795	1962	2121	2271	2411	2544	2669	2788	2901	3008	3109	3203	3289	3366	3436	3499	3558	3615
10	1438	1617	1790	1957	2114	2263	2403	2535	2660	2778	2890	2996	3096	3190	3276	3355	3426	3491	3552	3612
11	1436	1613	1786	1951	2108	2256	2395	2526	2650	2768	2879	2984	3084	3177	3264	3343	3415	3483	3546	3609
12	1434	1610	1782	1946	2102	2249	2387	2518	2641	2757	2868	2973	3071	3164	3251	3331	3405	3474	3540	3606
13	1432	1607	1778	1941	2096	2242	2380	2509	2632	2747	2857	2960	3059	3151	3238	3318	3393	3464	3534	3603
14	1430	1604	1774	1936	2090	2235	2372	2501	2622	2737	2845	2948	3046	3138	3224	3305	3381	3454	3525	3600
15	1428	1602	1770	1932	2085	2229	2364	2492	2612	2726	2834	2936	3032	3124	3210	3291	3368	3441	3513	3586
16	1427	1599	1767	1927	2079	2222	2357	2483	2603	2715	2822	2923	3019	3110	3196	3277	3354	3428	3500	3571
17	1425	1597	1763	1923	2074	2216	2349	2475	2593	2705	2811	2911	3006	3097	3182	3263	3340	3414	3486	3557
18	1423	1594	1760	1918	2068	2209	2342	2467	2584	2695	2800	2899	2994	3084	3169	3249	3326	3400	3472	3543
19	1421	1591	1756	1914	2063	2203	2335	2459	2575	2685	2789	2888	2982	3071	3156	3236	3312	3386	3457	3528
20	1419	1588	1753	1910	2058	2197	2328	2451	2567	2676	2779	2877	2970	3059	3143	3223	3299	3372	3444	3514
21	1417	1586	1749	1905	2053	2191	2321	2443	2558	2667	2769	2867	2959	3047	3131	3210	3286	3359	3430	3500
22	1415	1583	1746	1901	2048	2186	2315	2436	2550	2658	2760	2856	2948	3036	3119	3198	3274	3346	3417	3487

TABLE V(cont)

23	1413	1580	1742	1897	2043	2180	2308	2429	2542	2649	2750	2846	2938	3025	3108	3186	3261	3334	3405	3475
24	1410	1577	1738	1892	2038	2174	2302	2422	2534	2640	2741	2836	2927	3014	3096	3174	3249	3321	3392	3462
25	1408	1574	1735	1888	2033	2168	2295	2414	2526	2632	2732	2827	2917	3002	3084	3162	3237	3309	3380	3450
26	1405	1570	1731	1884	2028	2163	2289	2407	2518	2623	2723	2817	2906	2991	3072	3149	3224	3296	3367	3437
27	1402	1567	1727	1879	2023	2157	2283	2400	2511	2615	2713	2807	2895	2979	3060	3137	3211	3283	3354	3425
28	1400	1564	1723	1875	2018	2152	2277	2394	2503	2607	2704	2796	2884	2968	3047	3124	3198	3270	3341	3412
29	1398	1561	1720	1871	2013	2146	2271	2387	2496	2598	2695	2786	2873	2956	3035	3111	3185	3257	3329	3400
30	1396	1559	1716	1867	2008	2141	2264	2380	2488	2590	2685	2775	2861	2943	3022	3098	3171	3244	3316	3390
31	1394	1556	1713	1862	2003	2135	2258	2373	2480	2581	2675	2765	2849	2931	3008	3084	3157	3229	3302	3375
32	1392	1553	1709	1858	1998	2129	2251	2365	2472	2571	2665	2753	2837	2918	2995	3069	3142	3214	3286	3360
33	1390	1550	1706	1854	1993	2123	2244	2357	2463	2561	2654	2742	2825	2904	2980	3054	3126	3197	3268	3340
34	1388	1547	1702	1849	1987	2116	2237	2349	2453	2551	2643	2730	2812	2890	2965	3037	3108	3179	3249	3320
35	1386	1545	1698	1844	1981	2109	2229	2340	2444	2541	2632	2717	2798	2875	2949	3020	3090	3160	3230	3300
36	1384	1542	1694	1839	1975	2102	2221	2331	2434	2530	2620	2704	2784	2860	2932	3002	3072	3141	3210	3280
37	1382	1539	1690	1834	1969	2095	2213	2322	2424	2519	2608	2691	2769	2844	2915	2984	3053	3122	3191	3260
38	1380	1536	1686	1829	1963	2088	2205	2313	2414	2508	2596	2677	2754	2827	2897	2966	3034	3102	3171	3240
39	1378	1533	1682	1824	1957	2081	2197	2304	2404	2497	2583	2663	2739	2811	2880	2947	3015	3082	3151	3220
40	1376	1530	1678	1819	1951	2074	2189	2295	2393	2485	2570	2649	2723	2794	2862	2929	2995	3062	3130	3200
41	1374	1527	1674	1814	1945	2067	2181	2285	2383	2473	2557	2635	2708	2778	2845	2911	2976	3042	3109	3180
42	1372	1524	1670	1809	1939	2060	2172	2276	2372	2461	2543	2621	2693	2762	2828	2893	2957	3020	3082	3140
43	1371	1521	1666	1804	1933	2053	2164	2266	2361	2449	2531	2607	2679	2747	2812	2876	2938	3000	3061	3120
44	1369	1518	1662	1799	1927	2045	2155	2257	2350	2437	2518	2594	2665	2732	2797	2860	2921	2982	3041	3100

TABLE V (cont)

45	1367	1515	1658	1793	1920	2038	2147	2247	2340	2426	2506	2581	2651	2718	2782	2844	2904	2964	3022	3080
46	1365	1512	1654	1788	1913	2030	2138	2237	2329	2414	2494	2568	2638	2705	2768	2829	2888	2946	3003	3060
47	1363	1509	1649	1782	1907	2022	2129	2227	2319	2403	2482	2556	2625	2691	2754	2814	2872	2929	2985	3040
48	1361	1505	1645	1777	1900	2014	2120	2217	2308	2392	2470	2543	2612	2678	2739	2799	2856	2911	2966	3020
49	1359	1502	1640	1771	1893	2006	2111	2208	2297	2380	2458	2531	2599	2664	2725	2783	2839	2894	2947	3000
50	1358	1500	1636	1766	1887	1998	2102	2197	2286	2368	2445	2517	2585	2649	2709	2767	2822	2876	2928	2980
51	1356	1497	1632	1760	1880	1991	2093	2187	2275	2356	2432	2504	2571	2634	2693	2750	2804	2857	2909	2960
52	1354	1494	1628	1755	1874	1983	2084	2177	2264	2344	2419	2489	2555	2617	2676	2732	2786	2838	2889	2940
53	1352	1491	1624	1750	1867	1975	2075	2167	2252	2331	2405	2474	2539	2600	2658	2713	2766	2818	2869	2920
54	1350	1488	1620	1744	1860	1967	2066	2156	2240	2318	2391	2458	2522	2582	2639	2694	2747	2799	2849	2900
55	1348	1484	1615	1739	1853	1959	2056	2145	2228	2305	2376	2442	2505	2564	2621	2675	2728	2779	2830	2880
56	1346	1481	1611	1732	1846	1950	2046	2134	2216	2291	2361	2426	2488	2547	2603	2657	2709	2760	2810	2860
57	1344	1477	1606	1726	1838	1941	2036	2123	2203	2278	2347	2411	2472	2530	2585	2639	2691	2742	2791	2840
58	1342	1474	1600	1719	1830	1932	2025	2112	2191	2264	2332	2396	2457	2514	2569	2623	2674	2724	2773	2820
59	1340	1470	1595	1713	1822	1922	2015	2100	2178	2251	2319	2382	2442	2500	2554	2607	2658	2708	2755	2800
60	1338	1467	1590	1706	1814	1913	2004	2088	2166	2238	2305	2369	2429	2486	2540	2593	2644	2693	2741	2787
61	1336	1463	1585	1699	1806	1904	1994	2077	2154	2225	2292	2355	2415	2472	2527	2579	2630	2679	2727	2775
62	1334	1460	1580	1693	1798	1894	1983	2065	2141	2212	2279	2342	2401	2458	2513	2565	2616	2666	2714	2762
63	1332	1456	1575	1687	1790	1886	1973	2054	2129	2200	2265	2328	2387	2444	2499	2551	2602	2652	2701	2750
64	1330	1453	1570	1680	1783	1877	1964	2043	2118	2187	2252	2314	2373	2430	2484	2536	2588	2638	2688	2737
65	1328	1449	1565	1675	1776	1869	1954	2033	2106	2175	2239	2300	2359	2415	2469	2521	2573	2623	2674	2725
66	1326	1446	1561	1669	1769	1861	1945	2023	2095	2163	2226	2286	2344	2399	2453	2506	2557	2609	2661	2712
67	1324	1443	1556	1663	1762	1853	1936	2013	2085	2151	2214	2273	2330	2385	2438	2490	2542	2595	2647	2700

TABLE V (cont)

68	1322	1439	1551	1657	1755	1845	1928	2004	2075	2141	2202	2261	2317	2370	2423	2475	2527	2580	2634	2687
69	1320	1436	1547	1651	1748	1837	1919	1995	2065	2130	2191	2249	2303	2357	2408	2460	2513	2566	2620	2675
70	1318	1432	1542	1645	1741	1829	1911	1986	2055	2119	2180	2236	2291	2343	2394	2446	2498	2552	2607	2662
71	1316	1429	1537	1639	1733	1821	1901	1976	2044	2108	2168	2224	2277	2329	2380	2431	2484	2538	2594	2650
72	1314	1425	1532	1632	1726	1812	1892	1965	2033	2096	2155	2211	2264	2315	2365	2416	2469	2524	2580	2637
73	1312	1421	1526	1625	1717	1803	1882	1954	2021	2084	2142	2197	2250	2300	2351	2402	2454	2510	2567	2625
74	1310	1417	1521	1618	1709	1793	1871	1943	2009	2071	2129	2183	2235	2286	2336	2386	2440	2495	2553	2612
75	1308	1414	1515	1611	1701	1783	1860	1931	1996	2058	2115	2169	2221	2271	2320	2371	2424	2480	2538	2600
76	1306	1410	1510	1604	1692	1774	1849	1919	1984	2044	2101	2155	2206	2256	2305	2356	2409	2464	2521	2580
77	1304	1406	1504	1597	1684	1764	1839	1908	1972	2032	2088	2141	2192	2241	2291	2341	2393	2447	2503	2560
78	1302	1402	1499	1590	1676	1755	1829	1897	1960	2019	2075	2128	2178	2228	2277	2326	2378	2431	2485	2540
79	1300	1398	1493	1584	1668	1746	1819	1887	1949	2008	2063	2115	2166	2215	2263	2312	2363	2414	2467	2520
80	1296	1394	1488	1577	1661	1738	1810	1877	1939	1997	2052	2104	2154	2204	2250	2299	2348	2398	2449	2500
81	1292	1389	1482	1571	1653	1730	1802	1868	1929	1987	2042	2093	2143	2191	2238	2286	2334	2382	2431	2480
82	1288	1384	1477	1564	1646	1723	1793	1859	1920	1978	2032	2083	2132	2180	2227	2273	2320	2366	2413	2460
83	1284	1379	1471	1558	1640	1715	1785	1851	1911	1969	2022	2073	2122	2169	2215	2261	2306	2350	2395	2440
84	1280	1375	1466	1552	1633	1708	1778	1842	1903	1959	2013	2063	2112	2158	2204	2248	2291	2334	2377	2420
85	1276	1370	1460	1546	1626	1701	1770	1834	1894	1950	2003	2053	2101	2147	2192	2235	2277	2318	2359	2400
86	1272	1365	1455	1540	1619	1693	1762	1825	1885	1940	1993	2042	2090	2135	2179	2221	2262	2302	2341	2380
87	1268	1361	1450	1534	1613	1686	1753	1816	1875	1930	1982	2031	2078	2122	2165	2206	2246	2284	2322	2360
88	1264	1356	1444	1528	1606	1678	1745	1807	1865	1919	1970	2018	2064	2108	2150	2191	2229	2267	2303	2340
89	1260	1351	1439	1521	1598	1670	1736	1797	1854	1907	1958	2005	2050	2094	2135	2174	2212	2248	2284	2320
90	1256	1346	1433	1515	1591	1661	1726	1787	1843	1895	1945	1991	2036	2078	2118	2157	2194	2230	2265	2300

TABLE V (cont)

91	1252	1341	1427	1508	1583	1652	1717	1776	1831	1883	1931	1977	2020	2062	2101	2139	2176	2211	2246	2280
92	1248	1336	1421	1501	1575	1644	1707	1765	1819	1869	1917	1961	2004	2045	2084	2121	2157	2192	2226	2260
93	1244	1331	1415	1494	1567	1634	1696	1753	1806	1855	1902	1945	1987	2027	2066	2103	2138	2173	2207	2240
94	1240	1326	1409	1487	1559	1625	1685	1741	1792	1840	1885	1928	1969	2009	2047	2084	2119	2153	2187	2220
95	1236	1321	1402	1479	1549	1613	1673	1727	1777	1824	1868	1910	1951	1990	2028	2064	2100	2134	2168	2200
96	1232	1315	1395	1470	1538	1601	1659	1712	1761	1806	1850	1891	1931	1970	2008	2044	2080	2115	2149	2183
97	1228	1309	1387	1460	1527	1588	1644	1696	1743	1788	1831	1872	1911	1950	1987	2024	2060	2096	2131	2166
98	1224	1303	1378	1449	1514	1574	1629	1679	1726	1770	1812	1852	1891	1930	1967	2004	2041	2077	2114	2150
99	1220	1296	1369	1437	1501	1559	1613	1662	1708	1752	1793	1833	1872	1909	1947	1984	2021	2058	2096	2134
100	1216	1289	1359	1425	1487	1544	1596	1645	1690	1733	1774	1813	1852	1889	1926	1963	2001	2039	2077	2116
101	1212	1281	1348	1412	1472	1528	1580	1628	1672	1715	1755	1794	1832	1869	1906	1943	1981	2019	2059	2100
102	1208	1273	1337	1399	1457	1512	1562	1610	1654	1696	1735	1774	1811	1848	1884	1922	1959	1998	2039	2080
103	1200	1263	1325	1385	1441	1495	1544	1591	1634	1675	1715	1752	1789	1826	1862	1899	1937	1976	2017	2060
104	1189	1251	1311	1370	1425	1477	1525	1571	1613	1654	1692	1730	1766	1802	1838	1874	1912	1952	1994	2040
105	1178	1238	1297	1353	1407	1457	1504	1548	1590	1630	1667	1704	1740	1775	1810	1846	1884	1924	1968	2020
106	1167	1225	1281	1335	1387	1435	1480	1523	1564	1602	1639	1675	1710	1744	1779	1814	1851	1890	1933	1980
107	1156	1211	1264	1315	1363	1410	1453	1494	1533	1570	1606	1641	1674	1708	1742	1776	1812	1851	1893	1940
108	1145	1195	1243	1291	1336	1379	1420	1459	1497	1532	1567	1600	1633	1665	1698	1731	1767	1805	1848	1895
109	1134	1177	1220	1262	1304	1343	1382	1418	1453	1487	1520	1552	1583	1614	1646	1679	1714	1753	1798	1850
110	1123	1155	1191	1228	1265	1301	1336	1370	1403	1435	1466	1496	1526	1556	1586	1618	1652	1691	1739	1800
111	1110	1127	1158	1189	1221	1254	1286	1317	1347	1376	1405	1434	1462	1491	1520	1550	1582	1620	1667	1730
112	1050	1086	1116	1145	1174	1203	1231	1259	1287	1314	1341	1368	1394	1421	1448	1476	1506	1538	1578	1630
113	1000	1050	1075	1100	1125	1150	1175	1200	1225	1250	1275	1300	1325	1350	1375	1400	1425	1450	1475	1500

TABLE VI

ISOTOPE GROUPING OF RELEASE RATES

Group	Isotopes
1	Sr
2	Cs, Rb
3	Ba, Sm, Eu
4	Ce
5	Xe
6	Kr
7	Zr, Nb, Mo, Te
8	Pm, Nd, Pr, Y, Pd, Sn, La
9	Ru, Rh
10	Se, Br, Te, Sb, I

TABLE VII

SORS RELEASE RATE PARAMETERS

	INTACT		FAILED	
Group	$\alpha (h^{-1})$	$\beta (K)$	$\alpha (h^{-1})$	$\beta (K)$
1	9.7733×10^{-4}	8.2621×10^{3}	1.82889×10^{4}	2.2861×10^{4}
2a	5.3231×10^{9}	5.8360×10^{4}	5.3231×10^{9}	5.8360×10^{4}
	$[\frac{1}{T} < 5.64 \times 10^{-4} (K)^{-1}]$		$[\frac{1}{T} < 5.64 \times 10^{-4} (K)^{-1}]$	
2b	4.6144×10^{-2}	1.3198×10^{4}	4.6144×10^{-2}	1.3198×10^{4}
	$[\frac{1}{T} > 5.64 \times 10^{-4} (K)^{-1}]$		$(5.64 \times 10^{-4} < \frac{1}{T} < 7.59 \times 10^{-4})$	
2c	9.7733×10^{-4}	8.2621×10^{3}	9.7733×10^{-4}	8.2621×10^{3}
			$[\frac{1}{T} > 7.59 \times 10^{-4} (K)^{-1}]$	
3	9.7733×10^{-4}	8.2621×10^{3}	8.9524×10^{3}	2.2657×10^{4}
4	9.7733×10^{-4}	8.2621×10^{3}	2.2317×10^{3}	2.1229×10^{4}
5	9.7733×10^{-4}	8.2621×10^{3}	8.9524×10^{3}	2.2657×10^{4}
6	7.2751×10^{-3}	8.6963×10^{3}	3.9423×10^{4}	2.2435×10^{4}

TABLE VII (cont)

SORS RELEASE RATE PARAMETERS

Group	INTACT $\alpha(h^{-1})$	INTACT $\beta(K)$	FAILED $\alpha(h^{-1})$	FAILED $\beta(K)$
7a	1.7385×10^{3}	3.5259×10^{4}	2.317×10^{3}	2.1229×10^{4}
	$[\frac{1}{T} < 5.33 \times 10^{-4} (K)^{-1}]$			
7b	9.7733×10^{-4}	8.2621×10^{3}		
	$[\frac{1}{T} > 5.33 \times 10^{-4} (K)^{-1}]$			
8	9.7733×10^{-4}	8.2621×10^{3}	2.2317×10^{3}	2.1229×10^{4}
9a	1.10548×10^{4}	3.4207×10^{4}	2.2317×10^{3}	2.1229×10^{4}
	$[\frac{1}{T} < 6.26 \times 10^{-4} (K)^{-1}]$			
9b	9.7733×10^{-4}	8.2621×10^{3}		
	$[\frac{1}{T} > 6.26 \times 10^{-4} (K)^{-1}]$			
10	9.7733×10^{-4}	8.2621×10^{3}	8.9524×10^{3}	2.2657×10^{4}

TABLE VIII

GASSAR RELEASE RATE PARAMETERS

Group	Intact $\alpha(h^{-1})$	Intact $\beta(K)$	Failed $\alpha(h^{-1})$	Failed $\beta(K)$
1_B*	39.3	1.2×10^4	1.5937×10^2	1.1861×10^4
1_T	5.40686	2.5798×10^4	1.5937×10^{-2}	1.1861×10^4
$2_{B,T}$	5.9769×10^2	2.3157×10^4	1.6154×10^6	2.6374×10^4
3_B	1.7191×10^2	1.7858×10^4	1.3192×10^3	1.7782×10^4
3_T	1.2282×10^{-2}	1.4834×10^4	1.3192×10^3	1.7782×10^4
4_B	1.58225×10^5	2.86525×10^4	1.2316×10^6	2.8319×10^4
4_T	5.40686	2.5798×10^4	1.2316×10^6	2.8319×10^4
$5_{B,T}$	1.0742×10^{-2}	1.0313×10^4	1.74925×10^3	1.95451×10^4
$6_{B,T}$	4.427×10^{-2}	1.0482×10^4	1.5004×10^3	1.7662×10^4
$7_{B,T}$	5.40686	2.5798×10^4	1.2316×10^6	2.8319×10^4
8_B	4.427×10^{-2}	1.0482×10^4	1.2316×10^6	2.8319×10^4
8_T	5.40686	2.5798×10^4	1.2316×10^6	2.8319×10^4
9_B	4.427×10^{-2}	1.0482×10^4	1.2316×10^6	2.8319×10^4
9_T	5.40686	2.5798×10^4	1.2316×10^6	2.8319×10^4
10_B	0.10280	1.0314×10^4	2.1494×10^3	1.8175×10^4
10_T	0.10280	1.0314×10^4	7.3605	1.3777×10^4

*B - BISO; T - TRISO; B,T - BISO and TRISO

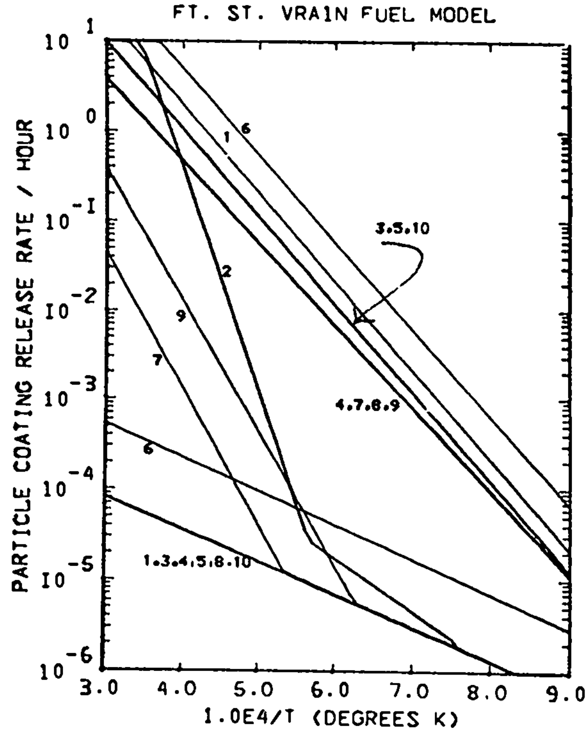


Fig. 13. Fission product release rate vs temperature, SORS data. The upper set of curves gives the release rate for failed particles; the lower set is for intact particles.

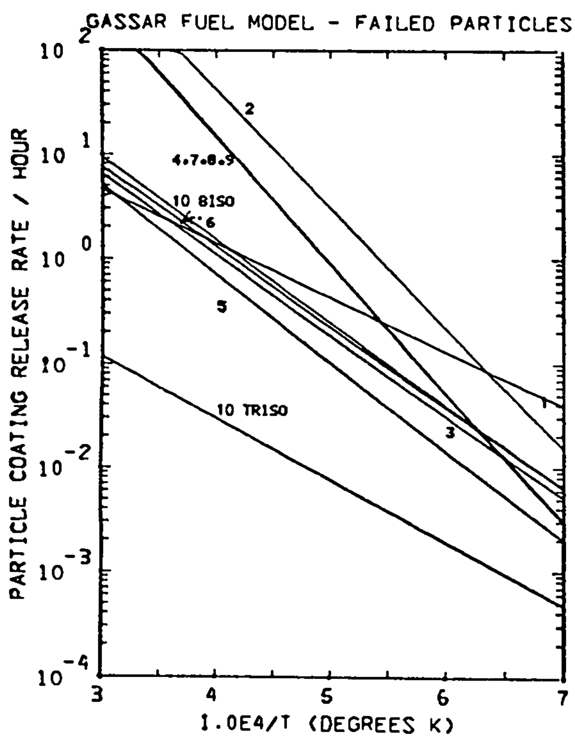


Fig. 14. Fission product release rate vs temperature for failed particles,GASSAR.

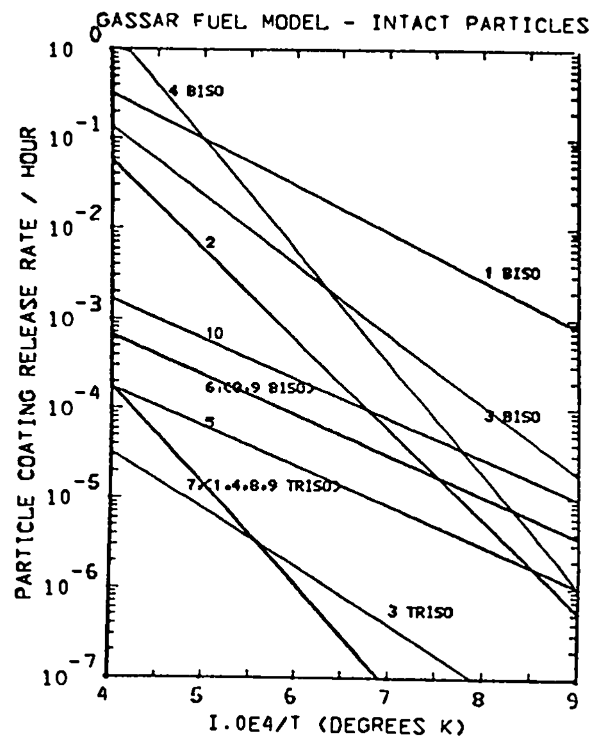


Fig. 15. Fission product release rate vs temperature for intact particles,GASSAR.

C. Fuel Failure Fraction (Particle Coatings)

The BISO and TRISO particle coatings begin to exhibit failure as a function of temperature (T) and age (t:time of a particular fuel rod in the reactor) of irradiation.

Analytic fits and a functional algorithm were developed from the graphic data displayed in the SORS[2] and GASSAR[6] reports for the failed fraction of particle coatings as a function of temperature and age, f(T,t).

SORS: f(T,t)

The SORS data is displayed graphically in Figs.5-1, 5-2 of the SORS report (see also Figs. 16 and 17). The failed fraction is approximated as a linear function of temperature in the partially failed region. The boundaries of no coating failures and 100% coating failures are a function of age and type (BISO, TRISO).

Using these assumptions we may write a simple analytic fit of the data to obtain the failed fraction, f(T,t), as a function of the temperature (T) and the age of the fuel (t) for BISO and TRISO fuels.

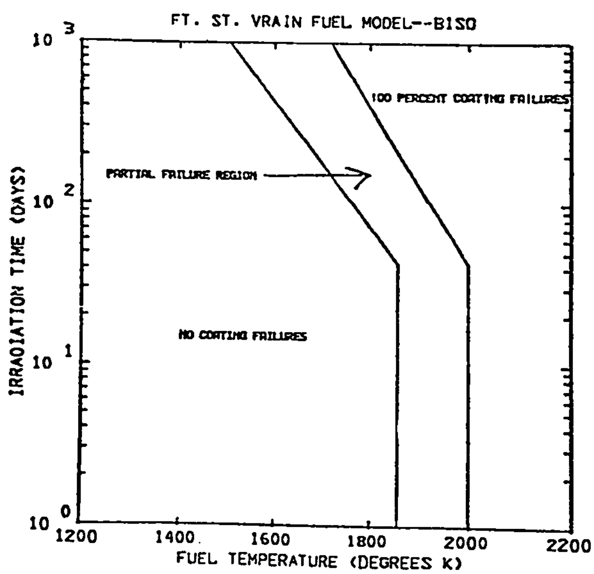


Fig. 16. Fuel failure diagram for BISO particles, SORS data.

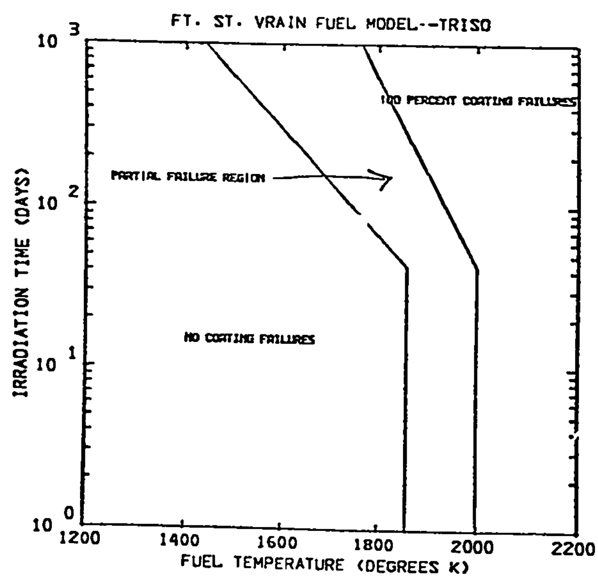


Fig. 17. Fuel failure diagram for TRISO particles, SORS data.

The temperatures for f = 0 (no coating failure) and f = 1 (100% coating failure) at 4 yr and 0.12 yr at the knee of the curves, are given in Table IX. The temperatures for $0 < t < 0.12$ yr are taken to be the same for BISO and TRISO fuels.

For $0 \leq t < 0.12$ yr, the failed fraction can be represented as a linear function of temperature by

$$f = A + BT \quad (101)$$

where the coefficients A and B for BISO and TRISO are given in Table X.

For $0.12 < t < 4$ yr, we fit the f = 0 and f = 1 boundaries by $\alpha_i e^{\beta_i t}$ (i = 0,1) and perform a linear interpolation between the f = 0 and f = 1 boundaries. This approximation leads us to the form

$$f(T,t) = \frac{T(t) - T_0(t)}{T_1(t) - T_0(t)} , \quad (102)$$

where

$$T_i(t) = \alpha_i e^{\beta_i t} \quad (i = 0,1) \quad (103)$$

and the coefficients α_i and β_i for BISO and TRISO are given in Table X.

As is mentioned on page 6-3 of the SORS report,[2] linear fuel failure is assumed with 10% failed fuel at 4 yr. This is an amount that is added to the fraction that fails due to temperature; 2.5%, 5%, 7.5% , and 10% failure is added to the 1 yr-,2 yr-,3 yr- and 4-yr-old-fuel respectively.

Figures 16 through 21 were generated using the above equations and data.

TABLE IX

SORS TEMPERATURES (K) FOR AGED FRACTION FAILURES, f		
Type/f	f = 0	f = 1
BISO:		
0.12 yr	1858.15	1998.15
4 yr	1360.15	1599.15
TRISO:		
0.12 yr	1858.15	1998.15
4 yr	1273.15	1663.15

TABLE X

SORS AGE-TEMPERATURE FUEL FAILURE PARAMETERS

Type	$0 \leq t \leq 0.12$ yr			
	A	10^3B K		
BISO	-13.2725	7.14286		
TRISO	-13.2725	7.14286		
	$0.12 \text{ yr} \leq t \leq 4 \text{ yr}$			
Type	$10^{-3}\alpha_o$(K)	$10^2\beta_o$(yr^{-1})	$10^{-3}\alpha_1$(K)	$10^2\beta_1$(yr^{-1})
BISO	1.87617	8.04098	2.01197	5.74098
TRISO	1.8801	9.74459	2.00953	4.72964

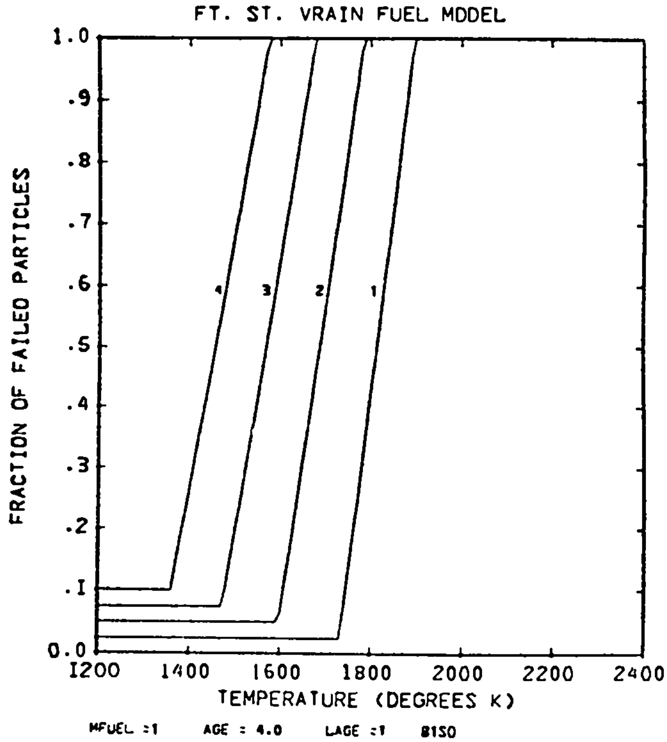


Fig. 18. Fraction of failed particles vs temperature, BISO particles, SORS data. This figure is derived from Fig. 16.

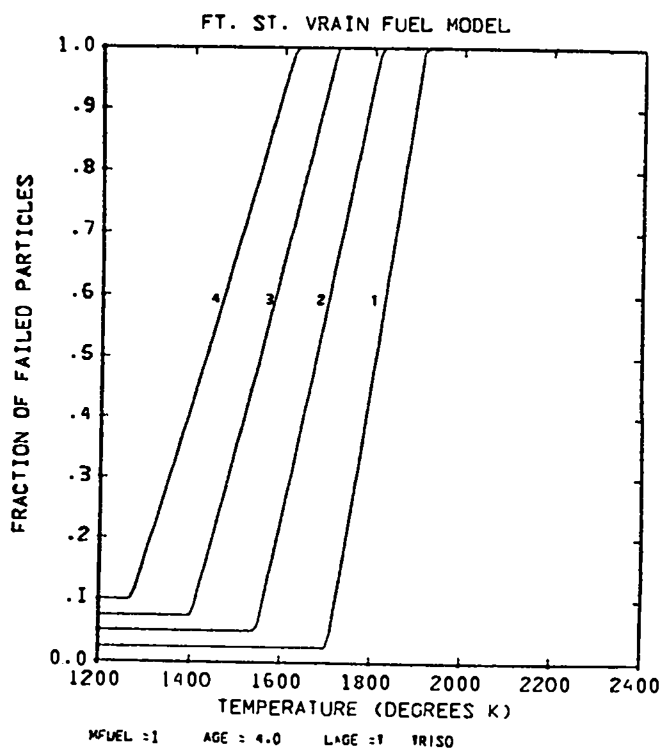


Fig. 19. Fraction of failed particles vs temperature, TRISO particles, SORS data. This figure is derived from Fig. 17.

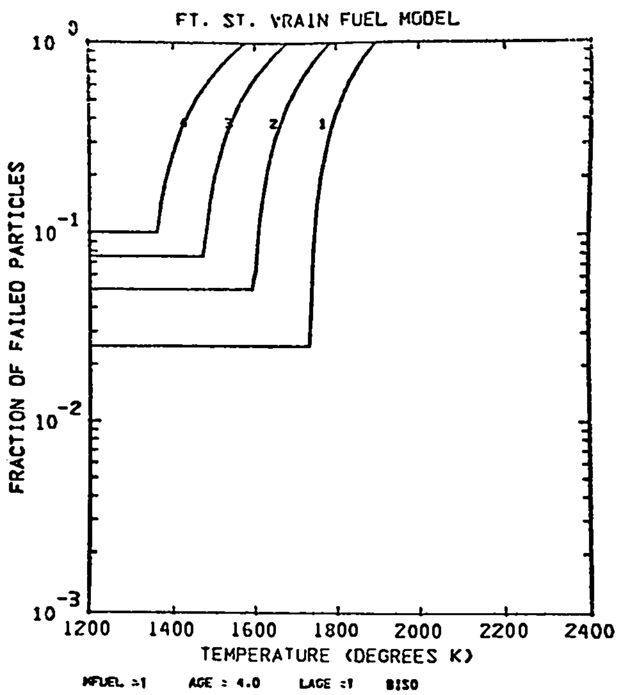


Fig. 20. Log of fraction of failed particles vs temperature, BISO particles, SORS data.

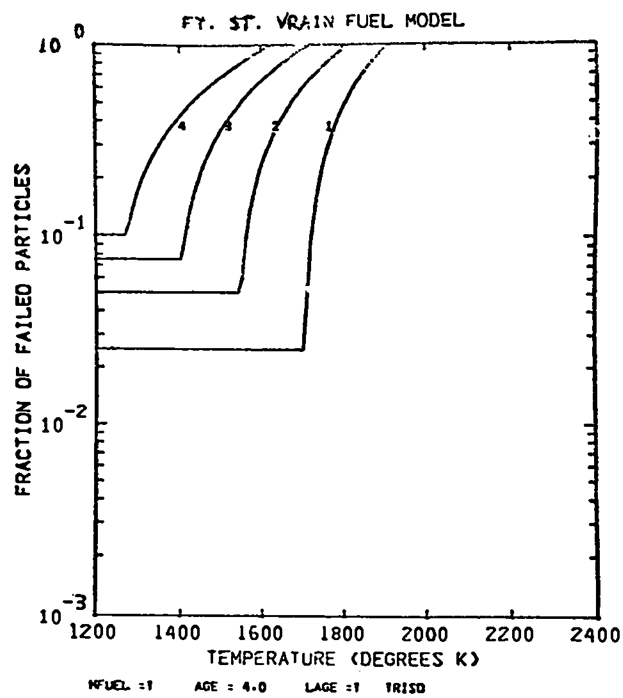


Fig. 21. Log of fraction of failed particles vs temperature, TRISO particles, SORS data.

<u>GASSAR</u>: f(T,t)

The graphic data obtained from Fig. 1 and 2 of the GASSAR report are summarized in Tables XI and XII for various aged fuels and particle coating failed fractions.

For the BISO particle coatings, a spline fit to the data was used below a certain failed fraction, f_o, and temperature T(marked with an asterisk in Table XI). Above f_o, a linear fit of the form

$$f(t) = A + BT \tag{104}$$

was used, where f = 1 if $T \geq T_1$. The BISO parameters A, B and the threshold for the linear fit, f_0, are given in Table XIII.

For the TRISO particle coatings an exponential fit of the form

$$f(t) = \alpha e^{\beta T} \tag{105}$$

TABLE XI

GASSAR BISO PARTICLE COATING FAILED FRACTIONS AND TEMPERATURES FOR VARIOUS AGES

Age = 1 yr		2 yr		3 yr		4 yr	
f	T(K)	f	T(K)	f	T(K)	f	T(K)
0.00179	T≤2073.15	0.00377	T<2073.16	0.00526	T≤1690.15	0.00718	T≤1673.15
0.282	2143.15	0.282	2143.15	0.0059	1743.15	0.0079	1697.15
1.0	2273.15	1.0	2273.15	0.0071	1793.15	0.010	1733.15
				0.0116	1873.15	0.021	1793.15
				0.0185	1917.15	0.0557	1853.15
				0.046	1973.15	0.10	1893.15
				0.057	2000.0	0.222	1973.15
				0.0815*	2073.15	0.4039*	2073.15
				0.10	2083.15	0.649	2153.15
				0.23	2113.15	1.0	2273.15
				1.0	2273.15		

*Linear fit above this fraction and temperature, spline fit below.

TABLE XII

GASSAR TRISO PARTICLE COATING FAILED FRACTIONS AND TEMPERATURES FOR VARIOUS AGES

Age = 1 yr		2 yr		3 yr		4 yr	
f	T(K)	f	T(K)	f	T(K)	f	T(K)
0.00157	1941.15	0.00385	1473.15	0.00601	1473.15	0.00677	1473.15
1.0	2273.15	0.00566	1902.15	0.00942	1888.85	0.0109	1873.15
		1.0	2273.15	1.0	2273.15	1.0	2273.15

TABLE XIII

GASSAR BISO FAILED FRACTION PARAMETERS

Age (yr)	f_o	A	$10^3 B(K)^{-1}$
1	0.00179	-10.3454	4.99105
2	0.00377	-10.3229	4.98115
3	0.0815	- 9.4394	4.5925
4	0.4039	- 5.7751	2.9805

was used for $f \leq f_o$, which corresponds for TRISO to the first row of Table XII. A linear fit of the form

$$f(T) = A + BT \tag{106}$$

was used above f_o, where $f = 1$ if $T \geq T_1$. The TRISO parameters and their temperature ranges are given in Table XIV.

The data described by these analytic fits are displayed for BISO and TRISO in Figs. 22-25.

D. Aged Fuel Failure Fraction (Particle Coatings)

Different segments of the HTGR core have been subjected to different irradiation times, or aging, due to the replacement of 1/4 of the fuel rods each year with new fuel rods.

SORS: For the SORS data, if this replacement process does not occur, we say the fuel is not aged, and the fraction of failed particle coatings is given by

$$\bar{f} = f(T,t) \ , \tag{107}$$

where t is the age in years and Eq. (107) is evaluated using Eqs.(102) and (103) of Section C with the parameters of Table X.

On the other hand, if the fuel replacement process occurs, we say the fuel is aged, and the fraction of failed particle coatings is given by

$$\bar{f} = \frac{1}{4} \sum_{i=1}^{4} f_i^s \, [\theta(t - i + 1) - \theta(t - i)] \ , \tag{108}$$

where t is the age in years, $i = [t] + 1$, and [ ] means "least integer", with

$$f_i^s = \begin{cases} 4f_1 & i = 1 \quad 0 \leq t \leq 1 \\ f_1 + 3f_2 & i = 2 \quad 1 \leq t \leq 2 \\ f_1 + f_2 + 2f_3 & i = 3 \quad 2 \leq t \leq 3 \\ f_1 + f_2 + f_3 + f_4 & i = 4 \quad 3 \leq t \leq 4 \end{cases} \tag{109}$$

TABLE XIV

GASSAR TRISO FAILED FRACTION PARAMETERS

Age (yr)	ΔT(K)	$10^3\alpha$	$10^3\beta(K)^{-1}$	ΔT	A	$10^2\beta(K)^{-1}$
1	<1941.15	1.57		$1941.15<T<2273.15$	5.8361	0.300732
2	<1894.15	0.99966	0.915323	$1894.15<T<2273.15$	4.9638	0.262359
3	<1888.15	1.2240	1.08109	$1888.15<T<2273.15$	4.8593	0.257762
4	<1873.15	1.17176	1.19064	$1873.15<T<2273.15$	4.6209	0.24728

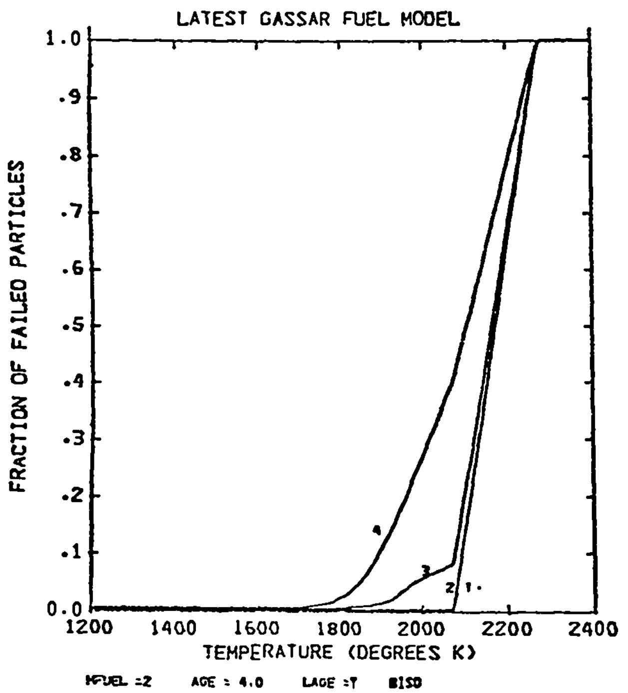


Fig. 22. Fraction of failed particles vs temperature, BISO particles, GASSAR data.

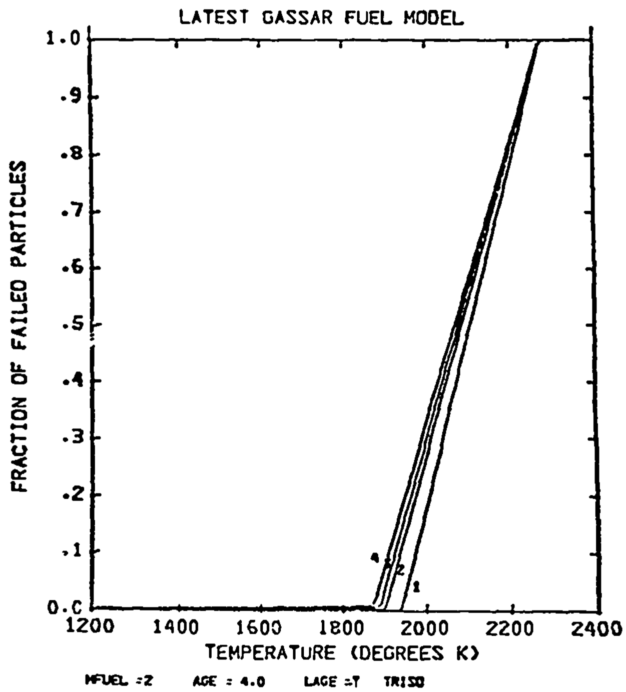


Fig. 23. Fraction of failed particles vs temperature, TRISO particles, GASSAR data.

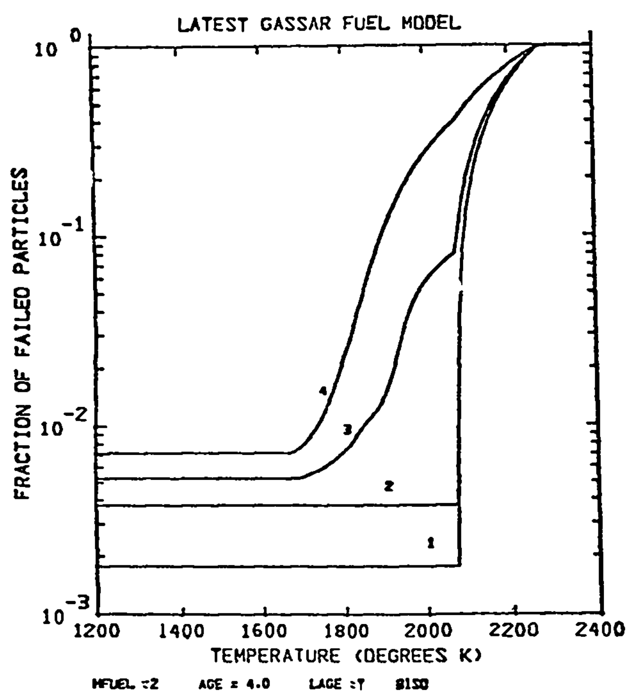


Fig. 24. Log of fraction of failed particles vs temperature, BISO particles, GASSAR data.

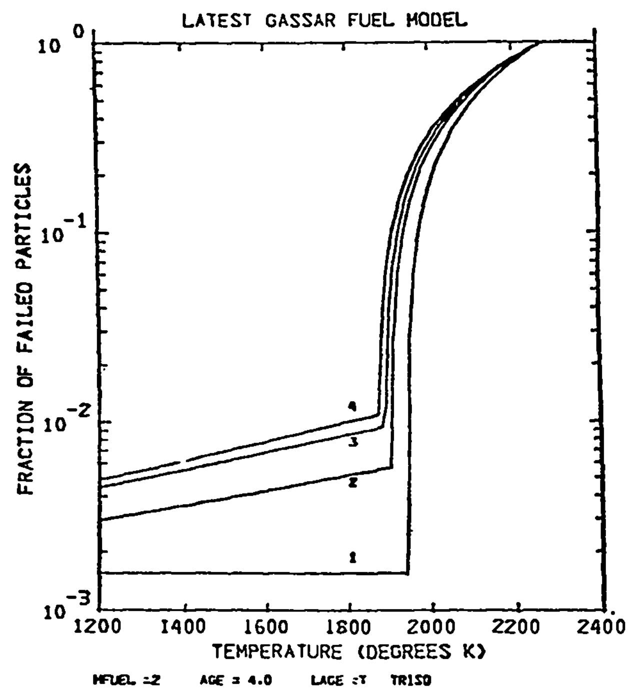


Fig. 25. Log of fraction of failed particles vs temperature, TRISO particles, GASSAR data.

and

$$f_i = f[T, t \bmod(4)] = f(T, i-1 + x) , \qquad (110)$$

where $x \equiv t - [t]$, using the parameters of Table X.

GASSAR: For the GASSAR data, if the fuel is not aged, then a linear interpolation is performed between the two nearest ages, or

$$\bar{f} = \sum_{i=1}^{4} [(1-x)f_{i-1}^{G} + xf_i^{G}][\theta(t-i+1) - \theta(t-1)] , \qquad (111)$$

where $f_o^G \equiv 0$, $i = [t] + 1$, $x = t - [t]$, and f_i^G is given by

$$f_i^G = f(T,t) = f(T, i-1 + x) , \qquad (112)$$

using Eqs. (104-106) and Tables XIII and XIV of Sec. C.

On the other hand, if the fuel is aged, then the particle coating failed fuel fraction is given by

$$\bar{f} = \frac{1}{4} \sum_{i=1}^{4} \tilde{f}_i^G [\theta(t - i + 1) - \theta(t-1)] , \qquad (113)$$

where

$$\tilde{f}_i^G = \begin{cases} 4xf_1^G & i = 1 \quad 0 \le t \le 1 \\ 3f_1^G - 2xf_1^G + 3xf_2^G & i = 2 \quad 1 \le t \le 2 \\ f_1^G + (2-x)f_2^G + 2xf_3^G & i = 3 \quad 2 \le t \le 3 \\ f_1^G + f_2^G + f_3^G + xf_4^G & i = 4 \quad 3 \le t \le 4 \end{cases} \qquad (114)$$

with

$$f_i^G = f(T,t) = f(T,\ i-1+x)\ , \qquad (115)$$

using Eqs. (104-106) and Tables XIII and XIV of Sec. C.

The failed fraction in BISO, TRISO, and TOTAL = 0.6 BISO + 0.4 TRISO for the SORS and GASSAR models are displayed in Figs. 26-37 for aged and not aged fuel. (LAGE = T and F respectively)

We note that the SORS (Ft. St. Vrain) model exhibits an exponential rise in the failed fraction between refuelings compared to the linear rise of the GASSAR model in the same circumstance. The temperatures of Fig. 1 were used and were held constant in time.

The maximum and minimum failed fraction for the SORS data are (0.08, 0.04). The maximum and minimum for the GASSAR data are (0.004, 0.0025). Thus, a factor of (20,16) decrease in the maximum and minimum, in going from SORS to GASSAR data is obtained.

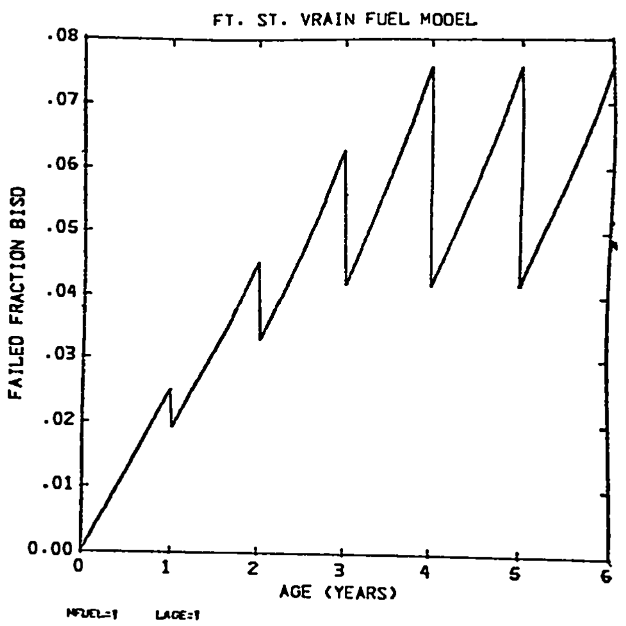


Fig. 26. Failed fraction vs age of the fuel in years, BISO particles, SORS data, aged fuel.

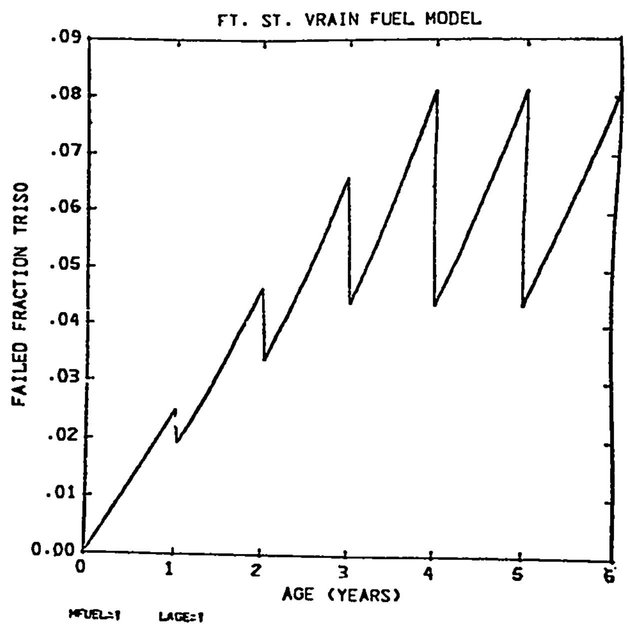


Fig. 27. Failed fraction vs age of the fuel in years, TRISO particles, SORS data, aged fuel.

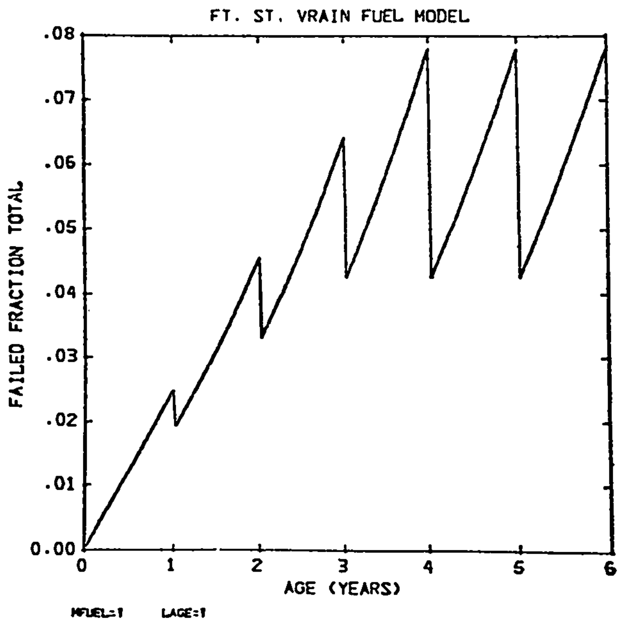


Fig. 28. Failed fraction vs age of the fuel in years, averaged total for aged fuel, SORS data.

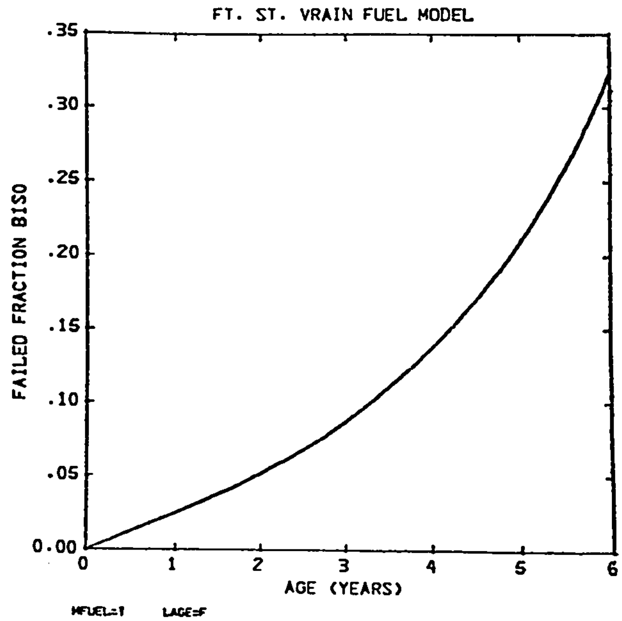


Fig. 29. Failed fraction vs age of the fuel in years, BISO particles, SORS data, fuel not aged.

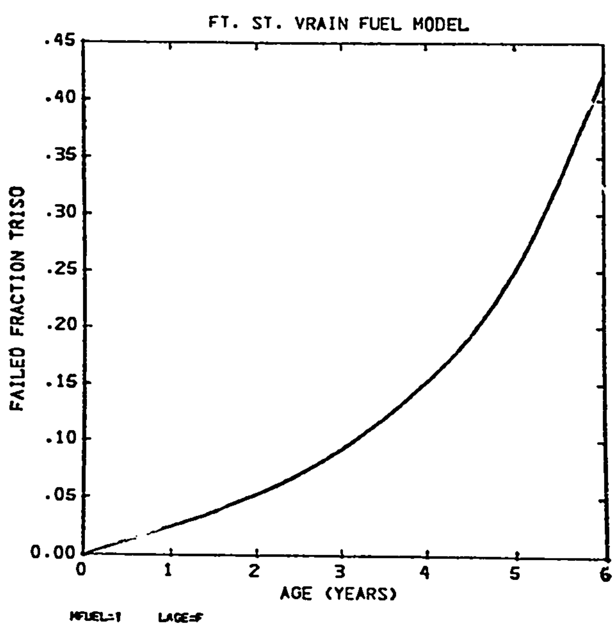


Fig. 30. Failed fraction vs age of the fuel in years, TRISO particles, SORS data, fuel not aged.

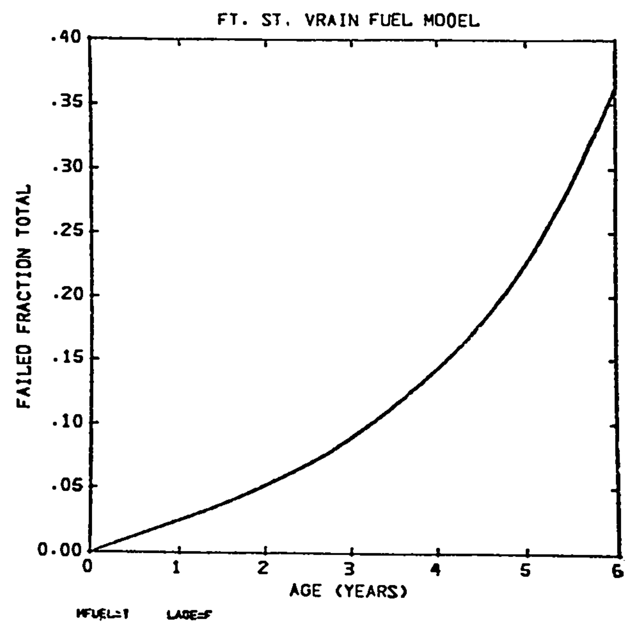


Fig. 31. Failed fraction vs age of the fuel in years, averaged total for fuel not aged, SORS data.

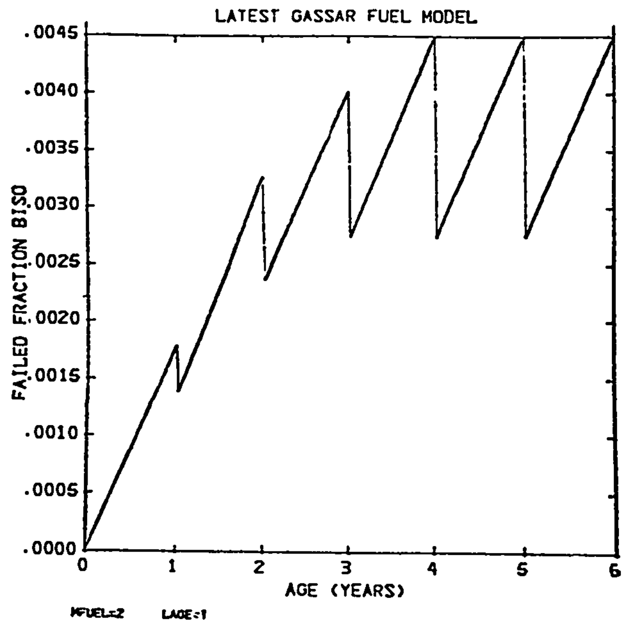


Fig. 32. Failed fraction vs age of the fuel in years, BISO particles, GASSAR data, aged fuel.

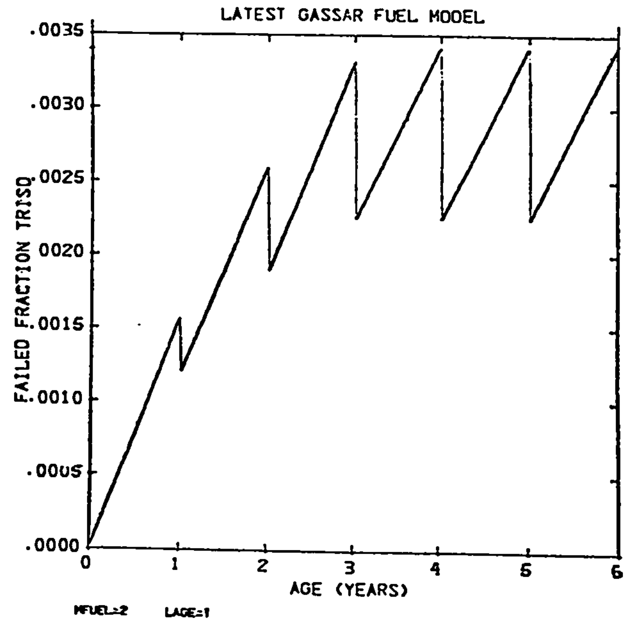


Fig. 33. Failed fraction vs age of the fuel in years, TRISO particles, GASSAR data, aged fuel.

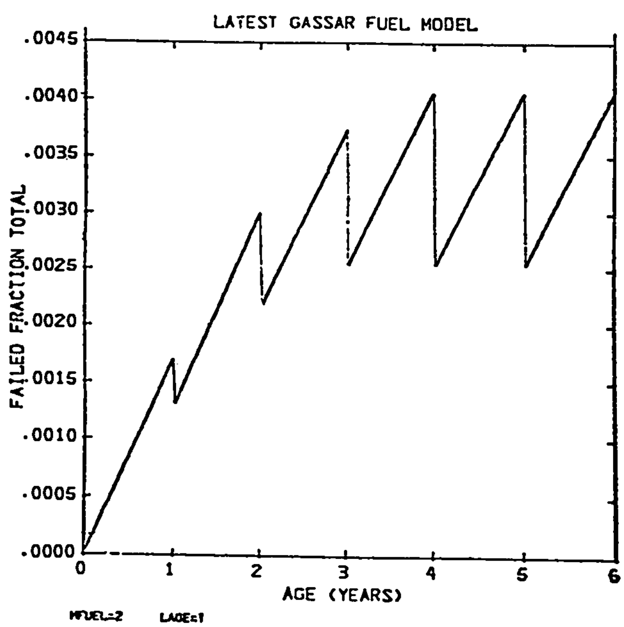


Fig. 34. Failed fraction vs age of the fuel in years, averaged total for aged fuel, GASSAR data.

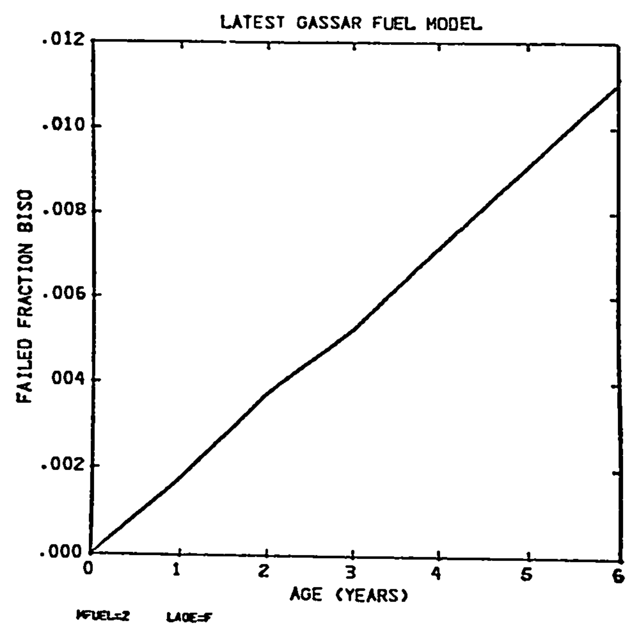


Fig. 35. Failed fraction vs age of the fuel in years, BISO particles, GASSAR data, fuel not aged.

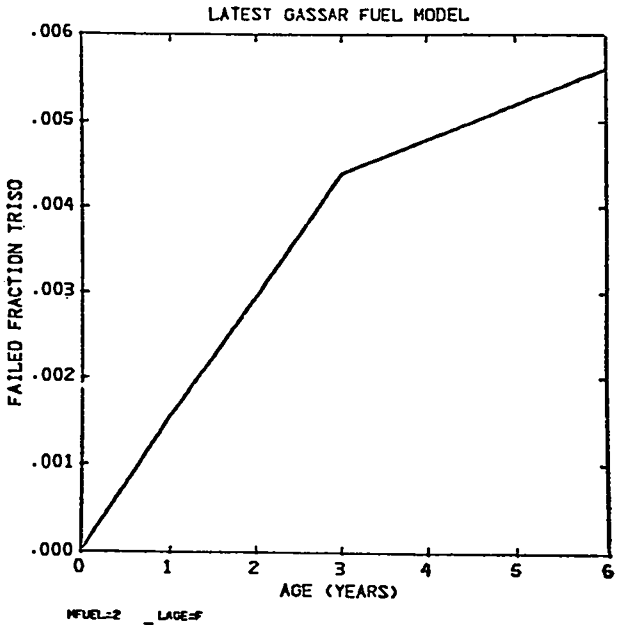


Fig. 36. Failed fraction vs age of the fuel in years, TRISO particles, GASSAR data, fuel not aged.

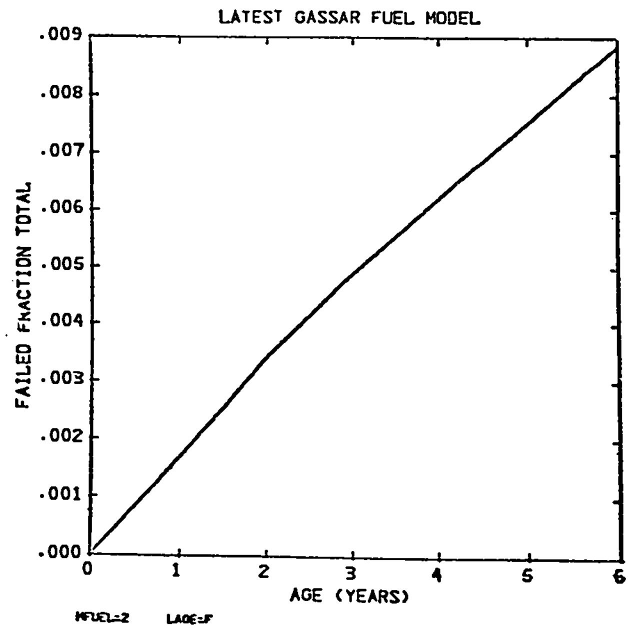
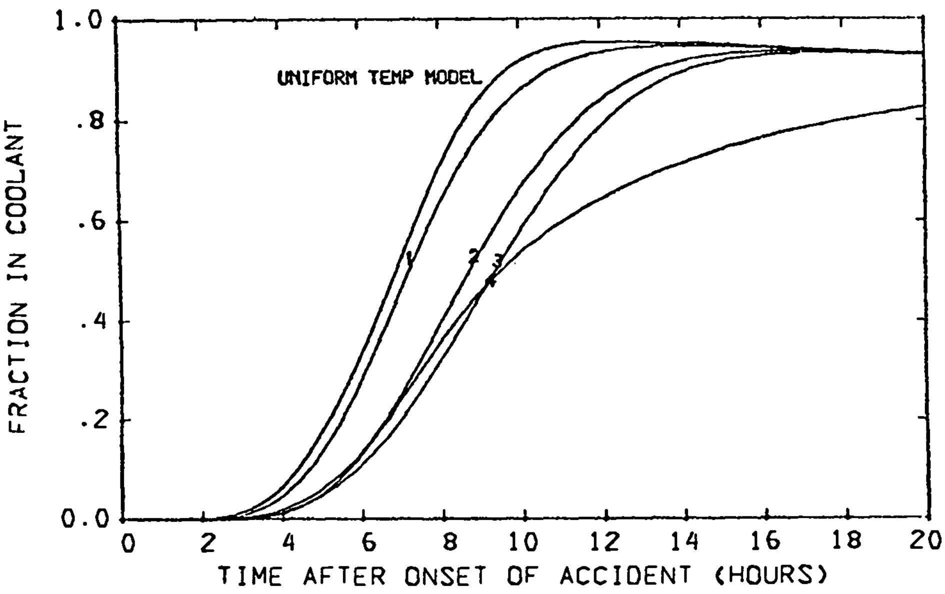


Fig. 37. Failed fraction vs age of the fuel in years, averaged total for fuel not aged, GASSAR data.

IV. COMPARISONS

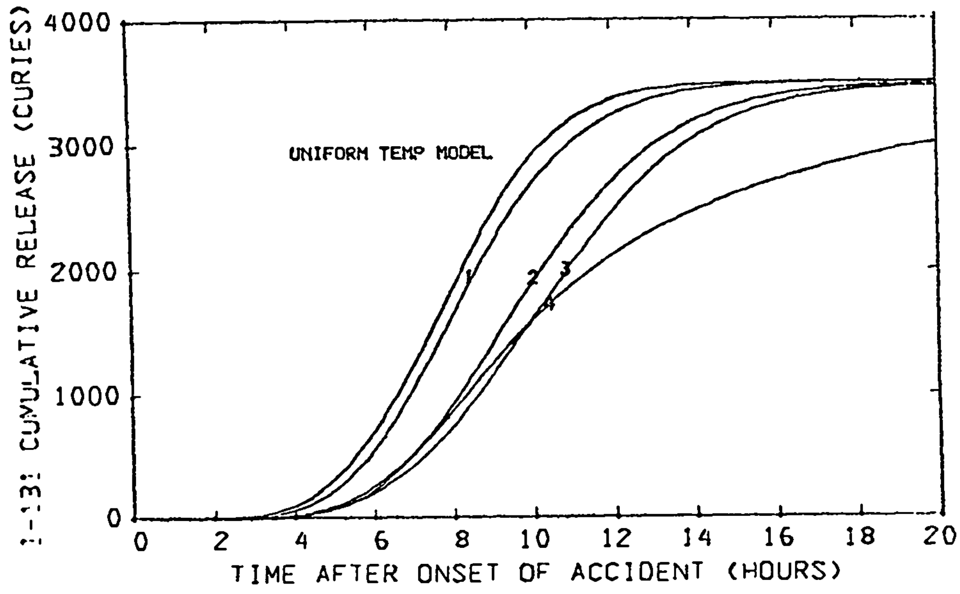
A comparison for ^{131}I was made for the Ft. St. Vrain fuel model (MFUEL = 1) with an average age of 2.5 yr (AGE = 2.5), fuel not aged (LAGE = F). A BISO-TRISO mixture (0.6, 0.4) was used (FRAC = 0.6). Six partitions of the core volume IC = 1, 5, 10, 25, 100, 200 and five partitions of the 20 h time period IT = 20, 40, 100, 300, 500 were used. A typical result is displayed in Figs. 38 and 39 and compared with the uniform temperature model of Ref. 1 for the fraction in the coolant and the cumulative release. Four temperature models SORS, CORCON, AYER, and AYER Fu-Cort (ITEMP = 1, 2, 3, 4) and the four equation models, Simplified Model-Renormalized, Constant Release-Renormalized, Linear Release-Renormalized, and Intact-Failed Self-Consistent fuel transition (NEQ = 1, 2, 3, 4) were used.

A typical terminal run output under the NOS system is displayed in Fig. 40.



I-131 ISO=10 MFUEL=1 AGE= 2.5 LAGE=F FRAC= .6 YIELD= .031
NTOT= 100 IVFMAX=100 JOB=R4LCP 5SS DATE=09/20/76
NEQ=2 CONSTANT RELEASE RATE, CONSTANT FAILURE

Fig. 38. LARC-1 and uniform temperature model results, fraction in coolant.



I-131 ISO=10 MFUEL=1 AGE= 2.5 LAGE=F FRAC= .6 YIELD= .031
NTOT= 100 IVFMAX=100 JOB=R4LCP 5SS DATE=09/20/76
NEQ=2 CONSTANT RELEASE RATE. CONSTANT FAILURE

Fig. 39. LARC-1 and uniform temperature model results, cumulative release.

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 END TEXT EDITING.
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/REPLACE,LARC1
/RUN,N,I=LARC1
CTIME 015.277 SEC.  RUN LASL20
/LGO
 JOBNAME =AJUI210       DATE = 76/08/30.      TIME =10.55.34
 ISOTOPE NAME =
? I-131
 DECAY CONSTANT (/HR)
? 3.58E-3
 RELEASE GROUP =
? 10
 YIELD (FRACTION) =
? .031
 AGE IN YEARS =
? 2.5
 FUEL TYPE (FT. ST. VRAIN =1, GASSAR =2) =
? 1
 FUEL AGED (T) OR NOT AGED (F)?
? F
 FRACTION OF BISO IN LOADING =
? 0.6
 NOBLE GAS?  (T OR F)
? F
 I-131            DECAY CONSTANT = 3.580E-03     GROUP =10      YIELD = 3.100E-02
 NZERO = 7.792E+07
 AGE =  2.50      LAGE =F      FRAC =    .60
 NEQ =4
 NTOT =  100
 TEMPERATURE MODEL USED = 1     MFUEL =1     ISOTOPE =I-131
 IVFMAX =  100
 INTERVAL TIME      AMOUNT      AMOUNT      FRACTION    AMOUNT IN      CUMULATED
 NUMBER   (HR)      REMAINING   IN COOLANT  IN COOLANT  CONTAINMENT    RELEASE
                    (CURIES)    (CURIES)                BLDG(CURIES)   (CURIES)


     5     1.00     7.76E+07     8.67E+02    1.11E-05     6.92E+02        .01
    10     2.00     7.73E+07     4.88E+04    6.26E-04     3.95E+04        .43
    15     3.00     7.63E+07     7.70E+05    9.88E-03     5.58E+05       9.82
    20     4.00     7.30E+07     3.77E+06    4.83E-02     2.35E+06      65.62
    25     5.00     6.59E+07     1.07E+07    1.37E-01     5.72E+06     229.13
    30     6.00     5.41E+07     2.22E+07    2.84E-01     1.01E+07     559.24
    35     7.00     3.95E+07     3.65E+07    4.68E-01     1.36E+07    1061.89
    40     8.00     2.57E+07     5.00E+07    6.42E-01     1.44E+07    1656.69
    45     9.00     1.51E+07     6.04E+07    7.75E-01     1.26E+07    2226.51
    50    10.00     8.13E+06     6.71E+07    8.61E-01     9.51E+06    2689.03
    55    11.00     4.03E+06     7.09E+07    9.10E-01     6.42E+06    3019.60
    60    12.00     1.84E+06     7.28E+07    9.35E-01     3.97E+06    3233.48
    65    13.00     7.72E+05     7.36E+07    9.45E-01     2.26E+06    3360.77
    70    14.00     2.99E+05     7.38E+07    9.48E-01     1.21E+06    3431.21
    75    15.00     1.06E+05     7.38E+07    9.47E-01     6.07E+05    3467.79
    80    16.00     3.40E+04     7.36E+07    9.44E-01     2.90E+05    3485.74
    85    17.00     9.81E+03     7.33E+07    9.41E-01     1.32E+05    3494.13
    90    18.00     2.51E+03     7.31E+07    9.38E-01     5.78E+04    3497.88
    95    19.00     5.71E+02     7.28E+07    9.35E-01     2.46E+04    3499.51
   100    20.00     1.15E+02     7.26E+07    9.31E-01     1.02E+04    3500.19
 DOES ANOTHER CASE FOLLOW?
? NO
EXIT
/
```

Fig. 40. Typical terminal run output for LARC-1 under NOS system.

The most sensitive test of these 320 calculations was the comparison of the fraction in the coolant and the cumulative release at 2 h time. These results are given in Appendix E. The main result is that at 2 h the maximum variation between (IT, IC) of (100, 100) and (500, 200) for the ^{131}I fraction release in the coolant is ∿ 20% for any temperature model whereas the various temperature models differ by as much as a factor of 3.7. Similarly for the cumulative release the maximum variation is ∿ 19% for any temperature model, whereas the various temperature models differ by as much as a factor of 3. At times greater than 2 h the variations decrease rapidly.

The ^{131}I fraction in the coolant and cumulative release as a function of time and model number (NEQ) are given in Tables XV - XXII for the four temperature models with IT = IC = 100. We note that better than two-digit agreement for the fraction in the coolant between the various equation models occurs after 4 h for all temperature models, Tables XV - XVIII.

Taking model 4, the Intact-Failed Self-Consistent Fuel model, as a standard, we compare the ^{131}I cumulative release in Tables XXIII-XXVI. Again we note that the maximum difference occurs at ∿ 2 h where as much as a 17% error can occur at the 0.4 Ci level. However, comparing Tables XIX - XXVI we can estimate an approximate upper bound on the error in the cumulative release, displayed in Fig. 41. A good rule of thumb is that the error made by the renormalized models compared to the Intact-Failed Self-Consistent model is " less than 5% at 50 Ci, and less than 1% at 300 Ci."

A similar set of comparisons was made for ^{127m}Te, and is summarized in Tables XXVII - XXIX for the fraction in the coolant, the cumulative release and the comparison to model 4. We note that the cumulative release at 20 h has only reached 25 Ci, as compared to 3500 for ^{131}I. The maximum error, 12%, occurs at 6 h as compared to 2 h for ^{131}I. The approximate upper bound for ^{131}I bounds the ^{127m}Te results.

TABLE XV

^{131}I FRACTION IN THE COOLANT

ITEMP = 1, IT = 100, IC = 100

T(H) \ NEQ	1,2	3	4
2	0.000522	0.000522	0.000626
4	0.0475	0.0475	0.0483
6	0.284	0.284	0.284
8	0.641	0.641	0.642
10	0.861	0.861	0.861
12	0.935	0.935	0.935
14	0.948	0.948	0.948
16	0.944	0.944	0.944
18	0.938	0.938	0.938
20	0.931	0.931	0.931

TABLE XVI

^{131}I FRACTION IN COOLANT AT 2 h

ITEMP = 2, IT = 100, IC = 100

T(H) \ NEQ	1,2	3	4
2	0.000157	0.000157	0.000175
4	0.0129	0.0129	0.0135
6	0.134	0.134	0.135
8	0.401	0.401	0.402
10	0.670	0.670	0.670
12	0.842	0.842	0.842
14	0.917	0.917	0.917
16	0.936	0.936	0.936
18	0.936	0.936	0.936
20	0.931	0.931	0.931

TABLE XVI

^{131}I FRACTION IN COOLANT

ITEMP = 3, IT = 100, IC = 100

T(H) \ NEQ	1,2	3	4
2	0.000144	0.000144	0.000169
4	0.0158	0.0158	0.0165
6	0.113	0.113	0.114
8	0.325	0.325	0.326
10	0.586	0.586	0.587
12	0.791	0.791	0.791
14	0.895	0.895	0.895
16	0.929	0.929	0.929
18	0.934	0.934	0.934
20	0.931	0.931	0.931

TABLE XVIII

^{131}I FRACTION IN COOLANT

ITEMP = 4, IT = 100, IC = 100

T(H) \ NEQ	1,2	3	4
2	0.000220	0.000220	0.000269
4	0.0206	0.0206	0.0211
6	0.139	0.139	0.139
8	0.362	0.362	0.362
10	0.540	0.540	0.540
12	0.646	0.646	0.646
14	0.717	0.717	0.717
16	0.767	0.767	0.767
18	0.803	0.803	0.802
20	0.827	0.827	0.827

TABLE XIX

^{131}I CUMULATIVE RELEASE (CURIES)
ITEMP = 1, IT = 100, IC = 100

T(H) \ NEQ	1	2	3	4
2	0.362	0.362	0.353	0.429
4	63.620	63.646	63.299	65.617
6	556.424	556.781	555.819	559.238
8	1654.131	1655.048	1654.214	1656.690
10	2687.453	2688.273	2687.888	2689.032
12	3232.777	3233.196	3233.047	3233.480
14	3430.953	3431.101	3431.045	3431.212
16	3485.639	3485.678	3485.651	3485.742
18	3497.822	3497.831	3497.810	3497.883
20	3500.136	3500.137	3500.118	3500.188

TABLE XX

^{131}CUMULATIVE RELEASE (CURIES)
ITEMP = 2, IT = 100, IC = 100

T(H) \ NEQ	1	2	3	4
2	0.164	0.164	0.162	0.177
4	15.101	15.105	14.994	16.071
6	235.211	235.330	234.763	237.816
8	942.483	942.944	942.250	945.159
10	1909.057	1909.699	1909.208	1911.122
12	2710.293	2710.852	2710.570	2711.583
14	3181.464	3181.803	3181.674	3182.123
16	3386.173	3386.317	3386.296	3386.450
18	3455.200	3455.246	3455.221	3455.327
20	3474.843	3474.855	3474.837	3474.919

TABLE XXI

^{131}I CUMULATIVE RELEASE (CURIES)
ITEMP = 3, IT = 100, IC = 100

T(H) \ NEQ	1	2	3	4
2	0.129	0.129	0.127	0.142
4	19.972	19.976	19.871	21.152
6	212.131	212.199	211.822	214.730
8	764.819	765.116	764.545	767.487
10	1620.123	1620.675	1620.123	1622.351
12	2468.057	2468.659	2468.291	2469.601
14	3043.649	3044.072	3043.891	3044.513
16	3323.847	3324.050	3323.975	3324.247
18	3429.105	3429.180	3429.143	3429.285
20	3463.127	3463.152	3463.130	3463.227

TABLE XXII

^{131}I CUMULATIVE RELEASE (CURIES)
ITEMP = 4, IT = 100, IC = 100

T(H) \ NEQ	1	2	3	4
2	0.186	0.186	0.183	0.214
4	27.313	27.320	27.172	28.390
6	262.656	262.801	262.290	264.627
8	888.430	889.010	888.353	890.765
10	1610.957	1611.575	1611.152	1612.910
12	2126.310	2126.664	2126.440	2127.661
14	2469.188	2469.388	2469.256	2470.152
16	2711.513	2711.641	2711.552	2712.238
18	2888.546	2888.635	2888.569	2889.110
20	3020.609	3020.671	3020.616	3021.063

TABLE XXIII

^{131}I: $|R_i/R_4 - 1| \times 10^2$

PERCENTAGE DIFFERENCE IN MODELS COMPARED TO MODEL 4
ITEMP = 1, IT = 100, IC = 100

T \ NEQ	1	2	3
2	15.62	15.62	17.72
4	3.04	3.00	3.53
6	0.50	0.44	0.61
8	0.15	0.10	0.15
10	0.06	0.03	0.04
12	0.02	0.009	0.013
14	0.008	0.003	0.005
16	0.003	0.002	0.003
18	0.002	0.0015	0.002
20	0.0015	0.0015	0.002

TABLE XXIV

^{131}I: $|R_i/R_4 - 1| \times 10^2$

PERCENTAGE DIFFERENCE IN MODELS COMPARED TO MODEL 4
ITEMP = 2, IT = 100, IC = 100

T \ NEQ	1	2	3
2	7.34	7.34	8.47
4	6.04	6.01	6.70
6	1.10	1.05	1.28
8	0.28	0.23	0.31
10	0.11	0.07	0.10
12	0.05	0.03	0.04
14	0.02	0.01	0.01
16	0.008	0.004	0.005
18	0.004	0.002	0.003
20	0.002	0.002	0.002

TABLE XXV

^{131}I: $|R_i/R_4 - 1| \times 10^2$

PERCENTAGE DIFFERENCE IN MODELS COMPARED TO MODEL 4
ITEMP = 3, IT = 100, IC = 100

T \ NEQ	1	2	3
2	9.15	9.15	10.56
4	5.58	5.56	6.06
6	1.21	1.18	1.35
8	0.35	0.31	0.38
10	0.14	0.10	0.14
12	0.06	0.04	0.05
14	0.03	0.01	0.02
16	0.01	0.006	0.008
18	0.005	0.003	0.004
20	0.003	0.002	0.003

TABLE XXVI

^{131}I: $|R_i/R_4 - 1| \times 10^2$

PERCENTAGE DIFFERENCE IN MODELS COMPARED TO MODEL 4
ITEMP = 4, IT = 100, IC = 100

T \ NEQ	1	2	3
2	13.08	13.08	14.49
4	3.79	3.77	4.29
6	0.74	0.69	0.88
8	0.26	0.20	0.27
10	0.12	0.08	0.11
12	0.06	0.05	0.06
14	0.04	0.03	0.04
16	0.03	0.02	0.03
18	0.020	0.016	0.019
20	0.015	0.013	0.015

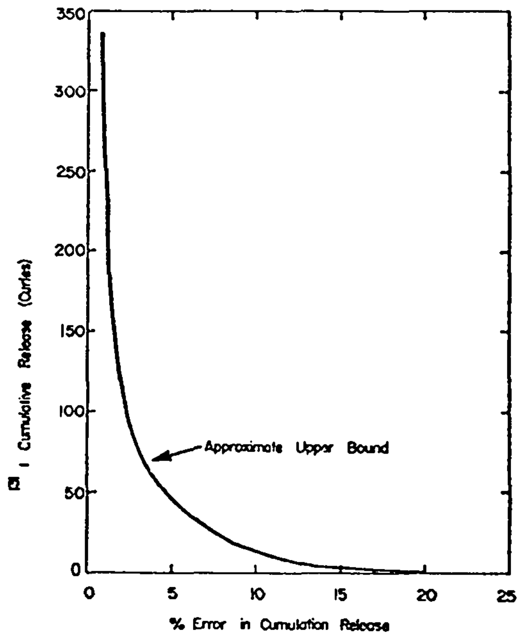

Fig. 41. Approximate upper bound to error in cumulative release in ^{131}I calculations using IT = IC = 100 for all temperature models.

TABLE XXVII

^{127m}Te FRACTION IN COOLANT
ITEMP = 4, IT = 100, IC = 100

T(H) \ NEQ	1,2	3	4
2	0.000128	0.000128	0.000128
4	0.00114	0.00114	0.00126
6	0.0435	0.0435	0.0484
8	0.205	0.205	0.210
10	0.324	0.324	0.327
12	0.405	0.405	0.408
14	0.475	0.475	0.477
16	0.539	0.539	0.541
18	0.594	0.594	0.595
20	0.642	0.642	0.644

TABLE XXVIII

^{127m}Te CUMULATIVE RELEASE (Ci)

ITEMP = 4, IT = 100, IC = 100

T(H) \ NEQ	1	2	3	4
2	0.002	0.002	0.002	0.002
4	0.019	0.019	0.019	0.020
6	0.627	0.629	0.627	0.713
8	5.063	5.071	5.067	5.269
10	10.573	10.571	10.577	10.733
12	14.597	14.601	14.600	14.717
14	17.746	17.749	17.748	17.847
16	20.517	20.519	20.519	20.605
18	22.970	22.971	22.971	23.039
20	25.102	25.103	25.102	25.160

TABLE XXIX

^{127m}Te: $|R_i/R_4 - 1| \times 10^2$

PERCENTAGE DIFFERENCE IN MODELS COMPARED TO MODEL 4

ITEMP = 4, IT = 100, IC = 100

T(H) \ NEQ	1	2	3
2	0.0	0.0	0.0
4	5.00	5.00	5.00
6	12.06	12.06	12.06
8	3.91	3.76	3.83
10	1.49	1.43	1.45
12	0.82	0.79	0.79
14	0.57	0.55	0.55
16	0.43	0.42	0.42
18	0.30	0.30	0.30
20	0.23	0.23	0.23

Results for three representative isotopes, ^{131}I, ^{135}Xe, and ^{138}Xe, are displayed in Figs. 42 through 45. On each figure four temperature models are displayed . The SORS (ITEMP = 1) model gives the largest release and the AYER-Fu Cort (ITEMP = 4) model the smallest.

The sensitivity of the accumulated release to fuel modeling where the fuel is the Ft. St. Vrain (FSV) or GASSAR model is illustrated in Figs. 42 and 43, respectively, where there is a 50% reduction at 9 h in using the GASSAR model.

The sensitivity of the temperature models and the effects of larger λ's is illustrated in Figs. 44 and 45 for ^{135}Xe and ^{138}Xe, respectively. For ^{135}Xe the different temperature models predict a 30% difference in fraction released in the coolant with a 4-h time spread in the maximum. The ^{135}Xe decay constant causes the decaying tail after the peak release.

The double peak exhibited by ^{137}Xe in Fig. 45 was investigated in detail and is explained as follows: the first peak is formed because of release from intact particles. Decay causes it to fall because most of the amount available for release is depleted by decay. During the fall, the rise in temperature of the SORS model is sufficient to cause a large increase in the failed fraction before decay again causes the second peak to fall off. In the CORCON and AYER temperature models. The temperature-time behavior is such that decay overrides the increased failure and a leveling off of the second peak is expected.

V. CONCLUSIONS

We have developed and compared four analytical models of fission product release from an HTGR core during the LOFC accident. We have also developed a numerical data base for release constants, temperature modeling, fission product release rates, coated fuel particle failure fraction and aged coated fuel particle failure fraction. Analytic fits and graphic displays for these data were given for the Ft. St. Vrain and GASSAR models.

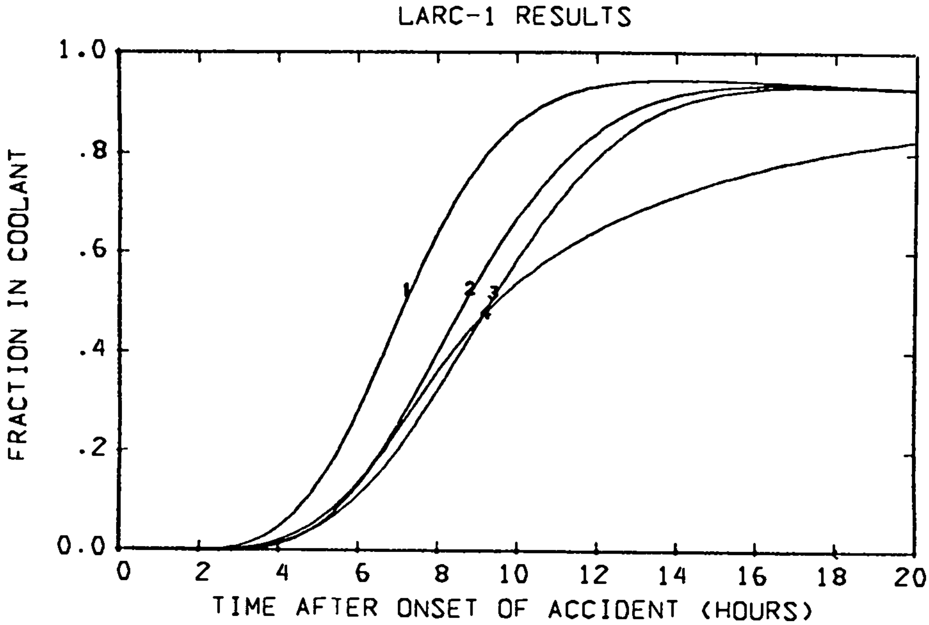

Fig. 42. Calculated time-dependent release of ^{131}I from the reactor core using the Ft. St. Vrain fuel failure model and using four different core temperature models.

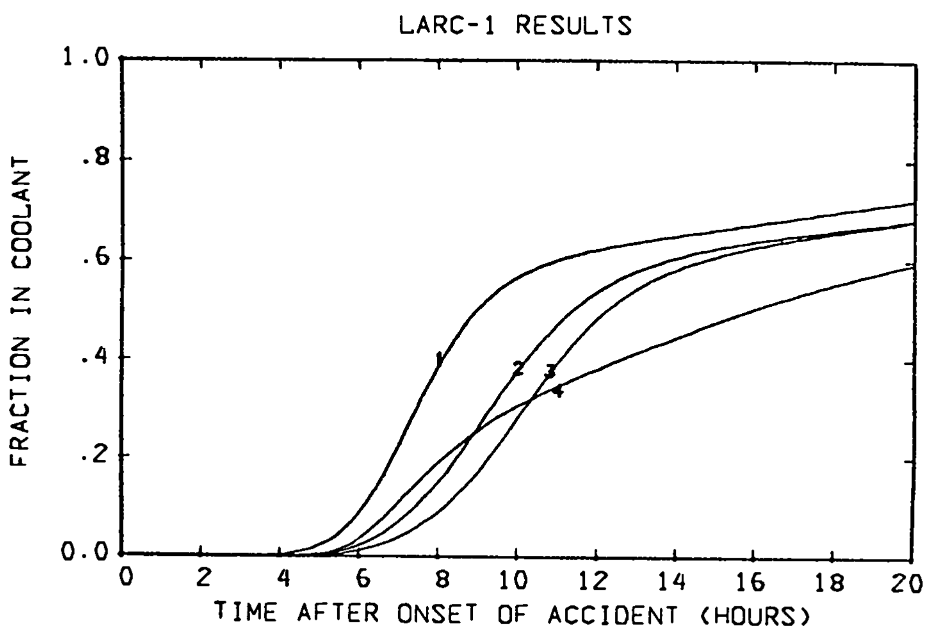

Fig. 43. Calculated time-dependent release of ^{131}I from the reactor core using the GASSAR fuel failure model and using four different core temperature models.

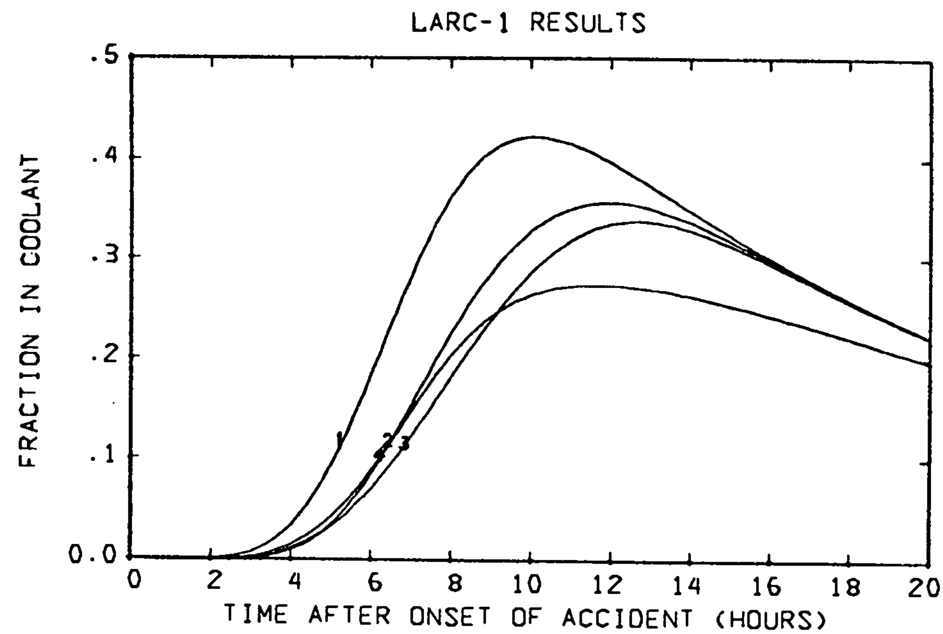

Fig. 44. Calculated time-dependent release of ^{135}Xe from a large HTGR using four different core temperature models.

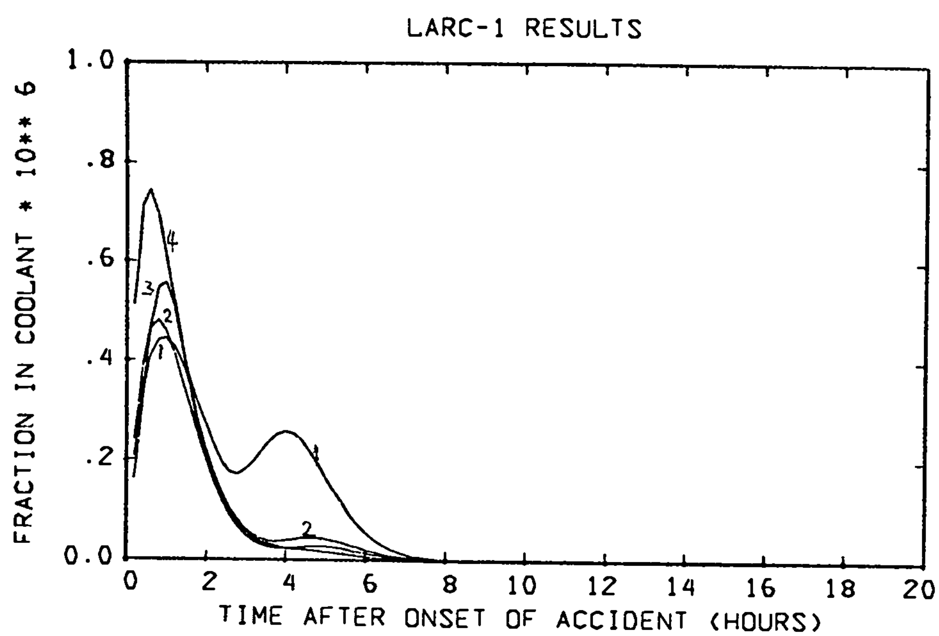

Fig. 45. Calculated time-dependent release of ^{138}Xe from a large HTGR using four different core temperature models.

The assumptions of the simplified model[1] have been systematically removed. However, the LARC-1 program neglects precursors, diffusion, and absorption and evaporation of the metallics. These topics will be treated in subsequent reports.

Comparison of the various analytic models indicates that the use of a renormalized constant release model is sufficiently accurate to warrant the extension of this method to more complex theoretical modelings.

Comparisons of the various temperature and release models indicate that these are the most sensitive LARC-1 parameters in that order. The need for detailed accurate temperature calculations and physically realistic release models, that are validated by experiment, must be emphasized.

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2. M. H. Schwartz, D. B. Sedgley, and M. M. Mendonca, "SORS: Computer Programs for Analyzing Fission Product Release from HTGR Cores During Transient Temperature Excursions," General Atomic Company report GA-A12462 (April 1974).

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APPENDIX A

EVALUATION OF THE $M_k(\tau)$, and $\hat{P}_k(\tau)$ FUNCTIONS

The $M_k(\tau)$, $P_k(\tau)$, and $\hat{P}_k(\tau)$ functions are defined by

$$M_o(\Lambda_1,\tau) = e^{-\Lambda_1 \tau} , \tag{A-1}$$

$$M_k(\Lambda_1,\alpha,\beta,\tau) = e^{-\Lambda_1 \tau} P_{k-1}(-\alpha,\beta,\tau) , \quad 1 \leq k \leq 3 \tag{A-2}$$

$$M_4(\gamma,\beta,\tau) = e^{-\gamma\tau-\beta\tau^2} , \tag{A-3}$$

$$M_5(\gamma,\beta,\tau) = \tau e^{-\gamma\tau-\beta\tau^2} , \tag{A-4}$$

$$P_k(\gamma,\beta,\tau) = \int_o^\tau ds\ s^k\ e^{-\gamma s-\beta s^2} , \text{ and} \tag{A-5}$$

$$\hat{P}_k(\tau) = \int_o^\tau ds\ M_k(s). \tag{A-6}$$

First, we investigate the function $P_k(\gamma,\beta,\tau)$ given by Eq. (A-5) as

$$P_k(\gamma,\beta,\tau) = \int_o^\tau ds\ s^k\ e^{-\gamma s-\beta s^2}$$

$$= \left(-\frac{\partial}{\partial\gamma}\right)^k P_o(\gamma,\beta,\tau) . \tag{A-7}$$

Thus, Eq. (A-5) need be integrated only for k = 0 as the other forms may be found by differentiation. For $\beta \neq 0$, we find

$$P_o(\gamma,\beta,\tau) = \int_o^\tau ds\ e^{-\gamma s-\beta s^2}$$

$$= \frac{1}{2}\sqrt{\frac{\pi}{\beta}}\ e^{\gamma^2/4\beta} \left[\mathrm{erf}\left(\sqrt{\beta}\tau + \frac{\gamma}{2\sqrt{\beta}}\right) - \mathrm{erf}\left(\frac{\gamma}{2\sqrt{\beta}}\right)\right] . \tag{A-8}$$

For $\beta = 0$, Eq. (A-8) becomes

$$P_o(\gamma,0,\tau) = \frac{1}{\gamma}(1 - e^{-\gamma\tau}) \tag{A-9}$$

and for $\beta = \gamma = 0$, we have

$$P_o(0,0,\tau) = \tau . \tag{A-10}$$

Using Eq. (A-7) we find for $P_1(\gamma,\beta,\tau)$ and its limiting forms

$$P_1(\gamma,\beta,\tau) = -\frac{\gamma}{2\beta} P_o(\gamma,\beta,\tau) + \frac{1}{2\beta}(1 - e^{-\gamma\tau-\beta\tau^2}) , \tag{A-11}$$

$$P_1(\gamma,0,\tau) = \frac{1}{\gamma^2}[1 - (1 + \gamma\tau)e^{-\gamma\tau}] , \tag{A-12}$$

and

$$P_1(0,0,\tau) = \frac{\tau^2}{2} . \tag{A-13}$$

Similarly, for $P_2(\gamma,\beta,\tau)$ we have

$$P_2(\gamma,\beta,\tau) = \frac{1}{4\beta^2}[(\gamma^2+2\beta)P_o(\gamma,\beta,\tau) - \gamma(1-e^{-\gamma\tau-\beta\tau^2}) + (\gamma-2\beta\tau)\, e^{-\gamma\tau-\beta\tau^2}] , \tag{A-14}$$

$$P_2(\gamma,0,\tau) = \frac{1}{\gamma^3}[2 - (2+2\gamma\tau+\gamma^2\tau^2)\, e^{-\gamma\tau}] , \tag{A-15}$$

and

$$P_2(0,0,\tau) = \frac{\tau^3}{3} . \tag{A-16}$$

Using the results of Eqs. (A-7) - (A-16), we may determine the $M_k(\tau)$ functions as given by Eqs. (A-1) - (A-4). Specifically, for $\beta \neq 0$

$$M_1(\Lambda_1,\alpha,\beta,\tau) = e^{-\Lambda_1\tau} P_o(-\alpha,\beta,\tau), \tag{A-17}$$

$$M_2(\Lambda_1,\alpha,\beta,\tau) = \frac{e^{-\Lambda_1\tau}}{2\beta} [\alpha P_o(-\alpha,\beta,\tau) + 1 - e^{\alpha\tau-\beta\tau^2}], \tag{A-18}$$

and

$$M_3(\Lambda_1,\alpha,\beta,\tau) = \frac{e^{-\Lambda_1\tau}}{4\beta^2} [(\alpha^2+2\beta)P_o(-\alpha,\beta,\tau) + \alpha(1 - e^{\alpha\tau-\beta\tau^2}) - (\alpha-2\beta\tau)e^{\alpha\tau-\beta\tau^2}]. \tag{A-19}$$

For $\beta = 0$ and $\beta = \alpha = 0$, the $M_k(\tau)$ functions for $1 \leq k \leq 3$ are found from Eq. (A-2) and the limiting forms of $P_k(\gamma,\beta,\tau)$.

Next we address the evaluation of $\hat{P}_k(\tau)$. For k = 0, 4, and 5 integration of Eqs (A-1),(A-3), and (A-4) yields

$$\hat{P}_o(\Lambda_1,\tau) = \frac{1}{\Lambda_1} (1 - e^{-\Lambda_1\tau}) , \tag{A-20}$$

$$\hat{P}_4(\gamma,\beta,\tau) = P_o(\gamma,\beta,\tau) , \tag{A-21}$$

and

$$\hat{P}_5(\gamma,\beta,\tau) = P_1(\gamma,\beta,\tau) , \tag{A-22}$$

where we have used Eq. (A-7). For $1 \leq k \leq 3$, using Eqs.(A-6) and (A-2),

$$\hat{P}_k(\Lambda,\gamma,\beta,\tau) = (-\frac{\partial}{\partial\gamma})^k \hat{P}_1(\Lambda,\gamma,\beta,\tau), \tag{A-23}$$

where

$$\hat{P}_1(\Lambda,\gamma,\beta,\tau) = \int_0^\tau ds\ e^{-\Lambda s}\ P_o(\gamma,\beta,s)$$

$$= \frac{1}{\Lambda}\ [P_o(\Lambda+\gamma,\beta,\tau) - e^{-\Lambda\tau} P_o(\gamma,\beta,\tau)], \qquad \text{(A-24)}$$

which can be proved by direct integration using Eq. (A-8). Differentiating Eq. (A-24), according to Eq. (A-23), we find

$$\hat{P}_2(\Lambda,\gamma,\beta,\tau) = \int_0^\tau ds\ e^{-\Lambda s}\ P_1(\gamma,\beta,s)$$

$$= + \frac{(\Lambda+\gamma)}{2\beta\Lambda}\ P_o(\Lambda+\gamma,\beta,\tau) - \frac{\gamma}{2\beta\Lambda}\ e^{-\Lambda\tau}\ P_o(\gamma,\beta,\tau)$$

$$+ \frac{1}{2\beta\Lambda}\ (1 - e^{-\Lambda\tau}) \qquad \text{(A-25)}$$

and

$$\hat{P}_3(\Lambda,\gamma,\beta,\tau) = \int_0^\tau ds\ e^{-\Lambda s}\ P_2(\gamma,\beta,s)$$

$$= \frac{1}{4\beta^2}\{-\frac{[2\beta+(\gamma\ \ \Lambda)^2]}{\Lambda}\ P_o(\Lambda+\gamma,\beta,\tau)$$

$$+ \frac{(-2\beta+\gamma^2)}{\Lambda}\ e^{-\Lambda\tau}\ P_o(\gamma,\beta,\tau) + (1 - e^{-\beta\tau^2-(\Lambda+\gamma)\tau})$$

$$+ \frac{\gamma}{\Lambda}\ (1 - e^{-\Lambda\tau})\} \qquad \text{(A-26)}$$

Substituting $-\alpha\rightarrow\gamma$ and $\Lambda_1\rightarrow\Lambda$ in Eqs(A-24) - (A-26), we have the results

$$\hat{P}_1(\Lambda_1,\alpha,\beta,\tau) = \frac{1}{\Lambda_1} [P_o(\Lambda_1 - \alpha,\beta,\tau) - e^{-\Lambda_1\tau} P_o(-\alpha,\beta,\tau)], \quad \text{(A-27)}$$

$$\hat{P}_2(\Lambda_1,\alpha,\beta,\tau) = + \frac{1}{2\beta\Lambda_1} [(\Lambda_1-\alpha)P_o(\Lambda_1-\alpha,\beta,\tau)+\alpha e^{-\Lambda_1\tau} P_o(-\alpha,\beta,\tau)$$

$$- 1 + e^{-\Lambda_1\tau}], \quad \text{(A-28)}$$

and

$$\hat{P}_3(\Lambda_1,\alpha,\beta,\tau) = \frac{1}{4\beta^2}\{-\frac{[2\beta+(\Lambda_1-\alpha)^2]}{\Lambda_1} P_o(\Lambda_1-\alpha,\beta,\tau)$$

$$+ \frac{(-2\beta+\alpha^2)}{\Lambda_1} e^{-\Lambda_1\tau} P_o(-\alpha,\beta,\tau)$$

$$+(1 - e^{-\beta\tau^2-(\Lambda_1-\alpha)\tau})+ \frac{\alpha}{\Lambda_1} (1 - e^{-\Lambda_1\tau})\} \quad \text{(A-29)}$$

For the case $\beta = 0$, $\hat{P}_k(\Lambda,\alpha,0,\tau)$ and $\hat{P}_k(\Lambda,0,0,\tau)$ are clearly integrable and convergent for $k = 2,3$ using the limiting forms for $P_k(\gamma,\beta,\tau)$. However, since for $k = 2,3$ these $\hat{P}_k(\Lambda,\alpha,0,\tau)$ and $\hat{P}_k(\Lambda, 0,0,\tau)$ are multiplied by $\beta \propto b/2$ in the model solution, they are not needed. On the other hand $\hat{P}_o(\tau)$, $\hat{P}_1(\tau)$, $\hat{P}_4(\tau)$, and $\hat{P}_5(\tau)$ are needed since their coefficients in the model solution are (or can be) nonvanishing even if $\beta = 0$.

For $\beta = 0$, $\hat{P}_o(\Lambda_1,\tau)$ is still given by Eq. (A-20). For $\hat{P}_1(\Lambda,\alpha,0,\tau)$ we may use

$$\hat{P}_1(\Lambda_1,\alpha,0,\tau) = \frac{1}{\Lambda_1} [P_o(\Lambda_1-\alpha,0,\tau) - e^{-\Lambda_1\tau} P_o(-\alpha,0,\tau)] \quad \text{(A-30)}$$

where Eqs. (A-12) and (A-13) are applicable for $P_o(\gamma,0,\tau)$. Similarly,

$$\hat{P}_4(\gamma,0,\tau) = P_o(\gamma,0,\tau) = \frac{1}{\gamma}(1-e^{-\gamma\tau}) \qquad \text{(A-31)}$$

$$\hat{P}_5(\gamma,0,\tau) = P_1(\gamma,0,\tau) = \frac{1}{\gamma^2}[1 - (1+\gamma\tau)e^{-\gamma\tau}]. \qquad \text{(A-32)}$$

APPENDIX B

EVALUATION OF THE $Q_k(\tau)$ AND $V_k(\tau)$ FUNCTIONS

The functions $Q_k(\tau)$ and $V_k(\tau)$ are defined by

$$Q_k(\tau) = \int_o^\tau ds\ e^{\Lambda^* s}\ M_k(s) \qquad \text{(B-1)}$$

and

$$V_k(\tau) = \int_o^\tau ds\ e^{-\Lambda^* s}\ Q_k(s)\ , \qquad \text{(B-2)}$$

where the $M_k(\tau)$ functions are given explicitly in Appendix A. We shall need these functions for the parameters Λ^*, Λ_1, α, β, and γ non-zero and zero. However, knowing the limiting forms of the $P_k(\gamma,\beta,\tau)$ functions, using the fact that some functions [$Q_2(\tau)$, $Q_3(\tau)$, $Q_5(\tau)$, $V_2(\tau)$, $V_3(\tau)$, and $V_5(\tau)$] have finite $\beta = 0$ limits and are multiplied by β, and that these same functions are expressible in terms of $Q_o(\tau)$, $Q_1(\tau)$, $Q_4(\tau)$, $V_o(\tau)$, $V_1(\tau)$, and $V_4(\tau)$ leads to considerable simplification in that limiting forms are needed only for the latter functions.

Evaluation of $Q_k(\tau)$

$Q_o(\tau)$: For $\Lambda_1 \neq \Lambda^*$ using Eqs. (B-1) and (A-1), we have

$$Q_o(\Lambda^*,\Lambda_1,\tau) = \int_o^\tau ds\; e^{\Lambda^* s}\; e^{-\Lambda_1 s} = \frac{1}{\Lambda_1-\Lambda^*}\,[1-e^{-(\Lambda_1-\Lambda^*)\tau}] \qquad \text{(B-3)}$$

and for $\Lambda_1 = \Lambda^*$, Eq. (B-3) becomes

$$Q_o(\Lambda^*,\Lambda^*,\tau) = \tau\,. \qquad \text{(B-4)}$$

$Q_1(\tau)$: For $\Lambda_1 \neq \Lambda^*$, using Eqs.(B-1), (A-17) and (A-27) we have

$$Q_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \int_o^\tau ds\; e^{\Lambda^* s}\; M_1(\Lambda_1,\alpha,\beta,s)$$

$$= \int_o^\tau ds\; e^{\Lambda^* s}\; e^{-\Lambda_1 s}\; P_o(-\alpha,\beta,s)$$

$$= \frac{1}{\Lambda_1-\Lambda^*}\,[P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau) - e^{-(\Lambda_1-\Lambda^*)\tau} P_o(-\alpha,\beta,\tau)]\,. \qquad \text{(B-5)}$$

For $\Lambda_1 = \Lambda^*$, we have from Eq. (B-5)

$$Q_1(\Lambda^*,\Lambda^*,\alpha,\beta,\tau) = \int_o^\tau ds\; P_o(-\alpha,\beta,s)\,, \qquad \text{(B-6)}$$

where

$$P_o(\gamma,\beta,\tau) = \frac{1}{2}\sqrt{\frac{\pi}{\beta}}\; e^{\gamma^2/4\beta}\,[\mathrm{erf}(\sqrt{\beta}\tau + \frac{\gamma}{2\sqrt{\beta}}) - \mathrm{erf}\,(\frac{\gamma}{2\sqrt{\beta}})] \qquad \text{(B-7)}$$

and

$$\int_0^\tau ds\ P_o(\gamma,\beta,s) = \frac{1}{2\beta}\ [(\gamma + 2\beta\tau)P_o(\gamma,\beta,\tau) - 1 + e^{-\gamma\tau-\beta\tau^2}]. \tag{B-8}$$

Thus,

$$Q_1(\Lambda^*,\Lambda^*,\alpha,\beta,\tau) = \frac{1}{2\beta}\ [(-\alpha + 2\beta\tau)P_o(-\alpha,\beta,\tau) - 1 + e^{\alpha\tau-\beta\tau^2}]. \tag{B-9}$$

Now for $\Lambda_1 = \Lambda^*$, and $\beta = 0$, using Eq. (A-9) in Eq. (B-6) we find

$$Q_1(\Lambda^*,\Lambda^*,\alpha,0,\tau) = \int_0^\tau ds\ P_o(-\alpha,\ 0,s) = \frac{1}{\alpha^2}\ [e^{\alpha\tau} - (1+\alpha\tau)]. \tag{B-10}$$

Finally, if $\Lambda_1 = \Lambda^*$, and $\alpha = \beta = 0$, we have

$$Q_1(\Lambda^*,\Lambda^*,0,0,\tau) = \frac{\tau^2}{2}\ , \tag{B-11}$$

which follows from the limit of Eq. (B-10) as $\alpha \to 0$ or from using Eq. (A-10) for $P_o(0,0,\tau)$ in Eq. (B-10). The limiting forms for Eq. (B-5) for $\alpha = 0$ and $\beta \neq 0$ follow from Eq. (A-8), namely

$$P_o(0,\beta,\tau) = \frac{1}{2}\sqrt{\frac{\pi}{\beta}}\ \ \mathrm{erf}(\sqrt{\beta\tau})\ . \tag{B-12}$$

<u>$Q_2(\tau)$:</u> For $\Lambda_1 \neq \Lambda^*$ and $\beta \neq 0$, using Eqs.(B-1), (A-8), (A-18) and (A-24), we find

$$Q_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \int_0^\tau ds\ e^{\Lambda^* s}\ M_2(\Lambda_1,\alpha,\beta,s)$$

$$= \frac{1}{2\beta(\Lambda_1-\Lambda^*)}\left[(\Lambda_1-\Lambda^*-\alpha)P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau) + \alpha e^{-(\Lambda_1-\Lambda^*)\tau} \times P_o(-\alpha,\beta,\tau) - [1-e^{-(\Lambda_1-\Lambda^*)\tau}]\right]. \quad \text{(B-13)}$$

Further limiting forms are not needed explicitly. For the cases

(a) $\Lambda_1 = \Lambda^*$, $\beta \neq 0$,

(b) $\Lambda_1 = \Lambda^*$, $\beta = 0$, $\alpha \neq \Lambda_1-\Lambda^*$,

(c) $\Lambda_1 = \Lambda^*$, $\beta = 0$, $\alpha = \Lambda_1-\Lambda^*$,

(d) $\Lambda_1 = \Lambda^*$, $\beta = 0$, $\alpha \neq 0$,

(e) $\Lambda_1 = \Lambda^*$, $\beta = 0$, $\alpha = 0$,

the integral for $Q_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau)$ is finite. In addition for $\beta = 0$, $Q_2(\tau)$ is independent of β. Since B_2 has a coefficient involving a factor β, the $\beta = 0$ contribution from $Q_2(\tau)$ vanishes. Re-expressing $Q_2(\tau)$ as

$$Q_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{Q_o(\Lambda^*,\Lambda_1,\tau)-Q_4(\Lambda^*,\Lambda_1-\alpha,\beta,\tau)+\alpha Q_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau)}{2\beta} \quad \text{(B-14)}$$

eliminates the necessity for the $\Lambda_1 = \Lambda^*$ limit since it is automatically accounted for by the limiting forms of $Q_o(\tau)$, $Q_1(\tau)$, and $Q_4(\tau)$. In Eq. (B-14) we have used the identity $\gamma = \Lambda_1-\alpha$ from the definitions given in the text.

<u>$Q_3(\tau)$:</u> For $\Lambda_1 \neq \Lambda^*$ and $\beta \neq 0$, using Eqs.(B-1), (A-7), (A-8), (A-19), and (A-24), we find

$$Q_3(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \int_0^\tau ds\, e^{\Lambda^* s} M_3(\Lambda_1,\alpha,\beta,s)$$

$$= \frac{1}{4\beta^2}\Bigg\{\frac{[2\beta+(\Lambda_1-\Lambda^*-\alpha)^2]}{\Lambda_1-\Lambda^*} P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau)$$

$$- \frac{2\beta+\alpha^2}{\Lambda_1-\Lambda^*} e^{-(\Lambda_1-\Lambda^*)\tau} P_o(-\alpha,\beta,\tau)$$

$$- [1-e^{-\beta\tau^2-(\Lambda_1-\Lambda^*-\alpha)\tau}]$$

$$+ \frac{\alpha}{\Lambda_1-\Lambda^*}[1-e^{-(\Lambda_1-\Lambda^*)\tau}]\Bigg\}. \quad \text{(B-15)}$$

Further limiting cases are not needed explicitly, just as for the $Q_2(\tau)$ function. The coefficient B_3 has a coefficient β, and all the limiting forms involving $\beta = 0$ for $Q_3(\tau)$ are finite and do not involve β. Thus, the $\beta = 0$ contribution from $Q_3(\tau)$ vanishes.

Re-expressing $Q_3(\tau)$ in Eq. (B-15) as

$$Q_3(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{Q_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau)-Q_5(\Lambda^*,\Lambda_1-\alpha,\beta,\tau)+\alpha Q_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau)}{2\beta} \quad \text{(B-16)}$$

eliminates the necessity for the $\Lambda_1 = \Lambda^*$ limit since it is automatically accounted for by the limiting forms of $Q_1(\tau)$, $Q_2(\tau)$, and $Q_5(\tau)$.

$\underline{Q_4(\tau)}$: Using Eqs. (B-1), (A-3), and (A-7) we have

$$Q_4(\Lambda^*,\gamma,\beta,\tau) = \int_0^\tau ds\ e^{\Lambda^* s}\ M_4(\gamma,\beta,s) = P_o(\gamma-\Lambda^*,\beta,\tau). \tag{B-17}$$

The limiting forms are given in Appendix A.

$\underline{Q_5(\tau)}$: Using Eqs. (B-1), (A-4) and (A-7) we have

$$Q_5(\Lambda^*,\gamma,\beta,\tau) = \int_0^\tau ds\ e^{\Lambda^* s}\ M_5(\gamma,\beta,s) = P_1(\gamma-\Lambda^*,\beta,\tau). \tag{B-18}$$

For $\beta \neq 0$, from Appendix A we have

$$Q_5(\Lambda^*,\gamma,\beta,\tau) = \frac{1}{2\beta}\ [-(\gamma-\Lambda^*)P_o(\gamma-\Lambda^*,\beta,\tau)+1-e^{-(\gamma-\Lambda^*)\tau-\beta\tau^2}]. \tag{B-19}$$

Using Eq. (A-12) for $\beta = 0$, $\gamma \neq \Lambda^*$ find

$$Q_5(\Lambda^*,\gamma,0,\tau) = \frac{1}{(\gamma-\Lambda^*)^2}\ \{1-[1+(\gamma-\Lambda^*)\tau]\ e^{-(\gamma-\Lambda^*)\tau}\}. \tag{B-20}$$

For $\beta = 0$ and $\gamma = \Lambda^*$, Eq. (B-20) limits to

$$Q_5(\Lambda^*,\Lambda^*,0,\tau) = \frac{\tau^2}{2}\ . \tag{B-21}$$

Since B_5 has β as a factor, the $\beta = 0$ limits will not contribute.

<u>Evaluation of $V_k(\tau)$:</u>

$\underline{V_o(\tau)}$: For $\Lambda_1 \neq \Lambda^*$, using Eqs. (B-2) and (B-3) we have

$$V_o(\Lambda^*,\Lambda_1,\tau) = \int_0^\tau ds\ e^{-\Lambda^* s}\ Q_o(\Lambda^*,\Lambda_1,s)$$

$$= \frac{1}{\Lambda_1-\Lambda^*}\ [\frac{1}{\Lambda^*}\ (1-e^{-\Lambda^*\tau}) - \frac{1}{\Lambda_1}\ (1-e^{-\Lambda_1\tau})]. \tag{B-22}$$

For $\Lambda_1 = \Lambda^*$, using Eq. (B-4) in Eq. (B-22) we find

$$V_o(\Lambda^*,\Lambda^*,\tau) = \frac{1}{\Lambda^{*2}} [1-(1+\Lambda^*\tau)\ e^{-\Lambda^*\tau}] \ . \tag{B-23}$$

<u>$V_1(\tau)$:</u> For $\Lambda_1 \neq \Lambda^*$, using Eqs. (B-2), (B-5), and (A-24) we find

$$V_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \int_o^\tau ds\ e^{-\Lambda^* s}\ Q_1(\Lambda^*,\Lambda_1,\alpha,\beta,s)$$

$$= \frac{1}{\Lambda_1\Lambda^*}\ P_o(\Lambda_1-\alpha,\beta,\tau)$$

$$- \frac{1}{\Lambda_1-\Lambda^*}\ [\frac{e^{-\Lambda^*\tau}}{\Lambda^*}\ P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau)$$

$$- \frac{e^{-\Lambda_1\tau}}{\Lambda_1}\ P_o(-\alpha,\beta,\tau)] \ . \tag{B-24}$$

One could use the identity

$$\int_o^\tau ds\ s\ e^{-\Lambda s}\ P_o(\gamma,\beta,s) = -\frac{\partial}{\partial\Lambda}\ [\hat{P}_1(\Lambda,\gamma,\beta,\tau)]$$

$$= \frac{2\beta-\Lambda(\Lambda+\gamma)}{2\beta\Lambda^2}\ P_o(\Lambda+\gamma,\beta,\tau) - \frac{1+\Lambda\tau}{\Lambda^2}\ e^{-\Lambda\tau}P_o(\gamma,\beta,\tau)$$

$$+ \frac{1}{2\beta\Lambda}\ [1-e^{-\beta\tau^2-(\gamma+\Lambda)\tau}] \ , \tag{B-25}$$

to solve explicitly for $V_1(\Lambda^*,\Lambda^*,\alpha,\beta,\tau)$. On the other hand, one can rewrite Eq. (B-24) as

$$V_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{V_4(\Lambda^*,\Lambda_1-\alpha,\beta,\tau) - e^{-\Lambda^*\tau} Q_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau)}{\Lambda_1} \qquad \text{(B-26)}$$

and incorporate the limiting forms from $Q_1(\tau)$ and $V_4(\tau)$.

$\underline{V_2(\tau)}$: For $\Lambda_1 \neq \Lambda^*$ and $\beta \neq 0$, using Eqs. (B-2), (B-13), and (A-24), we find

$$V_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \int_0^\tau ds\ e^{-\Lambda^* s}\ Q_2(\Lambda^*,\Lambda_1,\alpha,\beta,s)$$

$$= \frac{\Lambda_1-\Lambda^*-\alpha}{2\beta(\Lambda_1-\Lambda^*)}\ \frac{1}{\Lambda^*}\ [P_o(\Lambda_1-\alpha,\beta,\tau)-e^{-\Lambda^*\tau}P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau)]$$

$$+ \frac{\alpha}{2\beta(\Lambda_1-\Lambda^*)}\ \frac{1}{\Lambda_1-\Lambda^*}\ [P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau)-e^{(\Lambda_1-\Lambda)\tau} \times P_o(-\alpha,\beta,\tau)]$$

$$- \frac{1}{2\beta(\Lambda_1-\Lambda^*)}\ [\frac{1}{\Lambda^*}\ (1-e^{-\Lambda^*\tau}) - \frac{1}{\Lambda_1}\ (1-e^{-\Lambda 1\tau})]. \qquad \text{(B-27)}$$

Further limiting forms are not needed explicitly. For the cases given in connection with $Q_2(\tau)$, all the $V_2(\tau)$ integrals are also finite. In addition in the $\beta = 0$ limit they are finite and independent of β. Since B_2 has a factor β, the contribution $B_2V_2(\tau)$ is zero.

We may re-express $V_2(\tau)$ as

$$V_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{V_o(\Lambda^*,\Lambda_1,\tau) - V_4(\Lambda^*,\Lambda_1-\alpha,\beta,\tau) + \alpha V_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau)}{2\beta}, \tag{B-28}$$

which eliminates the necessity for using an explicit $\Lambda_1 = \Lambda^*$ limit except through the limiting forms for $V_o(\tau)$, $V_1(\tau)$, and $V_4(\tau)$.

$\underline{V_3(\tau)}$: For $\Lambda_1 \neq \Lambda^*$ and $\beta \neq 0$, using Eqs. (B-2), (B-15) and (A-24), we find

$$V_3(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \int_o^\tau ds\ e^{-\Lambda^* s}\ Q_3(\Lambda^*,\Lambda_1,\alpha,\beta,s)$$

$$= \frac{1}{4\beta^2}\{\frac{[2\beta+(\Lambda_1-\Lambda^*-\alpha)^2]}{\Lambda^*(\Lambda_1-\Lambda^*)} - \frac{2\beta+\alpha^2}{\Lambda_1(\Lambda_1-\Lambda^*)} + 1\}P_o(\Lambda_1-\alpha,\beta,\tau)$$

$$+ \frac{1}{4\beta^2}\frac{2\beta+\alpha^2}{\Lambda_1(\Lambda_1-\Lambda^*)}\ e^{-\Lambda_1\tau}\ P_o(-\alpha,\beta,\tau)$$

$$- \frac{1}{4\beta^2}\frac{2\beta+(\Lambda_1-\Lambda^*-\alpha^2)}{\Lambda^*(\Lambda_1-\Lambda^*)}\ e^{-\Lambda^*\tau}\ P_o(\Lambda_1-\Lambda^*-\alpha,\beta,\tau)$$

$$- \frac{1}{4\beta^2}\frac{1}{\Lambda^*}(1-e^{-\Lambda^*\tau})$$

$$+ \frac{1}{4\beta^2}\frac{\alpha}{\Lambda_1-\Lambda^*}[\frac{1}{\Lambda^*}(1-e^{-\Lambda^*\tau}) - \frac{1}{\Lambda_1}(1-e^{-\Lambda_1\tau})] \tag{B-29}$$

Further limiting forms are not needed explicitly, just as for the $V_2(\tau)$ function. The coefficient B_3 has a factor β, and all the limiting forms involving $\beta = 0$ for $V_3(\tau)$ are finite and do not involve β. Thus, the $B_3V_3(\tau)$ contribution vanishes for $\beta = 0$.

Re-expressing $V_3(\tau)$ we have

$$V_3(\Lambda^*,\Lambda_1,\alpha,\beta,\tau) = \frac{V_1(\Lambda^*,\Lambda_1,\alpha,\beta,\tau)-V_5(\Lambda^*,\Lambda_1-\alpha,\beta,\tau)+\alpha V_2(\Lambda^*,\Lambda_1,\alpha,\beta,\tau)}{2\beta}, \tag{B-30}$$

which eliminates the necessity for using explicit limiting forms for $\Lambda_1 = \Lambda^*$ except in $V_1(\tau)$, $V_2(\tau)$ and $V_5(\tau)$. Of course, $V_2(\tau)$, as given by Eq. (B-28) is expressible in terms of $V_o(\tau)$, $V_1(\tau)$, and $V_4(\tau)$.

$\underline{V_4(\tau)}$: Using Eqs. (B-2),(B-17), and (A-24), we find

$$V_4(\Lambda^*,\gamma,\beta,\tau) = \int_o^\tau ds\ e^{-\Lambda^* s}\ Q_4(\Lambda^*,\gamma,\beta,s)$$

$$= \frac{1}{\Lambda^*}\left[P_o(\gamma,\beta,\tau) - e^{-\Lambda^*\tau}\ P_o(\gamma-\Lambda^*,\beta,\tau)\right] \tag{B-31}$$

The limiting forms for $V_4(\tau)$ are accounted for by the forms given for the $P_o(\gamma,\beta,\tau)$ function in Appendix A.

$\underline{V_5(\tau)}$: For $\beta \neq 0$, using Eqs. (B-2),(B-18), and (A-24), we find

$$V_5(\Lambda^*,\gamma,\beta,\tau) = \int_0^\tau ds\; e^{-\Lambda^* s}\; Q_5(\Lambda^*,\gamma,\beta,s)$$

$$= -\frac{\gamma}{2\beta\Lambda^*} P_o(\gamma,\beta,\tau) + \frac{\gamma-\Lambda^*}{2\beta\Lambda^*} e^{-\Lambda^*\tau} P_o(\gamma-\Lambda^*,\beta,\tau)$$

$$+ \frac{1}{2\beta\Lambda^*} (1-e^{-\Lambda^*\tau}) \tag{B-32}$$

The limiting cases for $\beta = 0$ yield finite integrals for $V_5(\tau)$. Since B_5 has a factor β, the $\beta = 0$ limit contribution from $V_5(\tau)$ vanishes. The necessity for writing the other limiting cases for $V_5(\tau)$ is removed by re-expressing Eq. (B-32) for $\beta \neq 0$ as

$$V_5(\Lambda^*,\gamma,\beta,\tau) = \frac{\frac{1}{\Lambda^*}(1-e^{-\Lambda^*\tau}) - \gamma V_4(\Lambda^*,\gamma,\beta,\tau) - e^{-\Lambda^*\tau} Q_4(\Lambda^*,\gamma,\beta,\tau)}{2\beta} \tag{B-33}$$

and using the limiting forms for $V_4(\tau)$ and $Q_4(\tau)$.

APPENDIX C
CODE LISTING FOR LARC-1

LASL Identification: LP-0721

COPYSF 3 FILES FROM COMPILF

```
      PROGRAM LARC1 (INP,OUT,FILM,FSET12=FILM)
      PARAMETER (N500=500),(N501=N500+1)
      REAL NPRIME,L,N1,N2,N3,N4,NZER,NZERO,LAMBDA
      DIMENSION NPRIME(N500), L(N500), T(N501), RPRIME(N500), PSUM(N500)
     1, V(N500), FF(N501), ZN(N500), ZR(N500), ZA(N500), ZF(N500), ZN1(N
     2500), ZN2(N500), ZN3(N500), ZN4(N500), ZR1(N500), ZR2(N500), ZR3(N
     3500), ZR4(N500), ZA1(N500), ZA2(N500), ZA3(N500), ZA4(N500), ZF1(N
     4500), ZF2(N500), ZF3(N500), ZF4(N500), TABLE(N500,4), TABLX(N500,4
     5)
      DIMENSION TITLE1(7), TITLE2(6), TITLE3(4), XLIM(2), YLIM(2)
      DIMENSION ISET(6), NSET(5)
      COMMON /LJNEW/ IXSAVE,IYSAVE,IX2,IY2
      LOGICAL LAGE,BISO,NOBGAS
      REAL N1OLD,N2OLD,N3OLD,N4OLD
      COMMON /LA/ LAGE,AGE,MFUEL,ISO,BISO
      COMMON /TMODEL/ MODEL
C     MODEL = 1     SORS DATA FROM TMAX, TAVE GRAPHS
C     MODEL = 2     CORCON TABULAR DATA
C     MODEL = 3     FU - CORT TABULAR DATA
      DATA ISET/1,5,10,25,100,200/
      DATA NSET/20,40,100,300,500/
      INUM=6
      NNUM=5
      NEQ=4
C     NEQ INDICATES WHICH EQUATION SET TO USE
C     NEQ = 1        SIMPLE EQ FIRST HALF, OLD EQ SECOND HALF
C     NEQ = 2        SIMPLE EQ BOTH HALVES
C     NEQ = 3        LINEAR RELEASE BOTH HALVES
C     NEQ = 4        LINEAR FAILURE BOTH HALVES
      NZER=3.1*3.E9/3.7
      CALL GETQ (4LKJBN,JOBNAME)
      CALL DATE1 (DATE)
      Z=FRACP0(0.0)
      ITEMP=4
      ITEMP=1
      IF (ITEMP.EQ.4) Z=SPLINE(0.0,0.0)
   10 CONTINUE
      READ 300, NAME,LAMBDA,ISO,YIELD,AGE,MFUEL,LAGE,FRAC,NOBGAS
      IF (ISO.LT.1) GO TO 200
      NZERO=NZER*YIELD
C     UNITS OF NZERO ARE CI (CURIES).
      PRINT 220, NAME,LAMBDA,ISO,YIELD,NZERO
      PRINT 230, AGE,LAGE,FRAC
      IF (NOBGAS) PRINT 240
      VSET=0.9
      IF (NOBGAS) VSET=0.0
C     I ASSUMED RELEASED AS  91 PERCENT ELEMENTAL, 5 PERCENT PARTICULATE
C      AND 4 PERCENT ORGANIC.
C     FOR THESE MATERIALS THE CLEANUP SYSTEM FILTER EFFICIENCIES ARE
C      .90, .99, AND .70 RESPECTIVELY.
C     THEREFORE EACH RELEASE IS REDUCED BY
C          (.90).91 + (.05).99 + (.04).70 = .8965
C     RELEASED FRACTION IS THEREFORE .1035
C     LAMBDA IS THE RADIOACTIVE DECAY CONSTANT IN UNITS OF PER HOUR
      IVEMAX=100
      NTOT=100
      PRINT 210, NEQ
      IPRTF=NTOT/20
      PRINT 250, NTOT
C     NTOT IS THE TOTAL NUMBER OF INTERVALS
```

```
      DT=20./NTOT                                                        LARC1
      NTOT1=NTOT+1                                                       LARC1
      DO 20 I=1,NTOT1                                                    LARC1
   20 T(I)=(I-1)*DT                                                      LARC1
      DO 170 NR=1,ITEMP                                                  LARC1
      MODEL=NR                                                           LARC1
      PRINT 260, MODEL,MFUEL,NAME                                        LARC1
      IF (NR.EQ.4) GO TO 40                                              LARC1
C     CALCULATE SECOND DERIVATIVES FOR SPLINE....                        LARC1
      Z=TMAX0(0.0)                                                       LARC1
      Z=TAVE0(0.0)                                                       LARC1
      Z=TEMP0(0.0)                                                       LARC1
C     T(I) ARE THE TIMES OF THE INTERVAL BOUNDARIES (IN HOURS)           LARC1
      TDELT=TEMP(0.0)-1174.4                                             LARC1
      DO 30 I=1,NTOT1                                                    LARC1
      TIME=T(I)                                                          LARC1
   30 FF(I)=(TMAX(TIME)-TAVE(TIME))/TDELT                                LARC1
   40 CONTINUE                                                           LARC1
      XLIM(1)=T(1)                                                       LARC1
      XLIM(2)=T(NTOT1)                                                   LARC1
      DO 50 I=1,NTOT                                                     LARC1
      ZN1(I)=0.0                                                         LARC1
      ZN2(I)=0.0                                                         LARC1
      ZN3(I)=0.0                                                         LARC1
      ZN4(I)=0.0                                                         LARC1
      ZR1(I)=0.0                                                         LARC1
      ZR2(I)=0.0                                                         LARC1
      ZR3(I)=0.0                                                         LARC1
      ZR4(I)=0.0                                                         LARC1
      ZA1(I)=0.0                                                         LARC1
      ZA2(I)=0.0                                                         LARC1
      ZA3(I)=0.0                                                         LARC1
      ZA4(I)=0.0                                                         LARC1
      ZF1(I)=0.0                                                         LARC1
      ZF2(I)=0.0                                                         LARC1
      ZF3(I)=0.0                                                         LARC1
      ZF4(I)=0.0                                                         LARC1
C     1 REFERS TO FAILED BISO                                            LARC1
C     2 REFERS TO FAILED TRISO                                           LARC1
C     3 REFERS TO INTACT BISO                                            LARC1
C     4 REFERS TO INTACT TRISO                                           LARC1
C     NPRIME(I) IS THE AMOUNT OF THE ISOTOPE PRESENT IN THE CONTAINMENT  LARC1
C     BUILDING AT THE END OF THE ITH TIME INTERVAL (I.E. AT TIME T(I)).  LARC1
      NPRIME(I)=0.0                                                      LARC1
      RPRIME(I)=0.0                                                      LARC1
      RSUM(I)=0.0                                                        LARC1
      L(I)=.001/24                                                       LARC1
      V(I)=VSET                                                          LARC1
C     L IS THE CONTAINMENT BUILDING LEAK RATE..ASSUMED TO BE .001/DAY    LARC1
C     FOR THE FIRST 24 HOURS AND .0005/DAY THEREAFTER.                   LARC1
C     VSET=.8965                                                         LARC1
C     VSET ASSUMED TO BE .9 BY FOLEY.                                    LARC1
   50 CONTINUE                                                           LARC1
      PRINT 270, IVFMAX                                                  LARC1
      PER=1./IVFMAX                                                      LARC1
      DO 120 IVF=1,IVFMAX                                                LARC1
      BIN=PER*(IVF-0.5)                                                  LARC1
      IF (NR.NE.4) TEM=TEMP(BIN)                                         LARC1
C     TEM IS THE INITIAL AVERAGE TEMPERATURE OF ONE PERCENT OF THE TOTAL LARC1
C     CORE INVENTORY                                                     LARC1
      IF (NR.NE.4) TE=FF(1)*(TEM-1174.4)+TAVE(T(1))                      LARC1
      IF (NR.EQ.4) TE=SPL(0.,BIN)                                        LARC1
      FB=FRACB(TE)                                                       LARC1
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```
      FT=FRACT(TE)                                                      LARC1
C     FRACB = FRACTION OF BISO PARTICLES WITH FAILED COATINGS           LARC1
C     FRACT = FRACTION OF TRISO PARTICLES WITH FAILED COATINGS          LARC1
C     FRAC = 0.6 = FRACTION OF BISO FUEL IN THE LOADING                 LARC1
      BISO=.T.                                                          LARC1
      R1=RF(TE)                                                         LARC1
      R3=RI(TE)                                                         LARC1
      BISO=.FALSE.                                                      LARC1
      R2=RF(TE)                                                         LARC1
      R4=RI(TE)                                                         LARC1
      N1=NZERO*PER*FRAC*FB                                              LARC1
      N2=NZERO*PER*(1.0-FRAC)*FT                                        LARC1
      N3=NZERO*PER*FRAC*(1.0-FB)                                        LARC1
      N4=NZERO*PER*(1.0-FRAC)*(1.0-FT)                                  LARC1
      A1=0.0                                                            LARC1
      A2=0.0                                                            LARC1
      A3=0.0                                                            LARC1
      A4=0.0                                                            LARC1
C     NI IS THE AMOUNT OF THE ITH COMPONENT REMAINING IN THE CORE       LARC1
C     RRI IS THE AMOUNT OF THE ITH COMPONENT RELEASED TO THE COOLANT    LARC1
C     AI IS THE AMOUNT OF THE ITH COMPONENT IN THE COOLANT              LARC1
C     ALL THESE REFER TO THE GIVEN TIME STEP AND CORE FRACTION.         LARC1
      SUM=0.0                                                           LARC1
      PN1=0.0                                                           LARC1
      PN2=0.0                                                           LARC1
      PN3=0.0                                                           LARC1
      PN4=0.0                                                           LARC1
      DO 110 I=1,NTOT                                                   LARC1
      DT=T(I+1)-T(I)                                                    LARC1
      FBOLD=FB                                                          LARC1
      FTOLD=FT                                                          LARC1
      TIME=T(I+1)                                                       LARC1
C     TEMPB=TEMPERATURE AT BOUNDARY TIMES                               LARC1
      IF (NR.NE.4) TEMPB=FF(I+1)*(TEM-1174.4)+TAVE(TIME)                LARC1
      IF (NR.EQ.4) TEMPB=SPL(TIME,BIN)                                  LARC1
      FB=FRACB(TEMPB)                                                   LARC1
      FT=FRACT(TEMPB)                                                   LARC1
      R1OLD=R1                                                          LARC1
      R2OLD=R2                                                          LARC1
      R3OLD=R3                                                          LARC1
      R4OLD=R4                                                          LARC1
      BISO=.TRUE.                                                       LARC1
      R1=RF(TEMPB)                                                      LARC1
      R3=RI(TEMPB)                                                      LARC1
      BISO=.FALSE.                                                      LARC1
      R2=RF(TEMPB)                                                      LARC1
      R4=RI(TEMPB)                                                      LARC1
C     R(I) IS THE AVERAGE RELEASE CONSTANT OF THE ISOTOPE DURING THE ITH LARC1
C     INTERVAL.                                                         LARC1
      N1OLD=N1                                                          LARC1
      N2OLD=N2                                                          LARC1
      N3OLD=N3                                                          LARC1
      N4OLD=N4                                                          LARC1
      DECAY=LAMBDA+V(I)+L(I)                                            LARC1
      GO TO (60,70,80,90), NEQ                                          LARC1
   60 CONTINUE                                                          LARC1
      CALL CALC1 (N1,N3,R1,R3,LAMBDA,DT,FB,N1,N3,RR1,RR3,R1OLD,R3OLD)   LARC1
      CALL CALC1 (N2,N4,R2,R4,LAMBDA,DT,FT,N2,N4,RR2,RR4,R2OLD,R4OLD)   LARC1
      CALL FTN (PN1,RP1,RR1,LAMBDA,DECAY,DT,L(I))                       LARC1
      CALL FTN (PN2,RP2,RR2,LAMBDA,DECAY,DT,L(I))                       LARC1
      CALL FTN (PN3,RP3,RR3,LAMBDA,DECAY,DT,L(I))                       LARC1
      CALL FTN (PN4,RP4,RR4,LAMBDA,DECAY,DT,L(I))                       LARC1
      GO TO 100                                                         LARC1
```

```
   70 CONTINUE                                                              LARC1
      CALL CALC1 (N1,N3,R1,R3,LAMBDA,DT,FB,N1,N3,RR1,RR3,R1OLD,R3OLD)       LARC1
      CALL CALC1 (N2,N4,R2,R4,LAMBDA,DT,FT,N2,N4,RR2,RR4,R2OLD,R4OLD)       LARC1
      CALL FTN1 (PN1,RP1,LAMBDA,DECAY,DT,L(I),N1OLD,R1,R1OLD)               LARC1
      CALL FTN1 (PN2,RP2,LAMBDA,DECAY,DT,L(I),N2OLD,R2,R2OLD)               LARC1
      CALL FTN1 (PN3,RP3,LAMBDA,DECAY,DT,L(I),N3OLD,R3,R3OLD)               LARC1
      CALL FTN1 (PN4,RP4,LAMBDA,DECAY,DT,L(I),N4OLD,R4,R4OLD)               LARC1
      GO TO 100                                                             LARC1
   80 CONTINUE                                                              LARC1
      CALL CALC2 (N1,N3,R1,R3,LAMBDA,DT,FB,N1,N3,RR1,RR3,R1OLD,R3OLD)       LARC1
      CALL CALC2 (N2,N4,R2,R4,LAMBDA,DT,FT,N2,N4,RR2,RR4,R2OLD,R4OLD)       LARC1
      CALL FTN2 (PN1,RP1,LAMBDA,DECAY,DT,L(I),N1OLD,R1,R1OLD)               LARC1
      CALL FTN2 (PN2,RP2,LAMBDA,DECAY,DT,L(I),N2OLD,R2,R2OLD)               LARC1
      CALL FTN2 (PN3,RP3,LAMBDA,DECAY,DT,L(I),N3OLD,R3,R3OLD)               LARC1
      CALL FTN2 (PN4,RP4,LAMBDA,DECAY,DT,L(I),N4OLD,R4,R4OLD)               LARC1
      GO TO 100                                                             LARC1
   90 CONTINUE                                                              LARC1
      CALL CALC3 (N1,N3,R1,R3,LAMBDA,DT,FB,FBOLD,N1,N3,RR1,RR3,R1OLD,R3O   LARC1
     1LD)                                                                   LARC1
      CALL CALC3 (N2,N4,R2,R4,LAMBDA,DT,FT,FTOLD,N2,N4,RR2,RR4,R2OLD,R4O   LARC1
     1LD)                                                                   LARC1
      CALL FTN3 (PN1,PN3,RP1,RP3,LAMBDA,DECAY,DT,L(I),N1OLD,N3OLD,R1,R1O   LARC1
     1LD,R3,R3OLD,FB,FBOLD)                                                 LARC1
      CALL FTN3 (PN2,PN4,RP2,RP4,LAMBDA,DECAY,DT,L(I),N2OLD,N4OLD,R2,R2O   LARC1
     1LD,R4,R4OLD,FT,FTOLD)                                                 LARC1
  100 CONTINUE                                                              LARC1
      ELD=EXP(-LAMBDA*DT)                                                   LARC1
      A1=A1*ELD+RR1                                                         LARC1
      A2=A2*ELD+RR2                                                         LARC1
      A3=A3*ELD+RR3                                                         LARC1
      A4=A4*ELD+RR4                                                         LARC1
C     ZNI(J) IS THE TOTAL AMOUNT OF THE ITH COMPONENT REMAINING IN THE     LARC1
C     CORE AT THE END OF THE JTH INTERVAL                                   LARC1
C     ZRI(J) IS THE TOTAL AMOUNT OF THE ITH COMPONENT RELEASED TO THE      LARC1
C     COOLANT DURING THE JTH INTERVAL                                       LARC1
C     ZAI(J) IS THE AMOUNT OF THE ITH COMPONENT IN THE COOLANT AT THE      LARC1
C     END OF THE JTH INTERVAL                                               LARC1
C     ZFI(J) IS THE FRACTION OF THE ITH COMPONENT IN THE COOLANT AT THE    LARC1
C     END OF THE JTH INTERVAL                                               LARC1
      PN=PN1+PN2+PN3+PN4                                                    LARC1
      RP=RP1+RP2+RP3+RP4                                                    LARC1
      NPRIME(I)=NPRIME(I)+PN                                                LARC1
      RPRIME(I)=RPRIME(I)+RP                                                LARC1
      SUM=SUM+RP                                                            LARC1
      RSUM(I)=RSUM(I)+SUM                                                   LARC1
      ZN1(I)=ZN1(I)+N1                                                      LARC1
      ZN2(I)=ZN2(I)+N2                                                      LARC1
      ZN3(I)=ZN3(I)+N3                                                      LARC1
      ZN4(I)=ZN4(I)+N4                                                      LARC1
      ZR1(I)=ZR1(I)+RR1                                                     LARC1
      ZR2(I)=ZR2(I)+RR2                                                     LARC1
      ZR3(I)=ZR3(I)+RR3                                                     LARC1
      ZR4(I)=ZR4(I)+RR4                                                     LARC1
      ZA1(I)=ZA1(I)+A1                                                      LARC1
      ZA2(I)=ZA2(I)+A2                                                      LARC1
      ZA3(I)=ZA3(I)+A3                                                      LARC1
      ZA4(I)=ZA4(I)+A4                                                      LARC1
      ZF1(I)=ZF1(I)+A1/NZERO                                                LARC1
      ZF2(I)=ZF2(I)+A2/NZERO                                                LARC1
      ZF3(I)=ZF3(I)+A3/NZERO                                                LARC1
      ZF4(I)=ZF4(I)+A4/NZERO                                                LARC1
  110 CONTINUE                                                              LARC1
  120 CONTINUE                                                              LARC1
```

```
      DO 130 I=1,NTOT                                                   LARC1
      ZN(I)=ZN1(I)+ZN2(I)+ZN3(I)+ZN4(I)                                 LARC1
      ZR(I)=ZR1(I)+ZR2(I)+ZR3(I)+ZR4(I)                                 LARC1
      ZA(I)=ZA1(I)+ZA2(I)+ZA3(I)+ZA4(I)                                 LARC1
      ZF(I)=ZF1(I)+ZF2(I)+ZF3(I)+ZF4(I)                                 LARC1
      TABLE(I,NR)=ZF(I)                                                 LARC1
      TABLX(I,NR)=RSUM(I)                                               LARC1
  130 CONTINUE                                                          LARC1
      PRINT 310                                                         LARC1
      PRINT 320, (I,T(I+1),ZR(I),ZN(I),ZA(I),ZF(I),I=IPRTF,NTOT,IPRTF)  LARC1
      IF (NR.NE.ITEMP) GO TO 160                                        LARC1
      IOP=I                                                             LARC1
C     LINEAR-LINEAR PLOT  X,Y AXES                                      LARC1
      NCHAR=27                                                          LARC1
C     CHARACTER WILL BE  .                                              LARC1
      ICON=1                                                            LARC1
C     POINTS WILL BE CONNECTED                                          LARC1
      YLIM(1)=100.                                                      LARC1
      YLIM(2)=0.                                                        LARC1
      DO 140 II=1,NTOT                                                  LARC1
      DO 140 JJ=1,NR                                                    LARC1
      YLIM(1)=AMIN1(YLIM(1),TABLE(II,JJ))                               LARC1
      YLIM(2)=AMAX1(YLIM(2),TABLE(II,JJ))                               LARC1
  140 CONTINUE                                                          LARC1
      CALL SPLOT (IOP,2,XLIM,YLIM,48,0)                                 LARC1
      ENCODE (67,280,TITLE1)NAME,ISO,MFUEL,AGE,LAGE,FRAC,YIELD          LARC1
      ENCODE (60,290,TITLE2)NTOT,IVFMAX,JOBNAME,DATE                    LARC1
      ENCODE (35,240,TITLE3)                                            LARC1
      DO 150 IR=1,NR                                                    LARC1
      CALL PLOT (NTOT,T(2),1,TABLE(1,IR),1,NCHAR,ICON)                  LARC1
      ENCODE (5,350,TSAVE)IR                                            LARC1
      CALL WLCH (IXSAVE-15,IYSAVE,5,TSAVE,1)                            LARC1
  150 CONTINUE                                                          LARC1
      CALL WLCV (50,800,20,20HFRACTION IN COOLANT ,1)                   LARC1
      CALL WLCH (300,940,36,36HTIME AFTER ONSET OF ACCIDENT (HOURS),1)  LARC1
      CALL WLCH (100,965,67,TITLE1,1)                                   LARC1
      CALL WLCH (100,990,60,TITLE2,1)                                   LARC1
      IF (NEQ.EQ.1) CALL WLCH (100,5,64,64HNEQ=1  CONSTANT RELEASE RATE, LARC1
     1 CONSTANT FAILURE, AVERAGED RELEASE,1)                            LARC1
      IF (NEQ.EQ.2) CALL WLCH (100,5,46,46HNEQ=2  CONSTANT RELEASE RATE, LARC1
     1 CONSTANT FAILURE,1)                                              LARC1
      IF (NEQ.EQ.3) CALL WLCH (100,5,44,44HNEQ=3  LINEAR RELEASE RATE, C LARC1
     1ONSTANT FAILURE,1)                                                LARC1
      IF (NEQ.EQ.4) CALL WLCH (100,5,44,44HNEQ=4  CONSTANT RELEASE RATE, LARC1
     1 LINEAR FAILURE,1)                                                LARC1
      CALL ADV (1)                                                      LARC1
  160 CONTINUE                                                          LARC1
      PRINT 340                                                         LARC1
      PRINT 330, (I,T(I+1),NPRIME(I),RPRIME(I),RSUM(I),I=IPRTF,NTOT,IPRT LARC1
     1F)                                                                LARC1
      IF (NR.NE.ITEMP) GO TO 190                                        LARC1
      YLIM(1)=100.                                                      LARC1
      YLIM(2)=0.                                                        LARC1
      DO 170 II=1,NTOT                                                  LARC1
      DO 170 JJ=1,ITEMP                                                 LARC1
      YLIM(1)=AMIN1(YLIM(1),TABLX(II,JJ))                               LARC1
      YLIM(2)=AMAX1(YLIM(2),TABLX(II,JJ))                               LARC1
  170 CONTINUE                                                          LARC1
      CALL SPLOT (IOP,2,XLIM,YLIM,48,0)                                 LARC1
      DO 180 IS=1,ITEMP                                                 LARC1
      CALL PLOT (NTOT,T(2),1,TABLX(1,IS),1,NCHAR,ICON)                  LARC1
      ENCODE (5,350,TSAVE)IS                                            LARC1
      CALL WLCH (IXSAVE-15,IYSAVE,5,TSAVE,1)                            LARC1
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180 CONTINUE                                                            LARC1
    CALL WLCV (50,800,26,26HCUMULATED RELEASE (CURIES),1)               LARC1
    IF (NEQ.EQ.1) CALL WLCH (100,5,64,64HNEQ=1  CONSTANT RELEASE RATE,  LARC1
   1 CONSTANT FAILURE, AVERAGED RELEASE,1)                              LARC1
    IF (NEQ.EQ.2) CALL WLCH (100,5,46,46HNEQ=2  CONSTANT RELEASE RATE,  LARC1
   1 CONSTANT FAILURE,1)                                                LARC1
    IF (NEQ.EQ.3) CALL WLCH (100,5,44,44HNEQ=3  LINEAR RELEASE RATE, C  LARC1
   1ONSTANT FAILURE,1)                                                  LARC1
    IF (NEQ.EQ.4) CALL WLCH (100,5,44,44HNEQ=4  CONSTANT RELEASE RATE,  LARC1
   1 LINEAR FAILURE,1)                                                  LARC1
    CALL WLCH (300,940,36,36HTIME AFTER ONSET OF ACCIDENT (HOURS),1)    LARC1
    CALL WLCH (100,965,67,TITLE1,1)                                     LARC1
    CALL WLCH (100,990,60,TITLE2,1)                                     LARC1
    IF (NOBGAS) CALL WLCH (100,1023,35,TITLE3,1)                        LARC1
    CALL ADV (1)                                                        LARC1
190 CONTINUE                                                            LARC1
    GO TO 10                                                            LARC1
200 CALL EXIT                                                           LARC1
C                                                                       LARC1
210 FORMAT (* NEQ =*,I1)                                                LARC1
220 FORMAT (1X,A10,5X,16HDECAY CONSTANT =,E10.3,5X,7HGROUP =,I2,5X,7HY  LARC1
   1IELD =,E10.3,5X,7HNZERO =,F10.3)                                    LARC1
230 FORMAT (6H AGE =,F6.2,5X,6HLAGE =,L1,5X,6HFRAC =,F6.2)             LARC1
240 FORMAT (* NOBLE GAS....CLEANUP RATE ZERO     *)                     LARC1
250 FORMAT (* NTOT =*,I5)                                               LARC1
260 FORMAT (* TEMPERATURE MODEL USED =*,I2,5X,*MFUEL =*,I1,5X,*ISOTOPE  LARC1
   1 =*,A10)                                                            LARC1
270 FORMAT (* IVFMAX =*,I5)                                             LARC1
280 FORMAT (A10,*ISO=*,I2,2X,*MFUEL=*,I1,2X,*AGE=*,F4.1,2X,*LAGE=*,L1,  LARC1
   12X,*FRAC=*,F4.1,2X,*YIELD=*,F5.2)                                   LARC1
290 FORMAT (*NTD!=*,I4,2X,*IVFMAX=*,I3,10X,*JOB=*,A10,2X,*DATE=*,A8)    LARC1
300 FORMAT (A10,E10.3,I10,E10.3,F8.2,I1,L1,F10.3,9X,I1)                LARC1
310 FORMAT (* INTERVAL NO.      TIME        AMOUNT RELEASED       AMOUNT R LARC1
   1EMAINING    AMOUNT IN COOLANT    FRACTION IN COOLANT*//)            LARC1
320 FORMAT (I10,0PF12.2,1P4F21.2)                                       LARC1
330 FORMAT (I10,F12.2,1PE25.5,0P2F25.5)                                 LARC1
340 FORMAT (/13H INTERVAL NO.,5X,4HTIME,5X,23HAMT IN CONTAINMENT BLDG.  LARC1
   113X,12HAMT RELEASED,8X,17HCUMULATED RELEASE,//)                     LARC1
350 FORMAT (I1,4X)                                                      LARC1
    END                                                                 LARC1
    FUNCTION RI (T)                                                     LARC1
    LOGICAL LAGE,BISO                                                   LARC1
    COMMON /LA/ LAGE,AGE,MFUEL,ISO,BISO                                 LARC1
    IF (MFUEL.EQ.1) GO TO 160                                           LARC1
    GO TO (10,30,40,60,80,90,100,110,130,150), ISO                      LARC1
 10 IF (BISO) GO TO 20                                                  LARC1
    RI=5.46686*EXP(-25798./T)                                           LARC1
    RETURN                                                              LARC1
 20 RI=39.3*EXP(-12000./T)                                              LARC1
    RETURN                                                              LARC1
 30 RI=597.69*EXP(-23157./T)                                            LARC1
    RETURN                                                              LARC1
 40 IF (BISO) GO TO 50                                                  LARC1
    RI=.012282*EXP(-14834./T)                                           LARC1
    RETURN                                                              LARC1
 50 RI=171.91*EXP(-17858./T)                                            LARC1
    RETURN                                                              LARC1
 60 IF (BISO) GO TO 70                                                  LARC1
    RI=5.46686*EXP(-25798./T)                                           LARC1
    RETURN                                                              LARC1
 70 RI=1.58225E5*EXP(-28652.5/T)                                        LARC1
    RETURN                                                              LARC1
 80 RI=.010742*EXP(-10313./T)                                           LARC1
```

```
      RETURN
   90 RI=.04427*EXP(-10482./T)
      RETURN
  100 RI=5.40686*EXP(-25798./T)
      RETURN
  110 IF (BISO) GO TO 120
      RI=5.40686*EXP(-25798./T)
      RETURN
  120 RI=.04427*EXP(-10482./T)
      RETURN
  130 IF (BISO) GO TO 140
      RI=5.40686*EXP(-25798./T)
      RETURN
  140 RI=.04427*EXP(-10482./T)
      RETURN
  150 RI=.10280*EXP(-10314./T)
      RETURN
  160 GO TO (170,180,210,220,230,240,250,270,280,300), ISO
  170 RI=9.7733E-4*EXP(-8262.1/T)
      RETURN
  180 IF (1./T.GT.5.64E-4) GO TO 190
      RI=5.3231E9*EXP(-58360./T)
      RETURN
  190 IF (1./T.GT.7.59E-4) GO TO 200
      RI=.044144*EXP(-13198./T)
      RETURN
  200 RI=9.7733E-4*EXP(-8262.1/T)
      RETURN
  210 RI=9.7733E-4*EXP(-8262.1/T)
      RETURN
  220 RI=9.7733E-4*EXP(-8262.1/T)
      RETURN
  230 RI=9.7733E-4*EXP(-8262.1/T)
      RETURN
  240 RI=7.2751E-3*EXP(-8696.3/T)
      RETURN
  250 IF (1./T.GT.5.33E-4) GO TO 260
      RI=1738.5*EXP(-35259./T)
      RETURN
  260 RI=9.7733E-4*EXP(-8262.1/T)
      RETURN
  270 RI=9.7733E-4*EXP(-8262.1/T)
      RETURN
  280 IF (1./T.GT.6.26E-4) GO TO 290
      RI=1.0548E4*EXP(-34207./T)
      RETURN
  290 RI=9.7733E-4*EXP(-8262.1/T)
      RETURN
  300 RI=9.7733E-4*EXP(-8262.1/T)
      RETURN
      END
      FUNCTION RF (T)
      LOGICAL LAGE,BISO
      COMMON /LA/ LAGE,AGE,MFUEL,ISO,BISO
      IF (MFUEL.EQ.1) GO TO 120
      GO TO (10,20,30,40,50,60,70,80,90,100), ISO
   10 RF=159.37*EXP(-11861./T)
      RETURN
   20 RF=1.6154E6*EXP(-26374./T)
      RETURN
   30 RF=1319.2*EXP(-17782./T)
      RETURN
   40 RF=1.2316E6*EXP(-28319./T)
```

```
      RETURN
   50 RF=1749.25*EXP(-19545.1/T)
      RETURN
   60 RF=1500.4*EXP(-17662./T)
      RETURN
   70 RF=1.2316E6*EXP(-28319./T)
      RETURN
   80 RF=1.2316E6*EXP(-28319./T)
      RETURN
   90 RF=1.2316E6*EXP(-28319./T)
      RETURN
  100 IF (BISO) GO TO 110
      RF=7.3405*EXP(-13777./T)
      RETURN
  110 RF=2149.4*EXP(-18175./T)
      RETURN
  120 GO TO (130,140,170,180,190,200,210,220,230,240), ISO
  130 RF=1.8289E4*EXP(-22861./T)
      RETURN
  140 IF (1./T.GT.5.64E-4) GO TO 150
      RF=5.3231E9*EXP(-58360./T)
      RETURN
  150 IF (1./T.GT.7.59E-4) GO TO 160
      RF=.046144*EXP(-13198./T)
      RETURN
  160 RF=9.7733E-4*EXP(-8262.1/T)
      RETURN
  170 RF=8952.4*EXP(-22657./T)
      RETURN
  180 RF=2231.7*EXP(-21229./T)
      RETURN
  190 RF=8952.4*EXP(-22657./T)
      RETURN
  200 RF=39423.*EXP(-22435./T)
      RETURN
  210 RF=2231.7*EXP(-21229./T)
      RETURN
  220 RF=2231.7*EXP(-21229./T)
      RETURN
  230 RF=2231.7*EXP(-21229./T)
      RETURN
  240 RF=8952.4*EXP(-22657./T)
      RETURN
      END
      FUNCTION FRACBO (T)
      DIMENSION IOP(2), TAB(3)
      LOGICAL LAGE,BISO
      COMMON /LA/ LAGE,AGE,MFUEL,ISO,BISO
      COMMON /F/ F1,F2,F3,F4
      DIMENSION W3(8), A(8), B(8), C(8), W4(8), FRAC3(8), T3(8), FRAC4(8
     1), T4(8)
      DATA FRAC3/.00526,.0059,.0071,.0116,.0185,.046,.057,.0815/
      DATA T3/1690.15,1743.15,1793.15,1873.15,1917.15,1973.15,2000.0,207
     13.15/
      DATA FRAC4/.00718,.0079,.01,.021,.0557,.10,.222,.4039/
      DATA T4/1673.15,1697.15,1733.15,1793.15,1853.15,1893.15,1973.15,20
     173.15/
C     SPLINE BOUNDARY CONDITIONS ETC.
      IJ=1
      IOP(1)=5
      IOP(2)=5
      N3=8
      N4=8
```

```
      CALL SPL1D1 (N3,T3,FRAC3,W3,IOP,IJ,A,B,C)
      CALL SPL1D1 (N4,T4,FRAC4,W4,IOP,IJ,A,B,C)
      RETURN
      ENTRY FRACB
      IAGE=AGE
      IAGE1=IAGE+1
      F1=0.0
      F2=0.0
      F3=0.0
      F4=0.0
      F23=0.0
      X=AGE-IAGE
      IF (X.NE.0.0) GO TO 10
      IF (AGE.EQ.0.0) GO TO 10
      X=1.0
      IAGE1=IAGE
      IAGE=IAGE-1
   10 CONTINUE
      IF (MFUEL.EQ.1) GO TO 160
      F1=1.0
      F2=1.0
      F3=1.0
      F4=1.0
      IF (T.GE.2273.15) GO TO 50
      IF (T.GE.2073.15) GO TO 40
      F1=.00179
      F2=.00377
      IF (T.LT.1673.15) GO TO 20
      CALL SPL1D2 (N4,T4,FRAC4,W4,IJ,T,TAB)
      F4=TAB(1)
      IF (T.LT.1690.15) GO TO 30
      CALL SPL1D2 (N3,T3,FRAC3,W3,IJ,T,TAB)
      F3=TAB(1)
      GO TO 50
   20 F4=.00718
   30 F3=.00526
      GO TO 50
   40 CONTINUE
      F1=-10.3454+4.99105E-3*T
      F2=-10.3229+4.98115E-3*T
      F3=-9.439441+4.592500E-3*T
      F4=-5.775124+2.98050E-3*T
   50 CONTINUE
      F23=0.5*(F2+F3)
      IF (.NOT.LAGE) GO TO 100
      IF (IAGE.GT.3) GO TO 90
      GO TO (60,70,80,90), IAGE1
   60 FRACB=AGE*F1
      GO TO 150
   70 FRACB=0.25*(3.*F1-2.*X*F1+3.*X*F2)
      GO TO 150
   80 FRACB=0.25*(F1+(2.-X)*F2+2.*X*F3)
      GO TO 150
   90 FRACB=0.25*(F1+F2+F3+X*F4)
      GO TO 150
  100 IF (IAGE.GT.3) GO TO 140
      GO TO (110,120,130,140), IAGE1
  110 FRACB=AGE*F1
      GO TO 150
  120 FRACB=F1+X*(F2-F1)
      GO TO 150
  130 FRACB=F2+X*(F3-F2)
      GO TO 150
```

```
  140 FRACB=F3+(AGE-3.)*(F4-F3)
  150 RETURN
C     SORS FUEL AGE MODEL--BISO
  160 IF (LAGE) GO TO 200
      FRACB=1.0
      IF (AGE.GT.0.12) GO TO 180
      IF (T.GT.1998.15) GO TO 190
      IF (T.LT.1858.15) GO TO 170
      FRACB=-13.2725+7.14286E-3*T
      GO TO 190
  170 FRACB=0.0
      GO TO 190
C     BISO CONSTANTS
  180 TONE=2011.97*EXP(-.0574098*AGE)
      IF (T.GE.TONE) GO TO 190
      TZERO=1876.17*EXP(-.0804098*AGE)
      IF (T.LE.TZERO) GO TO 170
      FRACB=(T-TZERO)/(TONE-TZERO)
  190 FRACB=FRACB+.025*AGE
      FRACB=AMIN1(FRACB,1.0)
      RETURN
  200 F1=1.0
      F2=1.0
      F3=1.0
      F4=1.0
      AGE1=X
      AGE2=1.+X
      AGE3=2.+X
      AGE4=3.+X
      IF (X.GT.0.12) GO TO 220
      IF (T.GT.1998.15) GO TO 230
      IF (T.LT.1858.15) GO TO 210
      F1=-13.2725+7.14286E-3*T
      GO TO 230
  210 F1=0.0
      GO TO 230
  220 TONE1=2011.97*EXP(-.0574098*AGE1)
      IF (T.GT.TONE1) GO TO 290
      TZERO1=1876.17*EXP(-.0804098*AGE1)
      IF (T.LE.TZERO1) GO TO 210
      F1=(T-TZERO1)/(TONE1-TZERO1)
  230 TONE2=2011.97*EXP(-.0574098*AGE2)
      IF (T.GT.TONE2) GO TO 290
      TZERO2=1876.17*EXP(-.0804098*AGE2)
      IF (T.LE.TZERO2) GO TO 240
      F2=(T-TZERO2)/(TONE2-TZERO2)
      GO TO 250
  240 F2=0.0
  250 TONE3=2011.97*EXP(-.0574098*AGE3)
      IF (T.GT.TONE3) GO TO 290
      TZERO3=1876.17*EXP(-.0804098*AGE3)
      IF (T.LE.TZERO3) GO TO 260
      F3=(T-TZERO3)/(TONE3-TZERO3)
      GO TO 270
  260 F3=0.0
  270 TONE4=2011.97*EXP(-.0574098*AGE4)
      IF (T.GT.TONE4) GO TO 290
      TZERO4=1876.17*EXP(-.0804098*AGE4)
      IF (T.LE.TZERO4) GO TO 280
      F4=(T-TZERO4)/(TONE4-TZERO4)
      GO TO 290
  280 F4=0.0
  290 IF (IAGE.GT.3) GO TO 330
```

```
140 GO TO (300,310,320,330), IAGE1
300 F1=F1+.025*AGE1
    FRACB=F1
    GO TO 340
310 F1=F1+.025*AGE1
    F2=F2+.025*AGE2
    FRACB=0.25*(F1+3.*F2)
    GO TO 340
320 F1=F1+.025*AGE1
    F2=F2+.025*AGE2
    F3=F3+.025*AGE3
    FRACB=0.25*(F1+F2+2.*F3)
    GO TO 340
330 F1=F1+.025*AGE1
    F2=F2+.025*AGE2
    F3=F3+.025*AGE3
    F4=F4+.025*AGE4
    FRACB=0.25*(F1+F2+F3+F4)
340 FRACB=AMIN1(FRACB,1.0)
    RETURN
    END
    FUNCTION FRACT (T)
    LOGICAL LAGE,BISO
    COMMON /LA/ LAGE,AGE,MFUEL,ISO,BISO
    COMMON /F/ F1,F2,F3,F4
    IAGE=AGE
    IAGE1=IAGE+1
    F1=0.0
    F2=0.0
    F3=0.0
    F4=0.0
    F23=0.0
    X=AGE-IAGE
    IF (X.NE.0.0) GO TO 10
    IF (AGE.EQ.0.0) GO TO 10
    X=1.0
    IAGE1=IAGE
    IAGE=IAGE-1
 10 CONTINUE
    IF (MFUEL.EQ.1) GO TO 170
    F1=1.0
    F2=1.0
    F3=1.0
    F4=1.0
    IF (T.GE.2273.15) GO TO 60
    IF (T.GE.1941.15) GO TO 20
    F1=.00157
    IF (T.GE.1902.15) GO TO 30
C   THIS IS A CHANGE IN CALCULATION OF F2 IN FRACT
    F2=9.99665E-4*EXP(9.15323E-4*T)
    IF (T.GE.1888.85) GO TO 40
    F3=1.22240E-3*EXP(1.08109E-3*T)
    IF (T.GE.1873.15) GO TO 50
    F4=1.17176E-3*EXP(1.10064E-3*T)
    GO TO 60
 20 F1=-5.8361+.300732E-2*T
 30 F2=-5.0922+.268005E-2*T
 40 F3=-4.8593+.257762E-2*T
 50 F4=-4.6209+.24728E-2*T
 60 CONTINUE
    F23=0.5*(F2+F3)
    IF (.NOT.LAGE) GO TO 110
    IF (IAGE.GT.3) GO TO 100
```

```
      GO TO (70,80,90,100), IAGE1                                       LARC1
   70 FRACT=AGE*F1                                                      LARC1
      GO TO 160                                                         LARC1
   80 FRACT=0.25*(3.*F1-2.*X*F1+3.*X*F2)                                LARC1
      GO TO 160                                                         LARC1
   90 FRACT=0.25*(F1+(2.-X)*F2+2.*X*F3)                                 LARC1
      GO TO 160                                                         LARC1
  100 FRACT=0.25*(F1+F2+F3+X*F4)                                        LARC1
      GO TO 160                                                         LARC1
  110 IF (IAGE.GT.3) GO TO 150                                          LARC1
      GO TO (120,130,140,150), IAGE1                                    LARC1
  120 FRACT=AGE*F1                                                      LARC1
      GO TO 160                                                         LARC1
  130 FRACT=F1+X*(F2-F1)                                                LARC1
      GO TO 160                                                         LARC1
  140 FRACT=F2+X*(F3-F2)                                                LARC1
      GO TO 160                                                         LARC1
  150 FRACT=F3+(AGE-3.)*(F4-F3)                                         LARC1
  160 RETURN                                                            LARC1
C     SORS FUEL AGE MODEL--TRISO                                        LARC1
  170 IF (LAGE) GO TO 210                                               LARC1
      FRACT=1.0                                                         LARC1
      IF (AGE.GT.0.12) GO TO 190                                        LARC1
      IF (T.GT.1998.15) GO TO 200                                       LARC1
      IF (T.LT.1858.15) GO TO 180                                       LARC1
      FRACT=-13.2725+7.14286E-3*T                                       LARC1
      GO TO 200                                                         LARC1
  180 FRACT=0.0                                                         LARC1
      GO TO 200                                                         LARC1
  190 TONE=2009.53*EXP(-.0472964*AGE)                                   LARC1
      IF (T.GE.TONE) GO TO 200                                          LARC1
      TZERO=1880.1*EXP(-.0974459*AGE)                                   LARC1
      IF (T.LE.TZERO) GO TO 180                                         LARC1
      FRACT=(T-TZERO)/(TONE-TZERO)                                      LARC1
  200 FRACT=FRACT+.025*AGE                                              LARC1
      FRACT=AMIN1(FRACT,1.0)                                            LARC1
      RETURN                                                            LARC1
  210 F1=1.0                                                            LARC1
      F2=1.0                                                            LARC1
      F3=1.0                                                            LARC1
      F4=1.0                                                            LARC1
      AGE1=X                                                            LARC1
      AGE2=1.+X                                                         LARC1
      AGE3=2.+X                                                         LARC1
      AGE4=3.+X                                                         LARC1
      IF (X.GT.0.12) GO TO 230                                          LARC1
      IF (T.GT.1998.15) GO TO 240                                       LARC1
      IF (T.LT.1858.15) GO TO 220                                       LARC1
      F1=-13.2725+7.14286E-3*T                                          LARC1
      GO TO 240                                                         LARC1
  220 F1=0.0                                                            LARC1
      GO TO 240                                                         LARC1
  230 TONE1=2009.53*EXP(-.0472964*AGE1)                                 LARC1
      IF (T.GT.TONE1) GO TO 300                                         LARC1
      TZERO1=1880.1*EXP(-.0974459*AGE1)                                 LARC1
      IF (T.LE.TZERO1) GO TO 220                                        LARC1
      F1=(T-TZERO1)/(TONE1-TZERO1)                                      LARC1
  240 TONE2=2009.53*EXP(-.0472964*AGE2)                                 LARC1
      IF (T.GT.TONE2) GO TO 300                                         LARC1
      TZERO2=1880.1*EXP(-.0974459*AGE2)                                 LARC1
      IF (T.LE.TZERO2) GO TO 250                                        LARC1
      F2=(T-TZERO2)/(TONE2-TZERO2)                                      LARC1
      GO TO 260                                                         LARC1
```

```
250 F2=0.0
260 TONE3=2009.53*EXP(-.0472964*AGE3)
    IF (T.GT.TONE3) GO TO 300
    TZERO3=1880.1*EXP(-.0974459*AGE3)
    IF (T.LE.TZERO3) GO TO 270
    F3=(T-TZERO3)/(TONE3-TZERO3)
    GO TO 280
270 F3=0.0
280 TONE4=2009.53*EXP(-.0472964*AGE4)
    IF (T.GT.TONE4) GO TO 300
    TZERO4=1880.1*EXP(-.0974459*AGE4)
    IF (T.LE.TZERO4) GO TO 290
    F4=(T-TZERO4)/(TONE4-TZERO4)
    GO TO 300
290 F4=0.0
300 IF (IAGE.GT.3) GO TO 340
    GO TO (310,320,330,340), IAGE1
310 F1=F1+.025*AGE1
    FRACT=F1
    GO TO 350
320 F1=F1+.025*AGE1
    F2=F2+.025*AGE2
    FRACT=0.25*(F1+3.*F2)
    GO TO 350
330 F1=F1+.025*AGE1
    F2=F2+.025*AGE2
    F3=F3+.025*AGE3
    FRACT=0.25*(F1+F2+2.*F3)
    GO TO 350
340 F1=F1+.025*AGE1
    F2=F2+.025*AGE2
    F3=F3+.025*AGE3
    F4=F4+.025*AGE4
    FRACT=0.25*(F1+F2+F3+F4)
350 FRACT=AMIN1(FRACT,1.0)
    RETURN
    END
    SUBROUTINE PLOT(N,X,MX,Y,MY,ICHAR,ICON)
    DIMENSION X(1), Y(1)
    COMMON /CJE07/ IXL,IXR,IYT,IYB,XL,XR,YT,YB
    COMMON /LJNEW/ IXSAVE,IYSAVE,IX2,IY2
C   THIS SUBROUTINE IS MODIFIED BY THE INCLUSION OF LJNEW
C   LJNEW IS INCLUDED SO THAT IXSAVE, IYSAVE MAY BE USED FOR TITLES
    INTEGER BLANK,PLTDOT
    DATA BLANK,PLTDOT/60B,52B/
    IXSAVE=X(1)
    IYSAVE=Y(1)
    YN6=0.6*Y(N)
    IF (N.EQ.2) YN6=-2.0
    FX=XR-XL
    IF (FX.NE.0) FX=(IXR-IXL)/FX
    FY=YB-YT
    IF (FY.NE.0) FY=(IYB-IYT)/FY
    K=1
    M=N-1
    I=0
    J=0
    L=0
    JCON=ICON
    IF ((ICHAR.EQ.BLANK).OR.((ICHAR.EQ.PLTDOT).AND.(M*JCON.NE.0))) K=0
 10 IX2=MIN0(MAX0(IXL+IFIX((X(I+1)-XL)*FX),IXL),IXR)
    IY2=MIN0(MAX0(IYT+IFIX((Y(J+1)-YT)*FY),IYT),IYB)
    IF (K.NE.0) CALL PLT (IX2,IY2,ICHAR)
```

```
      IF (L.NE.0) CALL DRV (IX1,IY1,IX2,IY2)
      IF (M.LE.0) GO TO 30
      IF (Y(J+1).GT.YN6) GO TO 20
      IXSAVE=IX2
      IYSAVE=IY2
   20 CONTINUE
      M=M-1
      I=I+MX
      J=J+MY
      L=JCON
      IX1=IX2
      IY1=IY2
      GO TO 10
   30 RETURN
      END
      FUNCTION TEMPO (VF)
      DIMENSION IOP(2), TAB(3)
      DIMENSION X(14), TEMPF(14), W(14), A(14), B(14), C(14)
      COMMON /SPEC/ TEMPF,X
      DATA X/0.,.01,.03333,.06666,.1,.2,.3,.4,.5,.6,.7,.8,.9,1./
      DATA TEMPF/1699.82,1588.71,1479.26,1402.59,1347.59,1255.37,1205.37
     1,1173.41,1147.04,1127.59,1104.26,1079.08,1044.26,922.04/
C     SPLINE BOUNDARY CONDITIONS ETC.
      IJ=1
      IOP(1)=5
      IOP(2)=5
      N1=14
      CALL SPL1D1 (N1,X,TEMPF,W,IOP,IJ,A,B,C)
      RETURN
      ENTRY TEMP
      CALL SPL1D2 (N1,X,TEMPF,W,IJ,VF,TAB)
      TEMP=TAB(1)
      RETURN
      END
      FUNCTION TMAXO (T)
      DIMENSION IOP(2), TAB(3)
      DIMENSION TT(29), TMAXF(29), W(29), A(29), B(29), C(29)
      COMMON /TMODEL/ MODEL
      COMMON /SPECM/ NT,TT,TMAXF
C     THIS COMMON CONTAINS DIMENSIONS IN MAIN PROGRAM
C     SORS DATA
      DIMENSION T1(11), TMAX1(11)
      DATA T1/0.,1.3,2.3,3.5,5.,6.92,9.42,12.3,17.3,26.5,40./
      DATA TMAX1/1227.59,1644.26,1922.04,2199.82,2477.59,2755.37,3033.15
     1,3310.93,3588.71,3922.04,3922.04/
C     CORCON TABULAR DATA
      DIMENSION T2(10), TMAX2(10)
      DATA T2/0.,.0083,.2167,1.45,5.25,10.25,15.25,20.25,25.25,30.25/
      DATA TMAX2/1192.59,1192.59,1280.37,1618.15,2379.26,2969.82,3358.71
     1,3630.37,3665.37,3665.37/
C     FU - CORT DATA
      DIMENSION T3(29), TMAX3(29)
      DATA T3/.2,.4,.5,1.0,1.5,2.0,2.5,3.0,3.5,4.0,4.5,5.0,5.5,6.0,6.5,7
     1.,8.,9.,10.,11.,12.,13.,14.,15.,16.,17.,18.,19.,20./
      DATA TMAX3/1199.,1278.,1315.,1461.,1589.,1704.,1810.,1908.,2002.,2
     1091.,2176.,2257.,2335.,2411.,2483.,2554.,2687.,2915.,2936.,3053.,3
     2165.,3273.,3376.,3475.,3570.,3663.,3636.,3664.,3665./
C     SPLINE BOUNDARY CONDITIONS ETC.
      IJ=1
      IOP(1)=5
      IOP(2)=5
      GO TO (10,30,50), MODEL
   10 N2=11
```

```
      NT=9                                                              LARC1
      DO 20 I=1,N2                                                      LARC1
      TT(I)=T1(I)                                                       LARC1
      TMAXF(I)=TMAX1(I)                                                 LARC1
   20 CONTINUE                                                          LARC1
      GO TO 70                                                          LARC1
   30 N2=10                                                             LARC1
      NT=8                                                              LARC1
      DO 40 I=1,N2                                                      LARC1
      TT(I)=T2(I)                                                       LARC1
      TMAXF(I)=TMAX2(I)                                                 LARC1
   40 CONTINUE                                                          LARC1
      GO TO 70                                                          LARC1
   50 N2=29                                                             LARC1
      NT=29                                                             LARC1
      DO 60 I=1,N2                                                      LARC1
      TT(I)=T3(I)                                                       LARC1
      TMAXF(I)=TMAX3(I)                                                 LARC1
   60 CONTINUE                                                          LARC1
   70 CALL SPL1D1 (N2,TT,TMAXF,W,IOP,IJ,A,B,C)                          LARC1
      RETURN                                                            LARC1
      ENTRY TMAX                                                        LARC1
      CALL SPL1D2 (N2,TT,TMAXF,W,IJ,T,TAB)                              LARC1
      TMAX=TAB(1)                                                       LARC1
      RETURN                                                            LARC1
      END                                                               LARC1
      FUNCTION TAVE0 (T)                                                LARC1
      DIMENSION IOP(2), TAB(3)                                          LARC1
      DIMENSION TT(29), TAVEF(29), W(29), A(29), B(29), C(29)           LARC1
      COMMON /TMODEL/ MODEL                                             LARC1
      COMMON /SPECA/ NT,TT,TAVEF                                        LARC1
C     THIS COMMON CONTAINS DIMENSIONS IN MAIN PROGRAM                   LARC1
C     IN THE MAIN PROGRAM, TT IS CALLED T3 IN THIS COMMON STATEMENT     LARC1
C     SORS DATA                                                         LARC1
      DIMENSION T1(11), TAVE1(11)                                       LARC1
      DATA T1/0.,1.1,2.5,4.2,6.3,10.,14.8,22.5,34.6,40.,50./            LARC1
      DATA TAVE1/1088.71,1366.48,1644.26,1922.04,2199.82,2477.59,2755.37 LARC1
     1,3033.15,3310.93,3374.42,3459.08/                                 LARC1
C     CORCON TABULAR DATA                                               LARC1
      DIMENSION T2(10), TAVE2(10)                                       LARC1
      DATA T2/0.,.0083,.2167,1.45,5.25,10.25,15.25,20.25,25.25,30.25/   LARC1
      DATA TAVE2/1052.59,1052.59,1134.82,1413.71,1920.37,2338.71,2608.71 LARC1
     1,2793.71,2938.15,3026.48/                                         LARC1
C     FU - CORT DATA                                                    LARC1
      DIMENSION T3(29), TAVE3(29)                                       LARC1
      DATA T3/.2,.4,.5,1.0,1.5,2.0,2.5,3.0,3.5,4.0,4.5,5.0,5.5,6.0,6.5,7 LARC1
     1.,8.,9.,10.,11.,12.,13.,14.,15.,16.,17.,18.,19.,20./              LARC1
      DATA TAVE3/1167.,1219.,1243.,1338.,1421.,1496.,1566.,1631.,1692.,1 LARC1
     1749.,1804.,1856.,1906.,1954.,1999.,2044.,2126.,2204.,2278.,2347.,2 LARC1
     2414.,2477.,2538.,2596.,2653.,2707.,2756.,2801.,2840./             LARC1
C     SPLINE BOUNDARY CONDITIONS ETC.                                   LARC1
      IJ=1                                                              LARC1
      IOP(1)=5                                                          LARC1
      IOP(2)=5                                                          LARC1
      GO TO (10,30,50), MODEL                                           LARC1
   10 N3=11                                                             LARC1
      NT=7                                                              LARC1
      DO 20 I=1,N3                                                      LARC1
      TT(I)=T1(I)                                                       LARC1
      TAVEF(I)=TAVE1(I)                                                 LARC1
   20 CONTINUE                                                          LARC1
      GO TO 70                                                          LARC1
   30 N3=10                                                             LARC1
```

```
      NT=9                                                              LARC1
      DO 40 I=1,N3                                                      LARC1
      TT(I)=T2(I)                                                       LARC1
      TAVEF(I)=TAVE2(I)                                                 LARC1
   40 CONTINUE                                                          LARC1
      GO TO 70                                                          LARC1
   50 N3=29                                                             LARC1
      NT=29                                                             LARC1
      DO 60 I=1,N3                                                      LARC1
      TT(I)=T3(I)                                                       LARC1
      TAVEF(I)=TAVE3(I)                                                 LARC1
   60 CONTINUE                                                          LARC1
   70 CALL SPL1D1 (N3,TT,TAVEF,W,IOP,IJ,A,B,C)                          LARC1
      RETURN                                                            LARC1
      ENTRY TAVE                                                        LARC1
      CALL SPL1D2 (N3,TT,TAVEF,W,IJ,T,TAB)                              LARC1
      TAVE=TAB(1)                                                       LARC1
      RETURN                                                            LARC1
      END                                                               LARC1
      SUBROUTINE FIN(PN,RP,RR,LAMBDA,DECAY,DT,PLEAK)                    LARC1
C     ORIGINAL ANSWERS                                                  LARC1
      REAL LAMBDA                                                       LARC1
      E=EXP(-DECAY*DT)                                                  LARC1
      RD=RR/(DECAY*DT)                                                  LARC1
      RP=PLEAK*((PN-RD)*(1.-E)/DECAY+RD*DT)                             LARC1
      PN=PN*E+RD*(1.-E)                                                 LARC1
      RETURN                                                            LARC1
      END                                                               LARC1
      SUBROUTINE FIN1(PN,RP,LAMBDA,DECAY,DT,RLEAK,OLD,R,ROLD)           LARC1
C     SIMPLE EQUATIONS SECOND HALF                                      LARC1
      REAL LAMBDA                                                       LARC1
      E=EXP(-DECAY*DT)                                                  LARC1
      E1=1.-E                                                           LARC1
      S=0.5*(R+ROLD)                                                    LARC1
      ALA=LAMBDA+S                                                      LARC1
      EL=EXP(-ALA*DT)                                                   LARC1
      EM=1.-EL                                                          LARC1
      IF (DECAY.EQ.ALA) GO TO 10                                        LARC1
      RP=RLEAK*(PN*E1/DECAY+S*OLD*(EM/ALA-E1/DECAY)/(DECAY-ALA))        LARC1
      PN=E*PN+S*OLD*(EL-E)/(DECAY-ALA)                                  LARC1
      GO TO 20                                                          LARC1
   10 RP=RLEAK*(PN*E1/DECAY+S*OLD*(E1-DECAY*DT*E)/(DECAY*DECAY))        LARC1
      PN=E*(PN+S*OLD*DT)                                                LARC1
   20 RETURN                                                            LARC1
      END                                                               LARC1
      SUBROUTINE FIN2(PN,RP,LAMBDA,DECAY,DT,RLEAK,OLD,R,ROLD)           LARC1
C     LINEAR RELEASE SECOND HALF                                        LARC1
      REAL LAMBDA                                                       LARC1
      E=EXP(-DECAY*DT)                                                  LARC1
      E1=1.-E                                                           LARC1
      S=0.5*(R+ROLD)                                                    LARC1
      ALA=LAMBDA+ROLD                                                   LARC1
      BH=0.5*(R-ROLD)/DT                                                LARC1
      PTERM=(DECAY-LAMBDA)*PZERO(ALA-DECAY,BH,DT)                       LARC1
      RP=RLEAK*(PN*E1/DECAY+OLD*(E1-LAMBDA*PZERO(ALA,BH,DT)-E*PTERM)/DEC LARC1
     1AY)                                                               LARC1
      PN=E*(PN+OLD*(PTERM+1.-EXP((DECAY-LAMBDA-S)*DT)))                 LARC1
      RETURN                                                            LARC1
      END                                                               LARC1
      SUBROUTINE FIN3(PNF,PNI,RPF,RPI,LAMBDA,DECAY,DT,RLEAK,NFOLD,NIOLD, LARC1
     1RA,RFOLD,RB,RIOLD,F,FOLD)                                         LARC1
C     LINEAR FAILURE SECOND HALF                                        LARC1
      REAL LAMBDA,NFOLD,NIOLD,M0,M4                                     LARC1
```

```
      E=EXP(-DECAY*DT)
      E1=1.-E
      RF=0.5*(RA+RFOLD)
      RI=0.5*(RB+RIOLD)
      RFP=LAMBDA+RF
      RIP=LAMBDA+RI
      A4=N1OLD
      A0=NFOLD
      DF=F-FOLD
      DFDT=DF/DT
      DR=RF-RI
      FIOLD=1.-FOLD
      ALPHA=FIOLD*DR
      GAM=RFP-ALPHA
C     GAM=RFP*FOLD+RIP*FIOLD
      BET=DR*DFDT
      BETA=BET/2.
      IF (FIOLD.EQ.0.0) A5=0.0
      IF (FIOLD.NE.0.0) A5=-DFDT*A4/FIOLD
      A1=-A5+DR*FOLD*A4
      A2=-DR*(FIOLD-FOLD)*A5
      A3=DR*DFDT*A5
      DT2=DT*DT
      M4=EXP(-GAM*DT-BETA*DT2)
      M0=EXP(-RFP*DT)
      QE=M0/E
      DL=DECAY-RFP
      ADL=ALPHA+DL
      Q4=PZERO(GAM-DECAY,BETA,DT)
      IF (BET.NE.0.0) Q5=(1.-M4/E+ADL*Q4)/BET
C     THIS IS Q5 FOR BETA .NE. 0.0
      IF (DL.EQ.0.0) GO TO 10
      Q0=(QE-1.0)/DL
      Q1=(QE*PZERO(-ALPHA,BETA,DT)-Q4)/DL
      GO TO 40
   10 Q0=DT
C     THIS IS Q0 FOR DL = 0.0
      IF (BET.EQ.0.0) GO TO 20
      Q1=DT*Q4-Q5
C     THIS IS Q1 FOR BETA .NE. 0.0, DL = 0.0
      GO TO 40
   20 IF (ALPHA.EQ.0.0) GO TO 30
      Q1=(Q4-Q0)/ALPHA
C     THIS IS Q1 FOR BETA = 0.0. DL = 0.0, ALPHA .NE. 0.0
      GO TO 40
   30 Q1=0.5*DT2
C     THIS IS Q1 FOR BETA = 0.0, DL = 0.0, ALPHA = 0.0
   40 V0=(E1/DECAY-E*Q0)/RFP
      V4=(PZERO(GAM,BETA,DT)-E*Q4)/DECAY
      V1=(V4-E*Q1)/RFP
      IF (BET.EQ.0.0) GO TO 50
      Q2=(Q0-Q4+ALPHA*Q1)/BET
      Q3=(Q1-Q5+ALPHA*Q2)/BET
      V2=(V0-V4+ALPHA*V1)/BET
      V5=(E1/DECAY-GAM*V4-E*Q4)/BET
      V3=(V1-V5+ALPHA*V2)/BET
      RPF=RLEAK*(PNF*E1/DECAY+RF*(A0*V0+A1*V1+A2*V2+A3*V3))
      RPI=RLEAK*(PNI*E1/DECAY+RI*(A4*V4+A5*V5))
      PNF=E*(PNF+RF*(A0*Q0+A1*Q1+A2*Q2+A3*Q3))
      PNI=E*(PNI+RI*(A4*Q4+A5*Q5))
      GO TO 60
   50 CONTINUE
      RPF=RLEAK*(PNF*E1/DECAY+RF*(A0*V0+A1*V1))
```

```
      RPI=RLFAK*(PNI*EI/DECAY+RI*A4*V4)
      PNF=E*(PNF+RF*(A0*Q0+A1*Q1))
      PNI=E*(PNI+RI*A4*Q4)
   60 RETURN
      END
      SUBROUTINE CALC1(NFOLD,NIOLD,RA,RB,LAMBDA,DT,F,NF,NI,RRF,RRI,RFOLD
     1,RIOLD)
C     SIMPLE EQUATIONS FIRST HALF
      REAL NFP,NIP
      REAL NFOLD,NIOLD,LAMBDA,NF,NI,M0,M1,M2,M3,M4,M5
      IF ((NFOLD+NIOLD).EQ.0.0) GO TO 10
      A0=NFOLD
      A4=NIOLD
      RF=0.5*(RA+RFOLD)
      RI=0.5*(RB+RIOLD)
      RFP=RF+LAMBDA
      RIP=RI+LAMBDA
      RFL=RFP*DT
      RIL=RIP*DT
      M0=EXP(-RFL)
      EI=EXP(-RIL)
      NFP=NFOLD*M0
      NIP=NIOLD*EI
      SUM=NFP+NIP
      NF=F*SUM
      NI=(1.-F)*SUM
      RRF=RF*(A0-NFP)/RFP
      RRI=RI*(A4-NIP)/RIP
      GO TO 20
   10 NF=0.0
      NI=0.0
      RRF=0.0
      RRI=0.0
   20 RETURN
      END
      SUBROUTINE CALC2(NFOLD,NIOLD,RA,RB,LAMBDA,DT,F,NF,NI,RRF,RRI,RFOLD
     1,RIOLD)
C     LINEAR RELEASE FIRST HALF
      REAL NFP,NIP
      REAL NFOLD,NIOLD,LAMBDA,NF,NI
      IF ((NFOLD+NIOLD).EQ.0.0) GO TO 10
      RF=RA
      RI=RB
      A0=NFOLD
      A4=NIOLD
      EF=EXP(-LAMBDA*DT-0.5*(RFOLD+RF)*DT)
      EI=EXP(-LAMBDA*DT-0.5*(RIOLD+RI)*DT)
      NFP=NFOLD*EF
      NIP=NIOLD*EI
      SUM=NFP+NIP
      NF=F*SUM
      NI=(1.-F)*SUM
      GAMF=RFOLD+LAMBDA
      GAMI=RIOLD+LAMBDA
      BETF=(RF-RFOLD)/DT
      BETAF=BETF/2.
      RRF=-A0*LAMBDA*PZERO(GAMF,BETAF,DT)+A0*(1.-EF)
      BETI=(RI-RIOLD)/DT
      BETAI=BETI/2.
      RRI=-A4*LAMBDA*PZERO(GAMI,BETAI,DT)+A4*(1.-EI)
      GO TO 20
   10 NF=0.0
      NI=0.0
```

```
      RRF=0.0
      RRI=0.0
   20 RETURN
      END
      SUBROUTINE PZERO(A,B,C)
      DATA SQPI/1.772453850905514/
      CFNEW(Z,D)=RERFC(D1-EXP(Z*Z-2.*D*Z)*RERFC(D-Z)
      IF (B.EQ.0.0) GO TO 10
      IF (B.LT.0.0) GO TO 30
      SQB=SQRT(B)
      SQB2=SQB+SQB
      ARG1=SQB*C
      ARG2=-A/SQB2
      PZERO=SQPI*FNEW(ARG1,ARG2)/SQB2
      RETURN
   10 IF (A.EQ.0.0) GO TO 20
      PZERO=(1.-EXP(-A*C))/A
      RETURN
   20 PZERO=C
      RETURN
   30 CONTINUE
      SQB=SQRT(-B)
      SQB2=SQB+SQB
      ARG1=SQB*C
C     ARG1=Z  (ALWAYS POSITIVE)
      ARG2=A/SQB2
      PZERO=SQPI*CFNEW(ARG1,ARG2)/SQB2
      RETURN
      END
      FUNCTION RERFC (Z)
      IF (ABS(Z).GT.4.0) GO TO 10
      RERFC=QERFC(Z)
      RETURN
   10 RERFC=AERFC(Z)
      RETURN
      END
      FUNCTION QERFC (ZTEMP)
      COMPLEX S,T,Z
      DATA EPS/1.0E-15/
      DATA SQPI/1.772453850905516/
      IF (ZTEMP.EQ.0.0) GO TO 30
      Z=CMPLX(0.0,ZTEMP)
      D=SQPI/2
      T=Z/D
      S=T+1.0
      L=1
      K=1
   10 CONTINUE
      K=K+1
      T=T*Z*D
      D=2./((K+1)*D)
      S=S+T
      IF (CABS(S).EQ.0.0) GO TO 20
      IF (CABS(T)/CABS(S).GT.EPS) GO TO 10
      L=L+1
      IF (L.LT.4) GO TO 10
      QERFC=AIMAG(S)
      RETURN
   20 PRINT 40, Z,K,L
      GO TO 30
   30 QERFC=0.0
      RETURN
C
```

```
   40 FORMAT (* S=0.0 FOR Z=*,E10.3,* K=*,I10,* L=*,I10)           LARC1
      END                                                           LARC1
      FUNCTION AERFC (Z)                                            LARC1
      DATA EPS/1.0E-15/                                             LARC1
      DATA SQPI/1.77245385090551 6/                                 LARC1
      IF (Z.EQ.0.0) GO TO 40                                        LARC1
      CON=1.0/(Z*SQPI)                                              LARC1
      U=Z*Z                                                         LARC1
      D=0.5                                                         LARC1
      T=D/U                                                         LARC1
      S=1.0+T                                                       LARC1
      L=1                                                           LARC1
      K=1                                                           LARC1
   10 CONTINUE                                                      LARC1
      K=K+1                                                         LARC1
      D=K-0.5                                                       LARC1
      TSAVE=T                                                       LARC1
      T=T*D/U                                                       LARC1
      S=S+T                                                         LARC1
      IF (T.GT.TSAVE) GO TO 20                                      LARC1
      IF (S.EQ.0.0) GO TO 30                                        LARC1
      IF (ABS(T/S).GT.EPS) GO TO 10                                 LARC1
      L=L+1                                                         LARC1
      IF (L.LT.4) GO TO 10                                          LARC1
   20 CONTINUE                                                      LARC1
      AERFC=CON*S                                                   LARC1
      RETURN                                                        LARC1
   30 PRINT 50, Z,K,L                                               LARC1
      GO TO 10                                                      LARC1
   40 AERFC=0.0                                                     LARC1
      RETURN                                                        LARC1
C                                                                   LARC1
   50 FORMAT (* S=0.0 FOR Z=*,E10.3,* K=*,I10,* L=*,I10)           LARC1
      END                                                           LARC1
      SUBROUTINE CALC3(NFOLD,NIOLD,D,RA,RB,LAMBDA,DT,F,FOLD,NF,NI,RRF,RRI, LARC1
     1RFOLD,RIOLD)                                                  LARC1
C     LINEAR FAILURE FIRST HALF                                     LARC1
      REAL NFOLD,NIOLD,LAMBDA,NF,NI,M0,M1,M2,M3,M4,M5               LARC1
      DATA SQPI/1.772453850905514/                                  LARC1
      IF ((NFOLD+NIOLD).EQ.0.0) GO TO 70                            LARC1
      A0=NFOLD                                                      LARC1
      A4=NIOLD                                                      LARC1
      RF=0.5*(RA+RFOLD)                                             LARC1
      RI=0.5*(RB+RIOLD)                                             LARC1
      RFP=RF+LAMBDA                                                 LARC1
      RIP=RI+LAMBDA                                                 LARC1
      RFL=RFP*DT                                                    LARC1
      RIL=RIP*DT                                                    LARC1
      M0=EXP(-RFL)                                                  LARC1
      EI=EXP(-RIL)                                                  LARC1
      P0=(1.-M0)/RFP                                                LARC1
      DF=F-FOLD                                                     LARC1
      DFDT=DF/DT                                                    LARC1
      FI=1.-F                                                       LARC1
      FIOLD=1.-FOLD                                                 LARC1
      IF (RF.NE.RI) GO TO 30                                        LARC1
      IF (F.GT.0.0) GO TO 10                                        LARC1
      NF=0.0                                                        LARC1
      RRF=0.0                                                       LARC1
      NI=A4*FI                                                      LARC1
      RRI=(1.-EI)*RI*A4/RIP                                         LARC1
      GO TO 80                                                      LARC1
   10 IF (FOLD.LT.1.0) GO TO 20                                     LARC1
```

```
      NI=0.0
      RRI=0.0
      NF=A0*M0
      RRF=RF*A0*P0
      GO TO 80
   20 NI=A4*FI*FI/FIOLD
      NF=M0*(A0+DF*A4/FIOLD)
      PART=DFDT*RI*A4*(1.-(1.+RFL)*M0)/(FIOLD*RFP*RFP)
      RRF=PART+RF*A0*P0
      RRI=-PART+RF*A4*P0
      GO TO 80
   30 IF (F.GT.0.0) GO TO 40
      NF=0.0
      RRF=0.0
      NI=FI*A4
      RRI=RI*(A4-NI)/RIP
      GO TO 80
   40 IF (FOLD.LT.1.0) GO TO 50
      NI=0.0
      RRI=0.0
      NF=A0*M0
      RRF=RF*A0*P0
      GO TO 80
   50 DT2=DT*DT
      DR=DF-DI
      A1=(DFDT+DR*FOLD*FIOLD)*A4/FIOLD
      A5=-DFDT*A4/FIOLD
      A2=-DR*(FIOLD-FOLD)*A5
      A3=DR*DFDT*A5
      ALPHA=FIOLD*DR
      GAM=RFP*FOLD+RIP*FIOLD
      IF (DF.EQ.0.0) GO TO 60
      BET=DR*DFDT
      BETA=BET/2.
      IF (BETA.LT.0.0) PRINT 90, BETA,DF,DR
      IF (BETA.LT.0.0) BETA=0.0
      SQB=SQRT(BETA)
      SQB2=SQB+SQB
      SQBT=SQB*DT
      SQC=ALPHA/SQB2
      SQE=-GAM/SQB2
      W6=FNEW(SQBT,SQE)
      W7=M0*FNEW(SQBT,SQC)
      M4=EXP(-GAM*DT-BETA*DT2)
      M5=DT*M4
      M1=SQPI*W7/SQB2
      M2=(M0-M4+ALPHA*M1)/BET
      M3=(ALPHA*M2+M1-M5)/BET
      P4=SQPI*W6/SQB2
      P5=(1.-GAM*P4-M4)/BET
      P1=(P4-M1)/RFP
      P2=(P0-P4+ALPHA*P1)/BET
      P3=(ALPHA*P2+P1-P5)/BET
      NF=A0*M0+A1*M1+A2*M2+A3*M3
      NI=A4*M4+A5*M5
      RRF=RF*(A0*P0+A1*P1+A2*P2+A3*P3)
      RRI=RI*(A4*P4+A5*P5)
      GO TO 80
   60 M4=EXP(-GAM*DT)
      M1=(M4-M0)/ALPHA
      P4=(1.-M4)/GAM
      P1=(P4-P0)/ALPHA
      NF=A0*M0+A1*M1
```

```
      NI=A4*W4                                                          LARC1
      RRF=RF*(A0*P0+A1*P1)                                              LARC1
      RRI=RI*A4*P4                                                      LARC1
      GO TO 80                                                          LARC1
   70 NF=0.0                                                            LARC1
      NI=0.0                                                            LARC1
      RRF=0.0                                                           LARC1
      RRI=0.0                                                           LARC1
   80 RETURN                                                            LARC1
C                                                                       LARC1
   90 FORMAT (* BETA NEGATIVE IN CALC.  BETA =*,E10.3,*  OF =*,F10.3,*  LARC1
     1DR =*,F10.3,*  BETA SET TO ZERO*)                                 LARC1
      END                                                               LARC1
      FUNCTION FNEW (Z,D)                                               LARC1
      IF (D.LT.0.0) GO TO 20                                            LARC1
      IF (Z.GT.D) GO TO 10                                              LARC1
C     CASE 1  D.GT.0.  D.GT.Z                                           LARC1
      FNEW=EXP(-Z*Z+2.*Z*D)*PQERFC(D-Z)-PQERFC(D)                       LARC1
      RETURN                                                            LARC1
C     CASE 2  D.GT.0.  Z.GT.D                                           LARC1
   10 FNEW=2.*EXP(D*D)-PQERFC(D)-EXP(-Z*Z+2.*Z*D)*PQERFC(Z-D)           LARC1
      RETURN                                                            LARC1
C     CASE 3  D.LT.0.  Z.GT.D                                           LARC1
   20 IF (D.GT.Z) GO TO 30                                              LARC1
      FNEW=PQERFC(-D)-EXP(-Z*Z+2.*Z*D)*PQERFC(Z-D)                      LARC1
      RETURN                                                            LARC1
C     CASE 4  D.LT.0.  D.GT.Z                                           LARC1
   30 FNEW=-2.*EXP(D*D)+PQERFC(-D)+EXP(-Z*Z+2.*Z*D)*PQERFC(D-Z)         LARC1
      RETURN                                                            LARC1
      END                                                               LARC1
      FUNCTION SPLINE (TIME,RIN)                                        LARC1
      DIMENSION IBD(6), Z1(113), Z2(113), Z3(113), FX(20,113), FY(20,113LARC1
     1), FXY(20,113)                                                    LARC1
      DIMENSION TE(20,113), T(20), F(113)                               LARC1
      DIMENSION T1(200), T2(200), T3(200), T4(200), T5(200), T6(200), T7LARC1
     1(200)                                                             LARC1
      DIMENSION T8(200), T9(200), T10(200), T11(200), T12(60)           LARC1
      DATA T1/1455.,1694.,1895.,2073.,2236.,2387.,2526.,2657.,2782.,2901LARC1
     1.,3016.,3126.,3232.,3333.,3431.,3525.,3616.,3624.,3630.,3634.,1458LARC1
     2.,1691.,1891.,2070.,2232.,2380.,2521.,2650.,2775.,2896.,3012.,3120LARC1
     3.,3225.,3323.,3420.,3517.,3610.,3620.,3627.,3633.,1452.,1688.,1886LARC1
     4.,2065.,2227.,2372.,2514.,2640.,2764.,2887.,3000.,3110.,3212.,3312LARC1
     5.,3410.,3506.,3600.,3612.,3622.,3631.,1450.,1685.,1881.,2060.,2222LARC1
     6.,2364.,2507.,2630.,2752.,2872.,2987.,3100.,3200.,3300.,3398.,3492LARC1
     7.,3584.,3602.,3618.,3629.,1449.,1682.,1877.,2052.,2214.,2357.,2495LARC1
     8.,2620.,2741.,2857.,2967.,3075.,3180.,3285.,3385.,3481.,3567.,3593LARC1
     9.,3616.,3626.,1446.,1679.,1872.,2044.,2207.,2350.,2490.,2610.,2730LARC1
     $.,2850.,2956.,3062.,3167.,3271.,3371.,3464.,3550.,3584.,3614.,3623LARC1
     $.,1444.,1676.,1868.,2036.,2200.,2340.,2480.,2600.,2719.,2837.,2945LARC1
     $.,3050.,3155.,3257.,3357.,3448.,3534.,3576.,3612.,3620.,1442.,1673LARC1
     $.,1863.,2027.,2185.,2330.,2470.,2590.,2710.,2825.,2935.,3040.,3145LARC1
     $.,3245.,3343.,3431.,3517.,3567.,3610.,3617.,1440.,1670.,1859.,2018LARC1
     $.,2170.,2315.,2460.,2580.,2699.,2812.,2925.,3035.,3135.,3235.,3329LARC1
     $.,3415.,3500.,3550.,3600.,3615.,1438.,1667.,1854.,2009.,2159.,2305LARC1
     $.,2450.,2572.,2686.,2800.,2910.,3020.,3120.,3220.,3315.,3400.,3493LARC1
     $.,3537.,3590.,3612./                                              LARC1
      DATA T2/1436.,1664.,1850.,2000.,2151.,2297.,2445.,2564.,2678.,2790LARC1
     1.,2900.,3010.,3110.,3205.,3295.,3383.,3467.,3530.,3580.,3609.,1434LARC1
     2.,1661.,1846.,1996.,2146.,2292.,2440.,2556.,2670.,2784.,2894.,3000LARC1
     3.,3100.,3192.,3281.,3366.,3450.,3522.,3570.,3606.,1432.,1658.,1841LARC1
     4.,1992.,2141.,2287.,2433.,2548.,2663.,2778.,2888.,2990.,3085.,3175LARC1
     5.,3265.,3350.,3433.,3515.,3560.,3603.,1430.,1655.,1836.,1988.,2136LARC1
     6.,2282.,2425.,2540.,2655.,2770.,2880.,2980.,3071.,3162.,3252.,3336LARC1
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     7.,3416.,3498.,3557.,3600.,1428.,1652.,1832.,1984.,2130.,2277.,2416 LARC1
     8.,2531.,2646.,2760.,2870.,2970.,3060.,3150.,3240.,3320.,3400.,3491 LARC1
     9.,3546.,3586.,1427.,1649.,1827.,1980.,2126.,2272.,2408.,2520.,2630 LARC1
     $.,2740.,2850.,2960.,3040.,3120.,3220.,3309.,3380.,3464.,3520.,3571 LARC1
     $.,1425.,1646.,1823.,1975.,2122.,2267.,2400.,2510.,2610.,2730.,2840 LARC1
     $.,2950.,3020.,3100.,3200.,3288.,3360.,3433.,3510.,3557.,1423.,1643 LARC1
     $.,1818.,1971.,2118.,2262.,2393.,2500.,2600.,2720.,2830.,2931.,3010 LARC1
     $.,3088.,3187.,3277.,3340.,3400.,3500.,3543.,1421.,1640.,1814.,1967 LARC1
     $.,2115.,2257.,2386.,2493.,2593.,2710.,2820.,2912.,3000.,3077.,3175 LARC1
     $.,3266.,3320.,3387.,3483.,3528.,1419.,1636.,1809.,1962.,2112.,2252 LARC1
     $.,2380.,2486.,2566.,2700.,2810.,2905.,2990.,3066.,3162.,3255.,3300 LARC1
     $.,3375.,3467.,3514./                                               LARC1
      DATA T3/1417.,1632.,1805.,1958.,2108.,2247.,2373.,2480.,2579.,2690 LARC1
     1.,2800.,2900.,2980.,3055.,3150.,3244.,3292.,3362.,3450.,3500.,1415 LARC1
     2.,1628.,1800.,1953.,2104.,2241.,2366.,2473.,2572.,2680.,2790.,2899 LARC1
     3.,2970.,3044.,3137.,3233.,3285.,3350.,3433.,3487.,1413.,1624.,1797 LARC1
     4.,1949.,2100.,2236.,2360.,2467.,2564.,2671.,2779.,2878.,2960.,3033 LARC1
     5.,3125.,3222.,3277.,3348.,3417.,3475.,1410.,1620.,1794.,1945.,2095 LARC1
     6.,2231.,2353.,2460.,2557.,2662.,2769.,2867.,2950.,3022.,3112.,3211 LARC1
     7.,3269.,3336.,3400.,3462.,1408.,1616.,1791.,1941.,2090.,2225.,2346 LARC1
     8.,2454.,2550.,2652.,2758.,2856.,2940.,3011.,3100.,3200.,3262.,3324 LARC1
     9.,3387.,3450.,1405.,1612.,1788.,1937.,2084.,2216.,2340.,2448.,2544 LARC1
     $.,2643.,2747.,2845.,2930.,3000.,3068.,3191.,3246.,3312.,3373.,3427 LARC1
     $.,1402.,1608.,1785.,1933.,2079.,2211.,2333.,2442.,2537.,2633.,2737 LARC1
     $.,2834.,2920.,2993.,3075.,3172.,3231.,3300.,3360.,3425.,1400.,1604 LARC1
     $.,1781.,1928.,2074.,2206.,2326.,2436.,2531.,2624.,2726.,2823.,2910 LARC1
     $.,2986.,3063.,3143.,3215.,3283.,3349.,3412.,1398.,1600.,1777.,1924 LARC1
     $.,2069.,2200.,2320.,2430.,2525.,2615.,2715.,2812.,2900.,2975.,3050 LARC1
     $.,3125.,3200.,3267.,3333.,3400.,1396.,1508.,1773.,1920.,2063.,2193 LARC1
     $.,2315.,2425.,2515.,2610.,2710.,2810.,2885.,2960.,3034.,3110.,3183 LARC1
     $.,3250.,3317.,3390./                                               LARC1
      DATA T4/1394.,1596.,1769.,1916.,2058.,2186.,2310.,2420.,2505.,2605 LARC1
     1.,2705.,2805.,2870.,2947.,3023.,3100.,3167.,3233.,3300.,3375.,1392 LARC1
     2.,1594.,1765.,1912.,2053.,2180.,2305.,2415.,2500.,2600.,2700.,2800 LARC1
     3.,2855.,2930.,3010.,3085.,3153.,3222.,3280.,3360.,1390.,1592.,1761 LARC1
     4.,1908.,2048.,2174.,2300.,2410.,2497.,2593.,2689.,2775.,2840.,2920 LARC1
     5.,3000.,3070.,3140.,3211.,3260.,3340.,1388.,1590.,1757.,1904.,2043 LARC1
     6.,2157.,2290.,2400.,2493.,2586.,2678.,2752.,2826.,2900.,2983.,3056 LARC1
     7.,3128.,3200.,3240.,3320.,1386.,1588.,1754.,1900.,2038.,2160.,2290 LARC1
     8.,2386.,2479.,2573.,2667.,2740.,2813.,2887.,2965.,3040.,3110.,3175 LARC1
     9.,3220.,3300.,1384.,1586.,1750.,1895.,2032.,2153.,2270.,2372.,2466 LARC1
     $.,2560.,2655.,2733.,2800.,2873.,2948.,3024.,3100.,3150.,3200.,3290 LARC1
     $.,1382.,1584.,1746.,1890.,2027.,2147.,2260.,2359.,2453.,2547.,2644 LARC1
     $.,2722.,2789.,2860.,2930.,3000.,3070.,3115.,3160.,3260.,1380.,1582 LARC1
     $.,1742.,1885.,2022.,2140.,2250.,2345.,2440.,2535.,2633.,2710.,2779 LARC1
     $.,2844.,2909.,2975.,3040.,3080.,3133.,3240.,1379.,1580.,1738.,1880 LARC1
     $.,2016.,2134.,2240.,2335.,2430.,2525.,2622.,2705.,2769.,2835.,2900 LARC1
     $.,2950.,3025.,3060.,3117.,3220.,1376.,1578.,1735.,1875.,2011.,2127 LARC1
     $.,2230.,2325.,2420.,2515.,2612.,2695.,2758.,2816.,2875.,2925.,3000 LARC1
     $.,3040.,3100.,3200./                                               LARC1
      DATA T5/1374.,1575.,1731.,1870.,2005.,2120.,2225.,2318.,2412.,2506 LARC1
     1.,2600.,2673.,2736.,2800.,2850.,2900.,2973.,3025.,3079.,3180.,1372 LARC1
     2.,1573.,1727.,1866.,2000.,2110.,2220.,2310.,2400.,2500.,2575.,2644 LARC1
     3.,2712.,2781.,2837.,2890.,2946.,3000.,3059.,3140.,1371.,1571.,1723 LARC1
     4.,1862.,1992.,2105.,2215.,2305.,2390.,2487.,2558.,2629.,2700.,2762 LARC1
     5.,2825.,2878.,2932.,2985.,3043.,3120.,1369.,1569.,1720.,1858.,1994 LARC1
     6.,2100.,2210.,2300.,2380.,2475.,2548.,2600.,2670.,2741.,2812.,2864 LARC1
     7.,2916.,2970.,3026.,3100.,1367.,1566.,1716.,1854.,1975.,2090.,2205 LARC1
     8.,2290.,2370.,2463.,2536.,2590.,2660.,2730.,2800.,2850.,2900.,2956 LARC1
     9.,3011.,3080.,1365.,1563.,1712.,1850.,1967.,2080.,2200.,2280.,2340 LARC1
     $.,2450.,2524.,2580.,2650.,2720.,2785.,2837.,2889.,2945.,3000.,3060 LARC1
     $.,1363.,1560.,1708.,1846.,1958.,2070.,2182.,2270.,2350.,2437.,2512 LARC1
     $.,2573.,2640.,2710.,2770.,2823.,2877.,2933.,2985.,3040.,1361.,1557 LARC1
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$.,1704.,1841.,1948.,2056.,2164.,2260.,2340.,2425.,2500.,2567.,2633 LARC1
$.,2700.,2755.,2808.,2866.,2921.,2970.,3020.,1359.,1554.,1700.,1837 LARC1
$.,1939.,2042.,2146.,2250.,2330.,2412.,2488.,2555.,2622.,2691.,2741 LARC1
$.,2800.,2855.,2910.,2955.,3000.,1358.,1551.,1695.,1832.,1934.,2036 LARC1
$.,2138.,2240.,2320.,2400.,2475.,2542.,2611.,2669.,2726.,2784.,2842 LARC1
$.,2900.,2945.,2980./                                               LARC1
 DATA T6/1356.,1548.,1690.,1828.,1929.,2030.,2130.,2230.,2310.,2383 LARC1
1.,2460.,2525.,2600.,2656.,2713.,2767.,2821.,2875.,2922.,2960.,1354 LARC1
2.,1545.,1685.,1824.,1924.,2024.,2120.,2220.,2300.,2367.,2434.,2510 LARC1
3.,2586.,2643.,2700.,2750.,2800.,2850.,2900.,2940.,1352.,1542.,1680 LARC1
4.,1820.,1920.,2020.,2115.,2210.,2283.,2350.,2417.,2505.,2573.,2631 LARC1
5.,2680.,2735.,2780.,2835.,2880.,2920.,1350.,1539.,1675.,1816.,1917 LARC1
6.,2015.,2110.,2200.,2267.,2333.,2400.,2490.,2560.,2620.,2660.,2720 LARC1
7.,2760.,2820.,2860.,2900.,1348.,1536.,1670.,1812.,1915.,2010.,2105 LARC1
8.,2190.,2260.,2325.,2390.,2465.,2530.,2590.,2640.,2690.,2740.,2800 LARC1
9.,2840.,2880.,1346.,1533.,1665.,1808.,1905.,2000.,2095.,2180.,2250 LARC1
$.,2315.,2380.,2450.,2500.,2550.,2600.,2650.,2700.,2750.,2800.,2860 LARC1
$.,1344.,1530.,1660.,1804.,1895.,1985.,2080.,2170.,2240.,2310.,2370 LARC1
$.,2430.,2480.,2530.,2580.,2637.,2683.,2733.,2786.,2840.,1342.,1527 LARC1
$.,1655.,1800.,1885.,1970.,2055.,2150.,2230.,2305.,2360.,2410.,2460 LARC1
$.,2510.,2560.,2623.,2667.,2717.,2768.,2820.,1340.,1524.,1650.,1791 LARC1
$.,1875.,1960.,2045.,2130.,2215.,2290.,2350.,2400.,2450.,2500.,2550 LARC1
$.,2610.,2650.,2700.,2750.,2800.,1338.,1521.,1645.,1784.,1867.,1950 LARC1
$.,2033.,2116.,2200.,2262.,2341.,2387.,2440.,2490.,2540.,2600.,2645 LARC1
$.,2690.,2740.,2787./                                               LARC1
 DATA T7/1336.,1518.,1640.,1774.,1858.,1942.,2026.,2110.,2183.,2250 LARC1
1.,2312.,2375.,2430.,2480.,2530.,2588.,2640.,2680.,2730.,2775.,1334 LARC1
2.,1515.,1635.,1765.,1849.,1933.,2016.,2100.,2167.,2233.,2300.,2363 LARC1
3.,2420.,2470.,2520.,2575.,2630.,2670.,2720.,2762.,1332.,1512.,1630 LARC1
4.,1755.,1840.,1924.,2008.,2084.,2150.,2216.,2284.,2350.,2410.,2460 LARC1
5.,2510.,2565.,2620.,2660.,2710.,2750.,1330.,1509.,1625.,1745.,1830 LARC1
6.,1915.,2000.,2067.,2133.,2200.,2267.,2337.,2400.,2450.,2505.,2558 LARC1
7.,2610.,2650.,2700.,2737.,1328.,1506.,1620.,1735.,1827.,1910.,1990 LARC1
8.,2057.,2123.,2190.,2255.,2300.,2375.,2438.,2490.,2550.,2600.,2640 LARC1
9.,2683.,2725.,1326.,1503.,1615.,1725.,1825.,1905.,1980.,2047.,2116 LARC1
$.,2180.,2235.,2285.,2355.,2400.,2467.,2533.,2575.,2620.,2667.,2712 LARC1
$.,1324.,1500.,1610.,1720.,1820.,1900.,1970.,2037.,2108.,2170.,2224 LARC1
$.,2270.,2332.,2375.,2437.,2500.,2550.,2600.,2650.,2700.,1322.,1495 LARC1
$.,1605.,1715.,1810.,1890.,1960.,2030.,2100.,2160.,2210.,2260.,2310 LARC1
$.,2360.,2410.,2460.,2510.,2560.,2610.,2687.,1320.,1490.,1600.,1710 LARC1
$.,1800.,1880.,1955.,2025.,2092.,2154.,2205.,2255.,2306.,2356.,2405 LARC1
$.,2450.,2500.,2550.,2600.,2675.,1318.,1484.,1595.,1705.,1790.,1870 LARC1
$.,1945.,2020.,2083.,2147.,2200.,2250.,2303.,2352.,2400.,2440.,2496 LARC1
$.,2532.,2579.,2662./                                               LARC1
 DATA T8/1316.,1479.,1590.,1700.,1780.,1860.,1935.,2010.,2075.,2140 LARC1
1.,2195.,2245.,2300.,2343.,2387.,2430.,2472.,2514.,2557.,2650.,1314 LARC1
2.,1473.,1584.,1690.,1770.,1850.,1925.,2000.,2067.,2133.,2185.,2234 LARC1
3.,2283.,2328.,2375.,2420.,2461.,2502.,2543.,2637.,1312.,1469.,1578 LARC1
4.,1680.,1760.,1840.,1913.,1988.,2053.,2116.,2168.,2220.,2267.,2314 LARC1
5.,2362.,2410.,2450.,2489.,2528.,2625.,1310.,1462.,1572.,1670.,1750 LARC1
6.,1830.,1901.,1975.,2040.,2100.,2150.,2200.,2250.,2300.,2350.,2390 LARC1
7.,2425.,2465.,2510.,2612.,1308.,1457.,1565.,1659.,1740.,1820.,1887 LARC1
8.,1957.,2026.,2082.,2134.,2184.,2234.,2282.,2330.,2365.,2400.,2445 LARC1
9.,2489.,2600.,1306.,1452.,1559.,1649.,1732.,1810.,1875.,1940.,2013 LARC1
$.,2063.,2117.,2167.,2217.,2267.,2310.,2351.,2397.,2430.,2477.,2580 LARC1
$.,1304.,1446.,1553.,1638.,1724.,1800.,1860.,1925.,2000.,2045.,2100 LARC1
$.,2150.,2200.,2250.,2300.,2337.,2374.,2416.,2458.,2560.,1302.,1441 LARC1
$.,1547.,1631.,1716.,1789.,1845.,1916.,1980.,2030.,2082.,2133.,2183 LARC1
$.,2233.,2275.,2317.,2360.,2403.,2445.,2540.,1300.,1435.,1541.,1624 LARC1
$.,1708.,1779.,1840.,1908.,1960.,2015.,2065.,2115.,2166.,2217.,2259 LARC1
$.,2300.,2350.,2393.,2437.,2520.,1296.,1430.,1535.,1617.,1700.,1769 LARC1
$.,1833.,1900.,1952.,2010.,2060.,2107.,2153.,2200.,2244.,2289.,2335 LARC1
$.,2382.,2422.,2500./                                               LARC1
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 DATA T9/1292.,1424.,1528.,1609..1694.,1759.,1825.,1891..1948.,2005 LARC1
1.,2055.,2100.,2146..2192.,2235..2278.,2321.,2364.,2407..2480.,1288 LARC1
2.,1418.,1520.,1600.,1687.,1751.,1816.,1881.,1942.,2000.,2050.,2093 LARC1
3.,2139.,2184.,2227.,2270.,2313.,2356.,2400.,2460..1284..1412.,1512 LARC1
4.,1594.,1680.,1744..1808..1872..1936.,1990.,2043.,2086.,2129.,2175 LARC1
5.,2217.,2260.,2305.,2348.,2387.,2440.,1280.,1406..1505..1598.,1674 LARC1
6.,1737.,1800.,1863.,1923.,1980.,2026.,2072.,2120.,2170..2212.,2256 LARC1
7.,2295..2337.,2374.,2420.,1276.,1400.,1500.,1582.,1667..1730.,1793 LARC1
8.,1854.,1910.,1960..2015.,2065..2115.,2165.,2200.,2240..2280.,2320 LARC1
9.,2360.,2400.,1272.,1395.,1494..1576.,1660.,1723..1787..1845..1905 LARC1
$.,1955..2010.,2060..2110..2160.,2190.,2230.,2270.,2310..2345.,2380 LARC1
$.,1268.,1389.,1488..1571..1654.,1716.,1780.,1842.,1897..1946.,2000 LARC1
$.,2050.,2100.,2140.,2180.,2220.,2260.,2300.,2330.,2360.,1264.,1304 LARC1
$..1482.,1565.,1647..1710..1773.,1837.,1890.,1940.,1987.,2037.,2081 LARC1
$.,2120.,2165.,2210..2247.,2281..2315.,2340.,1260.,1379.,1475.,1559 LARC1
$.,1640.,1705.,1766.,1825.,1879..1927.,1975.,2020..2062..2100..2150 LARC1
$.,2200..2233..2267..2300.,2320..1256.,1374.,1460.,1553.,1633.,1700 LARC1
$.,1752.,1805.,1857.,1910.,1962.,2012.,2047..2083.,2131..2170..2216 LARC1
$.,2247.,2274.,2300./                                               LARC1
 DATA T10/1252.,1368.,1463..1547.,1627.,1684.,1742.,1795..1850.,190 LARC1
10..1950.,2000.,2033.,2067..2112.,2156.,2200..2227.,2254..2280.,124 LARC1
28..1362.,1457.,1541.,1620..1675..1730.,1785..1835..1887..1937.,198 LARC1
30.,2000.,2050.,2100.,2130..2160.,2190.,2220.,2260.,1244..1357.,145 LARC1
41..1535.,1613.,1665.,1717..1769.,1821.,1873..1925.,1960..1995.,203 LARC1
50.,2065.,2100.,2135.,2170..2205.,2240.,1240.,1351..1445..1529.,160 LARC1
67.,1658.,1709.,1760.,1811..1862.,1912.,1946.,1980.,2015..2055.,209 LARC1
74.,2128.,2163.,2191.,2220..1236.,1346.,1439.,1523..1600..1650.,170 LARC1
80..1753.,1800.,1850.,1900.,1933..1967.,2000.,2044..2088..2121.,215 LARC1
95.,2177.,2200.,1232.,1340.,1432.,1517.,1587.,1643.,1696..1747.,179 LARC1
$2.,1838.,1876.,1909.,1942..1975..2022.,2060..2100..2128..2157.,218 LARC1
$3..1228.,1334.,1425.,1511..1575.,1637.,1690..1733..1776..1815.,185 LARC1
$3.,1885.,1917.,1950.,2000.,2033.,2066..2100.,2133..2166..1224.,132 LARC1
$8.,1418.,1505.,1562.,1615.,1667..1700.,1740.,1780.,1825..1860.,190 LARC1
$0.,1925.,1970.,2000.,2044.,2075.,2122..2150.,1220..1322..1411.,150 LARC1
$0.,1550.,1600.,1633.,1667..1700.,1740..1780.,1820.,1860..1900.,194 LARC1
$0.,1980.,2022.,2050.,2111..2134.,1216.,1317.,1404.,1475..1527.,158 LARC1
$0.,1620.,1663.,1695.,1730..1770.,1810.,1849.,1888.,1926..1960.,200 LARC1
$0.,2025.,2100.,2116./                                              LARC1
 DATA T11/1212.,1311.,1400.,1450.,1500.,1550.,1605.,1660..1690.,172 LARC1
10.,1760.,1800.,1838.,1876.,1913.,1940.,1978.,2000..2050..2100.,120 LARC1
28.,1306.,1373.,1400.,1481..1540.,1587.,1635.,1672.,1710..1745.,178 LARC1
31.,1815.,1850.,1900.,1920..1955.,1990.,2025.,2080..1200..1300.,134 LARC1
47.,1395.,1463.,1520.,1565..1610..1655.,1700.,1731.,1762..1794.,182 LARC1
55.,1863.,1900.,1933.,1967..2000.,2060.,1189.,1283.,1335..1390.,144 LARC1
65.,1500.,1550.,1600.,1637.,16(5.,1710.,1745.,1780.,1810..1842.,188 LARC1
70..1916..1950.,1983..2040..1178.,1268..1321..1374..1427..1480.,153 LARC1
80.,1580.,1600.,1650.,1700..1733.,1767.,1794..1821..1860..1900.,193 LARC1
93.,1967.,2020.,1167.,1251..1300.,1350.,1410..1460..1510..1560.,157 LARC1
$5.,1625.,1666.,1700.,1733.,1767.,1800.,1833..1867.,1900..1950.,198 LARC1
$0.,1156.,1234.,1280.,1335..1393.,1440.,1490.,1540..1550..1600.,163 LARC1
$2.,1667.,1700.,1733.,1767..1800.,1833.,1867..1900..1940..1145.,121 LARC1
$7.,1260.,1318.,1375.,1420..1450.,1520.,1535..1565.,1598..1633.,166 LARC1
$6.,1700.,1733.,1765.,1775.,1833.,1865.,1895.,1134..1190..1240.,130 LARC1
$0.,1350.,1400.,1430.,1465..1500.,1530..1565..1600.,1632..1665.,170 LARC1
$0.,1730.,1765.,1800.,1830..1850..1123.,1170.,1220.,1270..1320.,135 LARC1
$5.,1390.,1424.,1458.,1492..1520.,1550.,1580..1607.,1635..1665.,169 LARC1
$2.,1720.,1750.,1800./                                              LARC1
 DATA T12/1110.,1140.,1200..1240..1280.,1320.,1350..1380..1410.,144 LARC1
10.,1470.,1500.,1525.,1550.,1575..1600.,1625.,1650..1675..1730.,105 LARC1
20.,1110.,1150.,1190.,1220.,1245.,1270.,1300..1325..1350..1390.,141 LARC1
30.,1435.,1455.,1490.,1520..1545.,1570.,1600..1630.,1000..1050.,107 LARC1
45..1100.,1125.,1150.,1175.,1200..1225.,1250.,1275.,1300..1325.,135 LARC1
50.,1375.,1400.,1425.,1450.,1475..1500./                            LARC1
```

```
      EQUIVALENCE (T1(1),TE(1,1)), (T2(1),TE(1,11)), (T3(1),TE(1,21)), (
     1T4(1),TE(1,31)), (T5(1),TE(1,41)), (T6(1),TE(1,51)), (T7(1),TE(1,6
     21)), (T8(1),TE(1,71)), (T9(1),TE(1,81)), (T10(1),TE(1,91)), (T11(1
     3),TE(1,101)), (T12(1),TE(1,111))
      DO 10 IT=1,10
      DO 10 I=2,19
      DO 10 J=2,112
      TE(I,J)=0.25*(TE(I-1,J)+TE(I+1,J)+TE(I,J+1)+TE(I,J-1))
   10 CONTINUE
      CALL ADV (1)
      WRITE (12,60)(J,(TE(I,J),I=1,20),J=1,113)
      CALL ADV (1)
      DO 20 I=1,20
   20 T(I)=I
      DB=1./112
      DO 30 I=1,113
   30 F(I)=(I-1)*DB
      IBD(1)=3
      IBD(2)=3
      IBD(3)=3
      IBD(4)=3
      IBD(5)=1
      IBD(6)=1
      FXY(1,1)=0.0
      FXY(1,113)=0.0
      FXY(20,1)=0.0
      FXY(20,113)=0.0
      DO 40 I=1,20
      FX(I,1)=(TE(I,2)-TE(I,1))/DB
      FX(I,113)=(TE(I,113)-TE(I,112))/DB
   40 CONTINUE
      DO 50 I=1,113
      FY(1,I)=TE(2,I)-TE(1,I)
      FY(20,I)=TE(20,I)-TE(19,I)
   50 CONTINUE
      CALL SPL2D1 (113,F,20,T,TE,FX,FY,FXY,20,IBD,Z1,Z2,Z3)
      RETURN
      ENTRY SPL
      SPL=SPL2D2(BIN,TIME,113,F,20,T,TE,FX,FY,FXY,20,0,0)
      RETURN
C
   60 FORMAT (/1X,I3,20F6.0)
      END

COPYSF   .END OF FILE
```

```
      FUNCTION ERFC(Z)                                                  C335A
      DIMENSION A(8),B(9),C(5),D(6),E(4)                                C335A
      DATA(A(I),I=1,8)/883.47394260349 5,1549.6793124037 2,             C335A
     C1347.1941340975 9,723.04000277752 9,255.50049469495 8,            C335A
     C59.24001011129141,8.3765310814197 0,.56418955944261 0/            C335A
      DATA(B(I),I=1,9)/883.47894260349 9,2546.57854330975,              C335A
     C3337.22136998926,2606.71201526511,1333.56997567996,               C335A
     C460.28512369 1601,103.50025439768 8,14.8470122375234,1.0/         C335A
      DATA(C(I),I=1,5)/1.63271618512628,2.35360143283567,               C335A
     C3.03185804944392,.89515718225550 6,.56418958354799 6/             C335A
      DATA(D(I),I=1,6)/1.29314873038422,5.08080210486989,               C335A
     C4.96496300826808,5.87382846427043,1.58662479494697,1.0/           C335A
      DATA(E(I),I=1,4)/-.5,.75,-1.875,1.77245385090551 6/               C335A
      ERFC = 0.0                                                        C335A
      IF (Z .GE. 26.) RETURN                                            C335A
      IF ( Z.GE. 0.5) GO TO 1                                           C335A
      ERFC = 1.0 - ERF(Z)                                               C335A
      RETURN                                                            C335A
    1 ERFC = EXP(-Z*Z)                                                  C335A
      GO TO 6                                                           C335A
      ENTRY PQERFC                                                      C335A
      IF (Z .GE. 0.5) GO TO 7                                           C335A
      ERFC = EXP(Z*Z) * (1.0 - ERF(Z))                                  C335A
      RETURN                                                            C335A
    7 ERFC = 1.0                                                        C335A
    6 IF (Z .GE. 100.)  GO TO 3                                         C335A
      IF (Z .GE.  8.0)  GO TO 2                                         C335A
      P=(A(1)+Z*(A(2)+Z*(A(3)+Z*(A(4)+Z*(A(5)+Z*(A(6)+Z*(A(7)+Z*A(8))))) C335A
     C)))/(B(1)+Z*(B(2)+Z*(B(3)+Z*(B(4)+Z*(B(5)+Z*(B(6)+Z*(B(7)+Z*(B(8)+ C335A
     CZ*B(9)))))))))                                                    C335A
      GO TO 4                                                           C335A
    2 P=(C(1)+Z*(C(2)+Z*(C(3)+Z*(C(4)+Z*C(5)))))/                       C335A
     C(D(1)+Z*(D(2)+Z*(D(3)+Z*(D(4)+Z*(D(5)+Z*D(6))))))                 C335A
      GO TO 4                                                           C335A
    3 W = 1./(Z*Z)                                                      C335A
      P=(1.+W*(E(1)+W*(E(2)+W*E(3))))/(E(4)*Z)                          C335A
    4 ERFC = ERFC*P                                                     C335A
      RETURN                                                            C335A
      END                                                               C335A
```

APPENDIX D

PLOTS

```
      PROGRAM PLOTS (INP,OUT,FILM,TAPE12=FILM)
      DIMENSION X(14), TEMPF(14)
      DIMENSION BIN(101), TIME(101), TPLOT(101), TM(101), TA(101)
      COMMON /SPEC/ TEMPF,X
      COMMON /SPECM/ N2,TT(29),TMAXF(29)
      COMMON /SPECA/ N3,T3(29),TAVEF(29)
C     IN TAVE0, T3 IS CALLED TT IN THIS COMMON STATEMENT
      COMMON /CJE07/ IXL,IXR,IYT,IYB,XMN,XMX,YMX,YMN
      COMMON /CJE08/ XMIN,XMAX,INTVALX,KX,YMIN,YMAX,INTVALY,KY
      COMMON /TMODEL/ MODEL
      COMMON /LINEW/ IXSAVE,IYSAVE,IX2,IY2
      NCHAR=27
      Z=TEMP0(0.0)
      NTOT=101
      DB=1./(NTOT-1)
      DT=20./(NTOT-1)
      DO 10 I=1,NTOT
      BIN(I)=(I-1)*DB
      TIME(I)=(I-1)*DT
      TPLOT(I)=TEMP(BIN(I))
   10 CONTINUE
      PRINT 40
      PRINT 50, (I,BIN(I),TPLOT(I),I=1,NTOT)
      CALL PLOPB (BIN,TPLOT,NTOT,1,0,NCHAR,0.,8.,7.,36HTEMPERATURE VS. C
     1ORE VOLUME FRACTION,36,20HCORE VOLUME FRACTION,20,23HTEMPERATURE (
     2DEGREES K),23,0,0,2,2)
      CALL PLOPB (X,TEMPF,14,1,-1,-1RX,0.,8.,7.,0,0,0,0,0,0,0,0,2,2)
      CALL ADV (1)
      DO 30 MODEL=1,3
      Z=TMAX0(0.0)
      T=TAVE0(0.0)
      DO 20 I=1,NTOT
      TM(I)=TMAX(TIME(I))
      TA(I)=TAVE(TIME(I))
   20 CONTINUE
      PRINT 60, MODEL
      PRINT 70, (I,TIME(I),TM(I),TA(I),I=1,NTOT)
      XMIN=0.
      XMAX=20.
      INTVALX=10
      KX=0
      YMIN=1000.
      YMAX=3800.
      INTVALY=7
      KY=0
      CALL PLOPB (TIME,TM,NTOT,1,0,1RM,-2,8.,8.,31HTEMPERATURE VS. TIME
     1 AFTER LOFC,31,12HTIME (HOURS),-12,23HTEMPERATURE (DEGREES K),23,0
     2,0,2,2)
      CALL PLOPB (TT,TMAXF,N2,1,-1,-1RX,0.,8.,8.,0,0,0,0,0,0,0,0,2,2)
      CALL PLOPB (TIME,TA,NTOT,1,0,-1RA,-2,8.,8.,0,0,0,-12,0,0,0,0,2,2)
      CALL PLOPB (T3,TAVEF,N3,1,-1,-1RX,0.,8.,8.,0,0,0,0,0,0,0,0,2,2)
      CALL CONVRT (9.0,IX,XMN,XMX,IXL,IXR)
      IF (MODEL.EQ.1) CALL CONVRT (3200.,IY,YMN,YMX,IYB,IYT)
      IF (MODEL.NE.1) CALL CONVRT (3050.,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,4,4HTMAX,1)
      CALL CONVRT (12.,IX,XMN,XMX,IXL,IXR)
      IF (MODEL.EQ.1) CALL CONVRT (2750.,IY,YMN,YMX,IYB,IYT)
      IF (MODEL.NE.1) CALL CONVRT (2600.,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,4,4HTAVE,1)
      IF (MODEL.EQ.1) CALL DLCH (100,1000,9,9HSORS DATA,2)
      IF (MODEL.EQ.2) CALL DLCH (100,1000,11,11HCORCON DATA,2)
      IF (MODEL.EQ.3) CALL DLCH (100,1000,9,9HAYER DATA,2)
```

```
      CALL ADV (1)
   30 CONTINUE
      CALL PLOT4
      CALL PLOT1
      CALL PLOT2
      CALL PLOT3
      CALL EXIT
C
   40 FORMAT (5X,1HI,7X,3HBIN,3X,16HTEMP HIGHER THAN/)
   50 FORMAT (1X,I5,5X,F5.2,5X,F10.2)
   60 FORMAT (///5X,1HI,9X,4HTIME,11X,4HTMAX,11X,4HTAVE,10X,6HMODEL=,T1/
     1)
   70 FORMAT (1X,I5,5X,F8.2,2F15.2)
      END
      SUBROUTINE PLOT1
      DIMENSION FB(131), F1B(131), F2B(131), F3B(131), F4B(131), TT(131)
     1, FT(131), F1T(131), F2T(131), F3T(131), F4T(131)
      DIMENSION TITLE(5)
      LOGICAL LAGE,BISO
      COMMON /F/ F1,F2,F3,F4
      COMMON /LA/ LAGE,AGE,MFUEL,ISO,BISO
      COMMON /LJNEW/ IXSAVE,IYSAVE,IX2,IY2
      COMMON /CJE07/ IXL,IXR,IYT,IYB,XMN,XMX,YMX,YMN
      COMMON /CJE08/ XMIN,XMAX,INTVALX,KX,YMIN,YMAX,INTVALY,KY
C     INITIALIZE PLOTS
      NCHAR=27
C     INITIALIZE SPLINE
      Z=FRACB0(0.0)
      NN=131
      LAGE=.T.
      AGE=4.0
      DO 110 MFUEL=1,2
      PRINT 40
      PRINT 50, MFUEL,AGE,LAGE
      IOPT=1
      DO 10 I=1,NN
      T=1100.+(I-1)*10.
      FB(I)=FRACB(T)
      F1B(I)=F1
      F2B(I)=F2
      F3B(I)=F3
      F4B(I)=F4
      TT(I)=T
      FT(I)=FRACT(T)
      F1T(I)=F1
      F2T(I)=F2
      F3T(I)=F3
      F4T(I)=F4
   10 CONTINUE
      PRINT 60
      PRINT 70, (I,TT(I),F1B(I),F2B(I),F3B(I),F4B(I),FB(I),I=1,NN)
      XMIN=1200.
      XMAX=2400.
      INTVALX=6
      KX=0
      YMIN=0.0
      YMAX=1.0
      INTVALY=10
      KY=1
      CALL PLOPB (TT,F1B,NN,1,0,NCHAR,0.,7.,8.,0,0,23HTEMPERATURE (DEGREE
     1ES K),-23,28HFRACTION OF FAILED PARTICLES,28,0,0,2,2)
      CALL PLOPB (TT,F2B,NN,1,0,-NCHAR,0.,7.,8.,0,0,0,-23,0,0,0,0,2,2)
      CALL PLOPB (TT,F3B,NN,1,0,-NCHAR,0.,7.,8.,0,0,0,-23,0,0,0,0,2,2)
```

```
      CALL PLOPB (TT,F4B,NN,1,0,-NCHAR,0.,7.,8.,0,0,0,-23,0,0,0.0,2,2)
      IF (MFUEL.EQ.1) CALL DLCH (250,5,24,24HFT. ST. VOATN FUEL MODEL,2)
      IF (MFUEL.EQ.2) CALL DLCH (250,5,24,24HLATEST GASSAR FUEL MODEL,2)
      IF (MFUEL.NE.1) GO TO 20
      CALL CONVRT (1480.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (0.6,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H4,1)
      CALL CONVRT (1580.,IX,XMN,XMX,IXL,IXR)
      CALL DLCH (IX,IY,1,1H3,1)
      CALL CONVRT (1690.,IX,XMN,XMX,IXL,IXR)
      CALL DLCH (IX,IY,1,1H2,1)
      CALL CONVRT (1810.,IX,XMN,XMX,IXL,IXR)
      CALL DLCH (IX,IY,1,1H1,1)
      GO TO 30
   20 CALL CONVRT (2100.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (.05,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H1,1)
      CALL CONVRT (2060.,IX,XMN,XMX,IXL,IXR)
      CALL DLCH (IX,IY,1,1H2,1)
      CALL CONVRT (2000.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (.08,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H3,1)
      CALL CONVRT (1800.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (.15,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H4,1)
   30 CONTINUE
      ENCODE (43,150,TITLE)MFUEL,AGE,LAGE
      CALL DLCH (100,1005,43,TITLE,1)
      CALL ADV (1)
      PRINT 140
      PRINT 180, MFUEL,AGE,LAGE
      PRINT 160
      PRINT 170, (I,TT(I),F1T(I),F2T(I),F3T(I),F4T(I),FT(I),I=1,NN)
      CALL PLOPB (TT,F1T,NN,1,0,NCHAR,0.,7.,8.,0,0,23HTEMPERATURE (DEGREE
     1ES K),-23,28HFRACTION OF FAILED PARTICLES,28,0,0.2,2)
      CALL PLOPB (TT,F2T,NN,1,0,-NCHAR,0.,7.,8.,0,0,0,-23,0,0,0.0,2,2)
      CALL PLOPB (TT,F3T,NN,1,0,-NCHAR,0.,7.,8.,0,0,0,-23,0,0,0.0,2,2)
      CALL PLOPB (TT,F4T,NN,1,0,-NCHAR,0.,7.,8.,0,0,0,-23,0,0,0.0,2,2)
      IF (MFUEL.EQ.1) CALL DLCH (250,5,24,24HFT. ST. VOATN FUEL MODEL,2)
      IF (MFUEL.EQ.2) CALL DLCH (250,5,24,24HLATEST GASSAR FUEL MODEL,2)
      IF (MFUEL.NE.1) GO TO 40
      CALL CONVRT (1480.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (0.6,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H4,1)
      CALL CONVRT (1580.,IX,XMN,XMX,IXL,IXR)
      CALL DLCH (IX,IY,1,1H3,1)
      CALL CONVRT (1690.,IX,XMN,XMX,IXL,IXR)
      CALL DLCH (IX,IY,1,1H2,1)
      CALL CONVRT (1810.,IX,XMN,XMX,IXL,IXR)
      CALL DLCH (IX,IY,1,1H1,1)
      GO TO 50
   40 CALL CONVRT (1970.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (.05,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H1,1)
      CALL CONVRT (1930.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (.08,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H2,1)
      CALL CONVRT (1900.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (.09,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H3,1)
      CALL CONVRT (1870.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (0.1,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H4,1)
```

```
50 CONTINUE
   ENCODE (43,180,TITLE)MFUEL,AGE,LAGE
   CALL DLCH (100,1005,43,TITLE,1)
   CALL ADV (1)
   FLIMIT=1.0E-3
   DO 60 I=1,NN
   IF (F1B(I).EQ.0.0) F1B(I)=FLIMIT
   IF (F2B(I).EQ.0.0) F2B(I)=FLIMIT
   IF (F3B(I).EQ.0.0) F3B(I)=FLIMIT
   IF (F4B(I).EQ.0.0) F4B(I)=FLIMIT
   IF (FB(I).EQ.0.0) FB(I)=FLIMIT
   IF (F1T(I).EQ.0.0) F1T(I)=FLIMIT
   IF (F2T(I).EQ.0.0) F2T(I)=FLIMIT
   IF (F3T(I).EQ.0.0) F3T(I)=FLIMIT
   IF (F4T(I).EQ.0.0) F4T(I)=FLIMIT
   IF (FT(I).EQ.0.0) FT(I)=FLIMIT
60 CONTINUE
   YMIN=-3.
   YMAX=0.0
   INTVALY=3
   KY=0
   CALL PLOPB (TT,F1B,NN,-1,0,NCHAR,0.,7.,8.,0,0,23HTEMPERATURE (DEGR
  1EES K),-23,28HFRACTION OF FAILED PARTICLES,28,0.0,2,2)
   CALL PLOPB (TT,F2B,NN,-1,0,-NCHAR,0.,7.,8.,0,0,0.,-23,0,0.0,0,2,2)
   CALL PLOPB (TT,F3B,NN,-1,0,-NCHAR,0.,7.,8.,0,0,0.,-23,0,0,0,0,2,2)
   CALL PLOPB (TT,F4B,NN,-1,0,-NCHAR,0.,7.,8.,0,0,0.,-23,0,0,0,0,2,2)
   IF (MFUEL.EQ.1) CALL DLCH (250,5,24,24HFT. ST. VRAIN FUEL MODEL,2)
   IF (MFUEL.EQ.2) CALL DLCH (250,5,24,24HLATEST GASSAR FUEL MODEL,2)
   IF (MFUEL.NE.1) GO TO 70
   CALL CONVRT (1420.,IX,XMN,XMX,IXL,IXR)
   CALL CONVRT (-.4,IY,YMN,YMX,IYB,IYT)
   CALL DLCH (IX,IY,1,1H4,1)
   CALL CONVRT (1530.,IX,XMN,XMX,IXL,IXR)
   CALL DLCH (IX,IY,1,1H3,1)
   CALL CONVRT (1640.,IX,XMN,XMX,IXL,IXR)
   CALL DLCH (IX,IY,1,1H2,1)
   CALL CONVRT (1760.,IX,XMN,XMX,IXL,IXR)
   CALL DLCH (IX,IY,1,1H1,1)
   GO TO 80
70 CALL CONVRT (1740.,IX,XMN,XMX,IXL,IXR)
   CALL CONVRT (-1.8,IY,YMN,YMX,IYB,IYT)
   CALL DLCH (IX,IY,1,1H4,1)
   CALL CONVRT (1800.,IX,XMN,XMX,IXL,IXR)
   CALL CONVRT (-2.0,IY,YMN,YMX,IYB,IYT)
   CALL DLCH (IX,IY,1,1H3,1)
   CALL CONVRT (1900.,IX,XMN,XMX,IXL,IXR)
   CALL CONVRT (-2.3,IY,YMN,YMX,IYB,IYT)
   CALL DLCH (IX,IY,1,1H2,1)
   CALL CONVRT (2000.,IX,XMN,XMX,IXL,IXR)
   CALL CONVRT (-2.6,IY,YMN,YMX,IYB,IYT)
   CALL DLCH (IX,IY,1,1H1,1)
80 CONTINUE
   ENCODE (43,150,TITLE)MFUEL,AGE,LAGE
   CALL DLCH (100,1005,43,TITLE,1)
   CALL ADV (1)
   CALL PLOPB (TT,F1T,NN,-1,0,NCHAR,0.,7.,8.,0,0,23HTEMPERATURE (DEGR
  1EES K),-23,28HFRACTION OF FAILED PARTICLES,28,0.0,2,2)
   CALL PLOPB (TT,F2T,NN,-1,0,-NCHAR,0.,7.,8.,0,0,0.,-23,0,0.0,0,2,2)
   CALL PLOPB (TT,F3T,NN,-1,0,-NCHAR,0.,7.,8.,0,0,0.,-23,0,0,0,0,2,2)
   CALL PLOPB (TT,F4T,NN,-1,0,-NCHAR,0.,7.,8.,0,0,0.,-23,0,0.0,0,2,2)
   IF (MFUEL.EQ.1) CALL DLCH (250,5,24,24HFT. ST. VRAIN FUEL MODEL,2)
   IF (MFUEL.EQ.2) CALL DLCH (250,5,24,24HLATEST GASSAR FUEL MODEL,2)
   IF (MFUEL.NE.1) GO TO 90
```

```
      CALL CONVRT (1400.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-.4,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H4,1)
      CALL CONVRT (1510.,IX,XMN,XMX,IXL,IXR)
      CALL DLCH (IX,IY,1,1H3,1)
      CALL CONVRT (1630.,IX,XMN,XMX,IXL,IXR)
      CALL DLCH (IX,IY,1,1H2,1)
      CALL CONVRT (1760.,IX,XMN,XMX,IXL,IXR)
      CALL DLCH (IX,IY,1,1H1,1)
      GO TO 100
   90 CALL CONVRT (1800.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-1.9,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H4,1)
      CALL CONVRT (-2.15,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H3,1)
      CALL CONVRT (-2.3,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H2,1)
      CALL CONVRT (-2.7,IY,YMN,YMX,IYB,IYT)
      CALL DLCH (IX,IY,1,1H1,1)
  100 CONTINUE
      ENCODE (43,180,TITLE)MFUEL,AGE,LAGE
      CALL DLCH (100,1005,43,TITLE,1)
      CALL ADV (1)
  110 CONTINUE
      XMIN=1200.
      XMAX=2200.
      INTVALX=5
      KX=0
      YMIN=0.0
      YMAX=3.0
      INTVALY=3
      KY=0
C     FIRST FOR BISO.......
C     USE FB ARRAY FOR LOWER TEMP, FT FOR HIGHER TEMP, TT FOR TIME
      TT(1)=1.0
      FB(1)=1858.15
      FT(1)=1998.15
      TT(2)=43.
      FB(2)=1858.15
      FT(2)=1998.15
      TT(3)=1000.0
C     1000. DAYS = 1000./365.25 YEARS
      FB(3)=1876.17*EXP(-80.4098/365.25)
      FT(3)=2011.97*EXP(-57.4098/365.25)
      CALL PLOPB (FB,TT,3,-1,0,NCHAR,0.,8.,8.,30HFT. ST. VRAIN FUEL MODE
     1L--BISO,30,28HFUEL TEMPERATURE (DEGREES K),-28,23HIRRADIATION TIME
     2 (DAYS),23,0,0,2,2)
      CALL PLOPB (FT,TT,3,-1,0,-NCHAR,0.,8.,8.,0,0,0,-28,0,0,0,0,2,2)
      CALL CONVRT (1400.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (1.2,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,19,19HNO COATING FAILURES,1)
      CALL CONVRT (1250.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (2.2,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,22,22HPARTIAL FAILURE REGION,1)
      CALL CONVRT (1800.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (2.7,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,28,28H100 PERCENT COATING FAILURES,1)
      CALL ADV (1)
C     FOR TRISO DO THE SAME.
      FB(3)=1880.1*EXP(-97.4459/365.25)
      FT(3)=2009.53*EXP(-47.2964/365.25)
C     THESE NUMBERS ARE THE SAME AS THOSE IN THE FRACB AND FRACT SUBROUT
C     INES.......5/9/76    L.C.
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      CALL PLOP8 (FB,TT,3,-1,0,NCHAR,0.,8.,8.,31HFT. ST. VRAIN FUEL MODE
     1L--TRISO,31,28HFUEL TEMPERATURE (DEGREES K),-28,23HIRRADIATION TIM
     2E (DAYS),23,0,0,2,2)
      CALL PLOP8 (FT,TT,3,-1,0,-NCHAR,0.,8.,8.,0,0,0,-28,0,0,0,0,2,2)
      CALL CONVRT (1400.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (1.2,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,19,19HNO COATING FAILURES,1)
      CALL CONVRT (1250.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (2.2,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,22,22HPARTIAL FAILURE REGION,1)
      CALL CONVRT (1800.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (2.7,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,28,28H100 PERCENT COATING FAILURES,1)
      CALL ADV (1)
C     NOW WE USE F1B, F2B, F3B TO REPRESENT J. FOLEY, AYER AND SORS
C     MODELS FIRST HALF, F1T AND F2T TO REPRESENT J. FOLEY AND AYER
C     MODELS SECOND HALF.
C     INITIALIZE SPLINE FUNCTIONS
      Z=UTMP0(0.0)
      Z=AYER0(0.0)
      Z=SORS0(0.0)
      Z=UTMPC0(0.0)
      Z=AYERC0(0.0)
      NN=101
      DT=20./(NN-1)
      DO 130 I=1,NN
      TT(I)=(I-1)*DT
      T=TT(I)
      IF (T.LT.2.0) GO TO 120
      F1B(I)=UTMP(T)
      F2B(I)=AYER(T)
      F3B(I)=SORS(T)
      F1T(I)=UTMPC(T)
      F2T(I)=AYERC(T)
      GO TO 130
  120 F1B(I)=0.0
      F2B(I)=0.0
      F3B(I)=0.0
      F1T(I)=0.0
      F2T(I)=0.0
  130 CONTINUE
      XMIN=0.0
      XMAX=20.0
      INTVALX=10
      KX=0
      YMIN=0.0
      YMAX=1.0
      INTVALY=5
      KY=1
      CALL PLOP8 (TT,F1B,NN,1,0,NCHAR,0.,8.,5.,42HUNIFORM TEMPERATURE. A
     1YER AND SORS RESULTS,42,36HTIME AFTER ONSET OF ACCIDENT (HOURS),-3
     26,19HFRACTION IN COOLANT,19,0,0,2,2)
      CALL PLOP8 (TT,F2B,66,1,0,-NCHAR,0.,8.,5.,0,0,0,-36,0,0,0,0,2,2)
      CALL PLOP8 (TT,F3B,81,1,0,-NCHAR,0.,8.,5.,0,0,0,-36,0,0,0,0,2,2)
      CALL CONVRT (2.0,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (0.8,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,18,18HUNIFORM TEMP MODEL,1)
      CALL CONVRT (4.0,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (0.4,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,4,4HAYER,1)
      CALL CONVRT (8.0,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (0.5,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,4,4HSORS,1)
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      CALL ADV (1)
      YMAX=4000.
      INTVALY=4
      KY=0
      CALL PLOPB (TT,F1T,NN,1,0,NCHAR,0.,8.,5.,36HUNIFORM TEMPERATURE AN
     1D AYER RESULTS,36,36HTIME AFTER ONSET OF ACCIDENT (HOURS),-36,33HT
     2-131 CUMULATIVE RELEASE (CURIES),33,0,0,2,2)
      CALL PLOPB (TT,F2T,NN,1,0,-NCHAR,0.,8.,5.,0,0,0,-36,0,0,0,0,2,2)
      CALL CONVRT (4.0,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (3000.,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,18,18HUNIFORM TEMP MODEL,I)
      CALL CONVRT (10.,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (2400.,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,4,4HAYER,1)
      CALL ADV (1)
      RETURN
C
  140 FORMAT (1H0)
  150 FORMAT (* MFUEL =*,I1,5X,*AGE =*,F4.1,5X,*LAGE =*,L1,*     BISO*)
  160 FORMAT (/4X,1HI,14X,1HT,13X,2HF1,13X,2HF2,13X,2HF3,13X,2HF4,14X,1H
     1F/)
  170 FORMAT (I5,6F15.5)
  180 FORMAT (* MFUEL =*,I1,5X,*AGE =*,F4.1,5X,*LAGE =*,L1,*    TRISO*)
      END
      SUBROUTINE PLOT2
      LOGICAL LAGE,BISO
      DIMENSION FRAC(241), BFRAC(241), TFRAC(241), A(241)
      DIMENSION FUEL(2)
      COMMON /LA/ LAGE,AGE,MFUEL,ISO,BISO
C     LAGE IS A LOGICAL VARIABLE SET TRUE IF ALL FOUR AGES OF FUEL ARE
C     TO BE USED.  IF LAGE IS TRUE, AGE IS SET EQUAL TO THE TIME SINCE
C     THE REACTOR WAS TURNED ON.
C     IF LAGE IS FALSE, AGE IS SET EQUAL TO THE AGE OF ALL OF THE FUEL.
C     MFUEL = 1  FT. ST. VRATN FUEL MODEL
C     MFUEL = 2  GASSAR FUEL MODEL
      NCHAR=27
C     INITIALIZE PLOTS
C     INITIALIZE SPLINE
      DO 30 IL=1,2
      IF (IL.EQ.1) LAGE=.T.
      IF (IL.EQ.2) LAGE=.F.
      DO 30 MFUEL=1,2
      ENCODE (18,40,FUEL)MFUEL,LAGE
      PRINT 50, MFUEL,LAGE
      NTL=241
      DO 20 IAGE=1,NTL
      AGE=(IAGE-1)*0.025
      A(IAGE)=AGE
      BFRAC(IAGE)=0.0
      TFRAC(IAGE)=0.0
      NN=100
      DO 10 I=1,NN
      PER=1./NN
      BIN=PER*I-PER/2
      T=TEMP(BIN)
      FB=FRACB(T)
      BFRAC(IAGE)=BFRAC(IAGE)+FB
      FT=FRACT(T)
      TFRAC(IAGE)=TFRAC(IAGE)+FT
   10 CONTINUE
      BFRAC(IAGE)=BFRAC(IAGE)*PER
      TFRAC(IAGE)=TFRAC(IAGE)*PER
      FRAC(IAGE)=0.6*BFRAC(IAGE)+0.4*TFRAC(IAGE)
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   20 CONTINUE
      PRINT 60
      PRINT 70, (I,A(I),BFRAC(I),TFRAC(I),FRAC(I),I=1,NTL)
      CALL PLOPB (A,BFRAC,NTL,1,0,NCHAR,0.,8.,8.,0,0,11HAGE (YEARS),11,2
     10HFAILED FRACTION BISO,20,0,0,2,2)
      CALL DLCH (100,1005,18,FUEL,1)
      IF (MFUEL.EQ.1) CALL DLCH (325,5,24,24HFT. ST. VRAIN FUEL MODEL,2)
      IF (MFUEL.EQ.2) CALL DLCH (325,5,24,24HLATEST GASSAR FUEL MODEL,2)
      CALL ADV (1)
      CALL PLOPB (A,TFRAC,NTL,1,0,NCHAR,0.,8.,8.,0,0,11HAGE (YEARS),11,2
     11HFAILED FRACTION TRISO,21,0,0,2,2)
      CALL DLCH (100,1005,18,FUEL,1)
      IF (MFUEL.EQ.1) CALL DLCH (325,5,24,24HFT. ST. VRAIN FUEL MODEL,2)
      IF (MFUEL.EQ.2) CALL DLCH (325,5,24,24HLATEST GASSAR FUEL MODEL,2)
      CALL ADV (1)
      CALL PLOPB (A,FRAC,NTL,1,0,NCHAR,0.,8.,8.,0,0,11HAGE (YEARS),11,2
     1HFAILED FRACTION TOTAL,21,0,0,2,2)
      CALL DLCH (100,1005,18,FUEL,1)
      IF (MFUEL.EQ.1) CALL DLCH (325,5,24,24HFT. ST. VRAIN FUEL MODEL,2)
      IF (MFUEL.EQ.2) CALL DLCH (325,5,24,24HLATEST GASSAR FUEL MODEL,2)
      CALL ADV (1)
   30 CONTINUE
      RETURN
C
   40 FORMAT (*MFUEL=*,I1,5X,*LAGE=*,L1)
   50 FORMAT (*0MFUEL =*,I1,5X,*LAGE =*,L1)
   60 FORMAT (///4X,1HI,17X,3HAGE,15X,5HFRACB,15X,5HFRACT,16X,4HFRAC/)
   70 FORMAT (I5,4F20.5)
      END
      SUBROUTINE PLOT3
      LOGICAL LAGE,BISO
      DIMENSION RINTAC(151), RFAILD(151), TT(151), TT4(151), RTLOG(151),
     1 RFLOG(151)
      COMMON /CJE07/ IXL,IXR,IYT,IYB,XMN,XMX,YMX,YMN
      COMMON /CJE08/ XMIN,XMAX,INTVALX,KX,YMIN,YMAX,INTVALY,KY
      COMMON /LA/ LAGE,AGE,MFUEL,ISO,BISO
      COMMON /LINEW/ IXSAVE,IYSAVE,IX2,IY2
      NCHAR=27
      NN=61
      DO 10 I=1,NN
      TT4(I)=9.0-(I-1)*0.1
   10 TT(I)=1.0E4/TT4(I)
      MFUEL=1
      XMIN=3.0
      XMAX=9.0
      INTVALX=6
      BISO=.F.
      KX=1
      YMIN=-6.
      YMAX=1.
      INTVALY=7
      KY=0
      CALL PLOPB (TT4,RFAILD,NN,-1,0,NCHAR,0.,5.,7.,24HFT. ST. VRAIN FUE
     1L MODEL,-24,19H1.0E4/T (DEGREES K),-19,36HPARTICLE COATING RELEASE
     2 RATE / HOUR,36,0,0,2,2)
      CALL CONVRT (3.5,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-4.75,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,12,12H1,3,4,5,9,10,1)
      CALL CONVRT (-3.5,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,1,1H6,1)
      CALL CONVRT (3.6,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-2.5,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,1,1H7,1)
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      CALL CONVRT (3.9,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-2.0,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,1,1H9,1)
      CALL CONVRT (4.5,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-1.5,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,1,1H2,1)
      CALL CONVRT (6.0,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-3.0,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,7,7H4,7,8,9,1)
      CALL CONVRT (6.5,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-1.0,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,6,6H3.5,10,1)
      CALL CONVRT (4.5,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (0.0,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,1,1H1,1)
      CALL CONVRT (4.75,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (0.1,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,1,1H6,1)
      DO 30 ISO=1,10
      DO 20 I=1,NN
      T=TT(I)
      RINTAC(I)=RI(T)
      RFAILD(I)=RF(T)
      RILOG(I)=ALOG10(RINTAC(I))
      RFLOG(I)=ALOG10(RFAILD(I))
   20 CONTINUE
      PRINT 80, ISO,MFUEL
      PRINT 90, (I,TT(I),TT4(I),RINTAC(I),RILOG(I),RFAILD(I),RFLOG(I),I=
     11,NN)
      CALL PLOPB (TT4,RFAILD,NN,-1,0,-NCHAR,0.,5.,7.,0,0,0,-19,0,0,0,0,2
     1,2)
      CALL PLOPB (TT4,RINTAC,NN,-1,0,-NCHAR,0.,5.,7.,0,0,0,-19,0,0,0,0,2
     1,2)
   30 CONTINUE
      MFUEL=2
      CALL ADV (1)
      XMIN=3.0
      XMAX=7.0
      INTVALX=4
      KX=0
      YMIN=-4.
      YMAX=2.0
      INTVALY=6
      KY=0
      CALL PLOPB (TT4,RFAILD,NN,-1,0,NCHAR,2.,5.,7.,36HGASSAR FUEL MODEL
     1 - FAILED PARTICLES,-36,19H1.0E4/T (DEGREES K),-19,36HPARTICLE COA
     2TING RELEASE RATE / HOUR,36,0,0,2,2)
      CALL CONVRT (4.0,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-1.4,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,8,8H10 TRISO,1)
      CALL CONVRT (-0.4,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,1,1H5,1)
      CALL CONVRT (6.0,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-1.6,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,1,1H3,1)
      CALL CONVRT (3.9,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (0.4,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,1,1H6,1)
      CALL CONVRT (3.6,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (0.6,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,7,7H10 BISO,1)
      CALL CONVRT (6.8,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-1.3,IY,YMN,YMX,IYB,IYT)
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      CALL WLCH (IX,IY,1,1H1,1)
      CALL CONVRT (3.6,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (1.0,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,7,7H4,7,8,9,1)
      CALL CONVRT (4.25,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (1.5,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,1,1H2,1)
      DO 50 ISO1=1,11
      ISO=ISOI
      IF (ISO.EQ.11) BISO=.T.
      IF (ISO.EQ.11) ISO=10
      DO 40 I=1,NN
      T=TT(I)
      RFAILD(I)=RF(T)
      RFLOG(I)=ALOG10(RFAILD(I))
   40 CONTINUE
      PRINT 80, ISO,MFUEL
      PRINT 100, (I,TT(I),TT4(I),RFAILD(I),RFLOG(I),I=1,NN)
      CALL PLOP8 (TT4,RFAILD,NN,-1,0,-NCHAR,0.,5.,7.,0.0,0,-1,0,0,0,0,2,
     12)
   50 CONTINUE
      CALL ADV (1)
      XMIN=4.0
      XMAX=9.0
      YMIN=-7.
      YMAX=0.
      INTVALX=5
      KX=0
      INTVALY=7
      KY=0
      CALL PLOP8 (TT4,RINTAC,NN,-1,0,NCHAR,2.,5.,7.,36HGASSAR FUEL MODEL
     1 - INTACT PARTICLES,-36,19H1.0E4/T (DEGREES K),-19,36HPARTICLE COA
     2TING RELEASE RATE / HOUR,36,0,0,2,2)
      CALL CONVRT (7.0,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-6.2,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,7,7H3 TRISO,1)
      CALL CONVRT (4.8,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-4.8,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,17,17H7,(1,4,8,9 TRISO),1)
      CALL CONVRT (5.0,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-4.1,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,1,1H5,1)
      CALL CONVRT (-3.7,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,12,12H6,(8,9 BISO),1)
      CALL CONVRT (-3.1,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,2,2H10,1)
      CALL CONVRT (-2.1,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,1,1H2,1)
      CALL CONVRT (8.0,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-4.0,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,6,6H3 BISO,1)
      CALL CONVRT (-2.4,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,6,6H1 BISO,1)
      CALL CONVRT (4.6,IX,XMN,XMX,IXL,IXR)
      CALL CONVRT (-0.4,IY,YMN,YMX,IYB,IYT)
      CALL WLCH (IX,IY,6,6H4 BISO,1)
      DO 70 ISO=1,10
      DO 70 IBISO=1,2
      IF (IBISO.EQ.1) BISO=.F.
      IF (IBISO.EQ.2) BISO=.T.
      DO 60 I=1,NN
      T=TT(I)
      RINTAC(I)=RI(T)
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      RILOG(I)=ALOG10(RINTAC(I))
   60 CONTINUE
      PRINT 80, ISO,MFUEL
      CALL PLOPB (TT4,RINTAC,NN,-1,0,-NCHAR,0.,5.,7.,0,0,0,-1,0,0,0,0,2,
     12)
   70 CONTINUE
      CALL ADV (1)
      RETURN
C
   80 FORMAT (6H0ISO =,I2,3X,7HMFUEL =,I1,10X,7H1.0E4/T,18X,2HRT,15X,5HR
     1ILOG,18X,2HRF,15X,5HRFLOG/)
   90 FORMAT (1X,I5,F12.1,5F20.5)
  100 FORMAT (1X,I5,F12.1,E20.5,40X,2E20.5)
      END
      SUBROUTINE PLOT4
      INTEGER DATE
      DIMENSION T(41), FF(41), TX(41,50), B(50), VECP(250), ITITLE(36)
      DIMENSION TEMP1(41,50), TEMP2(41,50)
      COMMON /TMODEL/ MODEL
      DO 10 I=1,36
   10 ITITLE(I)=10H
      CALL GETQ (4LKJRN,JOBNAME)
      CALL DATE1 (DATE)
      ITITLE(1)=JOBNAME
      ITITLE(2)=DATE
      ITITLE(12)=10HTEMPERATUR
      ITITLE(13)=10HE MODEL =
      Z=SPLIME(0.0,0.0)
      Z=TEMP0(0.0)
      CALL ADV (1)
      NTOT=40
      IVFMAX=50
      DT=20./NTOT
      NTOT1=NTOT+1
      DO 20 I=1,NTOT1
   20 T(I)=(I-1)*DT
      ITEMP=4
      DO 60 MODEL=1,ITEMP
      ENCODE (10,70,ITITLE(14))MODEL
      IF (MODEL.EQ.4) GO TO 40
      Z=TAVE0(0.0)
      Z=TMAX0(0.0)
      TDELT=TEMP(0.01-1174.4
      DO 30 I=1,NTOT1
      TIME=T(I)
   30 FF(I)=(TMAX(TIME)-TAVE(TIME))/TDELT
   40 CONTINUE
      PER=1./IVFMAX
      DO 50 IVF=1,IVFMAX
      BIN=PER*(IVF-0.5)
      B(IVF)=BIN
      DO 50 I=1,NTOT1
      TIME=T(I)
      IF (MODEL.NE.4) TE=FF(I)*(TEMP(BIN)-1174.4)+TAVE(TIME)
      IF (MODEL.EQ.4) TE=SPL(TIME,BIN)
      TX(I,IVF)=TE
   50 CONTINUE
      ITITLE(9)=10HTIME(HRS)
      ITITLE(10)=10HCORE FRACT
      ITITLE(11)=10HTEMP (K)
      PRINT 80, MODEL
      PRINT 90, (J,(TX(I,J),I=1,NTOT1,2),J=1,IVFMAX)
      CALL PLNOW (TX,NTOT1,IVFMAX,T,B,VECP,250,ITITLE)
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      CALL PICTURE (TX,TEMP1,TEMP2,NTOT1,IVFMAX,NTOT1,1.0,1.0,2.0,2.0,2.
     10,900.,3700.,0,-2,3,0,-1.)
C     WRITE JOB IDENTIFICATION
      CALL DLCH (154,992,4,4HJOB=,1)
      CALL DLCH (206,992,10,ITITLE,1)
C     WRITE DATE
      CALL DLCH (400,992,5,5HDATE=,1)
      CALL DLCH (464,992,10,ITITLE(2),1)
C     WRITE ID
      CALL DLCH (154,972,60,ITITLE(12),1)
C     WRITE FUNCTION RANGE
      CALL DLCH (696,952,7,7HRANGE=-,1)
      CALL DLCH (780,952,20,ITITLE(3),1)
C     WRITE X RANGE
      CALL DLCH (780,972,20,ITITLE(5),1)
C     WRITE Y RANGE
      CALL DLCH (780,992,20,ITITLE(7),1)
      CALL ADV (1)
      CALL ADV (1)
   60 CONTINUE
      CALL EXH
C
      RETURN
C
   70 FORMAT (I2,8X)
   80 FORMAT (//* TEMPERATURE MODEL =*,I1/)
   90 FORMAT (1X,I3,21F6.0/)
      END
      FUNCTION UTMPO (T)
C     THESE NUMBERS FROM TABULAR DATA IN REPORT BY J. FOLEY
      DIMENSION IOP(2), TAB(3)
      DIMENSION X(16), F(16), W(16), A(16), B(16), C(16)
      DATA X/2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,14.,16.,18.,20./
      DATA F/0.,.0157,.0658,.1774,.3355,.5280,.7147,.8470,.9177,.9473,.9
     1550,.9537,.953,.946,.939,.933/
C     SPLINE BOUNDARY CONDITIONS ETC.
      IJ=1
      IOP(1)=5
      IOP(2)=5
      N1=16
      CALL SPL1D1 (N1,X,F,W,IOP,IJ,A,B,C)
      RETURN
      ENTRY UTMP
      CALL SPL1D2 (N1,X,F,W,IJ,T,TAB)
      UTMP=TAB(1)
      RETURN
      END
      FUNCTION AYERO (T)
C     THESE NUMBERS FROM GRAPHICAL DATA IN REPORT BY J. FOLEY
      DIMENSION IOP(2), TAB(3)
      DIMENSION X(7), F(7), W(7), A(7), B(7), C(7)
      DATA X/2.,4.,6.,8.,10.,12.,13./
      DATA F/0.,.115,.435,.645,.75,.82,.845/
C     SPLINE BOUNDARY CONDITIONS ETC.
      IJ=1
      IOP(1)=5
      IOP(2)=5
      N1=7
      CALL SPL1D1 (N1,X,F,W,IOP,IJ,A,B,C)
      RETURN
      ENTRY AYER
      CALL SPL1D2 (N1,X,F,W,IJ,T,TAB)
      AYER=TAB(1)
```

```
      RETURN                                                            PLOTS
      END                                                               PLOTS
      FUNCTION SORSO (T)                                                PLOTS
C     THESE NUMBERS FROM GRAPHICAL DATA IN REPORT BY J. FOLEY           PLOTS
      DIMENSION IOP(2), TAB(3)                                          PLOTS
      DIMENSION X(8), F(8), W(8), A(8), B(8), C(8)                      PLOTS
      DATA X/2.,4.,6.,8.,10.,12.,14.,16./                               PLOTS
      DATA F/0.,.085,.340,.560,.70,.79,.845,.88/                        PLOTS
C     SPLINE BOUNDARY CONDITIONS ETC.                                   PLOTS
      IJ=1                                                              PLOTS
      IOP(1)=5                                                          PLOTS
      IOP(2)=5                                                          PLOTS
      N1=8                                                              PLOTS
      CALL SPL1D1 (N1,X,F,W,IOP,IJ,A,B,C)                               PLOTS
      RETURN                                                            PLOTS
      ENTRY SORS                                                        PLOTS
      CALL SPL1D2 (N1,X,F,W,IJ,T,TAB)                                   PLOTS
      SORS=TAB(1)                                                       PLOTS
      RETURN                                                            PLOTS
      END                                                               PLOTS
      FUNCTION UTMPCO (T)                                               PLOTS
C     THESE NUMBERS FROM TABULAR DATA IN REPORT BY J. FOLEY             PLOTS
      DIMENSION IOP(2), TAB(3)                                          PLOTS
      DIMENSION X(16), F(16), W(16), A(16), B(16), C(16)                PLOTS
      DATA X/2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,14.,16.,18.,20./   PLOTS
      DATA F/0.,19.2,102.8,319.4,702.7,1240.,1866.,2456.,2909.,3200.,336PLOTS
     11.,3439.,3473.,3493.,3496.,3496./                                 PLOTS
C     SPLINE BOUNDARY CONDITIONS ETC.                                   PLOTS
      IJ=1                                                              PLOTS
      IOP(1)=5                                                          PLOTS
      IOP(2)=5                                                          PLOTS
      N1=16                                                             PLOTS
      CALL SPL1D1 (N1,X,F,W,IOP,IJ,A,B,C)                               PLOTS
      RETURN                                                            PLOTS
      ENTRY UTMPC                                                       PLOTS
      CALL SPL1D2 (N1,X,F,W,IJ,T,TAB)                                   PLOTS
      UTMPC=TAB(1)                                                      PLOTS
      RETURN                                                            PLOTS
      END                                                               PLOTS
      FUNCTION AYERCO (T)                                               PLOTS
C     THESE NUMBERS FROM GRAPHICAL DATA IN REPORT BY J. FOLEY           PLOTS
      DIMENSION IOP(2), TAB(3)                                          PLOTS
      DIMENSION X(8), F(8), W(8), A(8), B(8), C(8)                      PLOTS
      DATA X/2.,4.,6.,8.,10.,12.,14.,16./                               PLOTS
      DATA F/0.,250.,1020.,1930.,2480.,2800.,3000.,3110./               PLOTS
C     SPLINE BOUNDARY CONDITIONS ETC.                                   PLOTS
      IJ=1                                                              PLOTS
      IOP(1)=5                                                          PLOTS
      IOP(2)=5                                                          PLOTS
      N1=8                                                              PLOTS
      CALL SPL1D1 (N1,X,F,W,IOP,IJ,A,B,C)                               PLOTS
      RETURN                                                            PLOTS
      ENTRY AYERC                                                       PLOTS
      CALL SPL1D2 (N1,X,F,W,IJ,T,TAB)                                   PLOTS
      AYERC=TAB(1)                                                      PLOTS
      RETURN                                                            PLOTS
      END                                                               PLOTS
      SUBROUTINE PLOPB(X,Y,NPTS,INC,LNN,NSYM,C,XAA,YAA,LABELZ,NZL,LABELX PLOTS
     1,NXL,LABELY,NYL,LABELP,NRL,LSIZE,ISIZE)                           PLOTS
C     PLOPB PRODUCES A STANDARD 2-DIMENSIONAL PLOT SIMILAR TO PLOJB     PLOTS
C     WHICH IS SUITABLE FOR PUBLICATION.                                PLOTS
C     LABELS MAY BE WRITTEN ON 4 SIDES OF PLOT                          PLOTS
C     LSIZE IS THE SIZE OF THE LABELS, 1≤IABS(LSIZE)≤6                  PLOTS
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C     IF LSIZE > 0, DEPENDENT VARIABLES ARE PLOTTED ON LEFT-HAND SCALE
C     IF LSIZE < 0, DEPENDENT VARIABLES ARE PLOTTED ON RIGHT-HAND SCALE
C     ISIZE IS THE SIZE OF THE SCALES. 1≤IABS(ISIZE)<4
C     LINEAR PLOTS FOR DEPENDENT VARIABLES MAY HAVE 2 SCALES ON
C     MULTIPLE PLOTS.
C     IF ISIZE < 0, ONLY LEFT SIDE OF PLOT HAS SCALE
C     IF LSIZE > 0 AND ISIZE < 0, ALLOWANCE IS MADE TO DRAW SCALE ON
C     RIGHT SIDE WITH A LATER CALL TO PLOPB
C     IF LSIZE < 0 AND ISIZE < 0, SCALE IS DRAWN ON RIGHT SIDE.
C     SCALES PRINT 4 FIGURES. DATA MUST BE ADJUSTED BEFORE CALL PLOPB.
C     IF LABEL OTHER THAN TOP DOES NOT FIT ON ONE LINE,
C     LSIZE WILL BE REDUCED BY 1
C     ALSO THE LOG AXES WILL BE FULL CYCLES,
C     IF XXA AND/OR YYA ARE NON-ZERO THE LENGTHS
C     WILL BE CONSIDERED AS RATIOS WHERE THE LONGEST
C     SIDE IS FITTED ON A 860 POINT LINE.
C     AXES LENGTHS WILL BE REDUCED IN ORDER TO ALLOW ROOM FOR
C     LABELS AND SCALES IF NECESSARY.
      COMMON /CJE07/ IXL,IXR,IYT,IYB,XMN,XMX,YMX,YMN
      COMMON /CJE08/ XMIN,XMAX,MAJORX,KX,YMIN,YMAX,MAJORY,KY
      DIMENSION X(1), Y(1)
      DIMENSION ISZ(6), IVSZ(6)
      DATA ISZ/12,18,24,30,36,42/
      DATA IVSZ/16,24,32,40,48,56/
      INTEGER GRIDF
      B=AMAX1(AMAX1(C,0.)*(LNN+1),0.)
      LIN=LNN
      KSYM=IABS(NSYM)
      KINC=MAX0(IABS(INC),1)
      MPTS=IABS(NPTS)
      MZL=MZM=IABS(NZL)
      XXA=ABS(XAA)
      YYA=ABS(YAA)
      NXN=NXM=IABS(NXL)
      NYN=NYM=IABS(NYL)
      NRN=NRM=IABS(NRL)
      LSZ=IABS(LSIZE)
      ISIZ=IABS(ISIZE)
      GRIDF=AMAX1(1.,ABS(C))
      IF (NSYM.GT.0) CALL ADV (1)
      IF (NXL.LT.0) GO TO 50
      IF ((NSYM.LT.0).A.(ISIZE.GT.0)) GO TO 100
      CALL MAXV (X,KINC,MPTS,ISUB,XMX)
      CALL MAXV (Y,KINC,MPTS,ISUB,YMX)
      CALL MINV (X,KINC,MPTS,ISUB,XMN)
      CALL MINV (Y,KINC,MPTS,ISUB,YMN)
      IF (XXA.EQ.0) XXA=6.
      IF (YYA.EQ.0) YYA=10.
      IF (NPTS.LT.0) GO TO 20
      IF (XMN.NE.XMX) GO TO 10
      DXM=.001*ABS(XMX)
      IF (DXM.EQ.0) DXM=.0001
      XMN=XMN-DXM
      XMX=XMX+DXM
   10 CALL ASCL (5,XMN,XMX,MAJX,MINX,KKX)
      GO TO 30
   20 XMN=ALOG10(XMN)
      XMX=ALOG10(XMX)
   30 IF (INC.LT.0) GO TO 60
      IF (YMN.NE.YMX) GO TO 40
      DYM=.001*ABS(YMX)
      IF (DYM.EQ.0) DYM=.0001
      YMN=YMN-DYM
```

```
      YMX=YMX+DYM
   40 CALL ASCL (5,YMN,YMX,MAJY,MINY,KKY)
      GO TO 70
   50 XMN=XMIN
      XMX=XMAX
      MAJX=MAKX=MAJORX
      KKX=KX
      YMN=YMIN
      YMX=YMAX
      MAJY=MAKY=MAJORY
      KKY=KY
      GO TO 70
   60 YMN=ALOG10(YMN)
      YMX=ALOG10(YMX)
   70 MAKX=GRIDF*MAJX
      MAKY=GRIDF*MAJY
      IF (NSYM.LT.0) GO TO 90
      IXL=4.5*ISZ(ISIZ)+1.5*IVSZ(LSZ)
      IH=IVSZ(ISIZ)
      IF (INC.GE.0) IH=IH/2
      IYT=2*MAX0(IVSZ(LSZ),IH)
      IF ((MZL+1)*ISZ(LSZ).GT.1023-IXL/2) IYT=IYT+IVSZ(LSZ)
      FACT=860./AMAX1(XXA,YYA)
      IXR=MIN0(IXL+IFIX(FACT*XXA),1023-MAX0(3*IVSZ(LSZ)/2+ISZ(ISIZ),5*IS
     1Z(ISIZ)/2))
      IF (ISIZE.LT.0) IXR=IXR-4*ISZ(ISIZ)
      IYB=MIN0(IYT+IFIX(FACT*YYA),1023-5*IVSZ(ISIZ)/3-3*IVSZ(LSZ)/2)
      CALL FRAME (IXL,IXR,IYT,IYB)
      IF (SIGN(1.,XAA).GT.0) GO TO 80
      SWAP=XMN
      XMN=XMX
      XMX=SWAP
   80 IF (SIGN(1.,YAA).GT.0) GO TO 90
      SWAP=YMN
      YMN=YMX
      YMX=SWAP
   90 CALL DGA (IXL,IXR,IYT,IYB,XMN,XMX,YMX,YMN)
  100 IF (LSIZE.LT.0) MAKY=-MAKY
      IF ((NSYM.LT.0).A.(LSIZE.GT.0)) GO TO 230
      IF ((NSYM.LT.0).A.(LSIZE.LT.0).A.(ISIZE.GT.0)) GO TO 230
      IF (NPTS.LT.0.AND.INC.LT.0) CALL DLGLGT
      IF (NPTS.LT.0.AND.INC.GE.0) CALL DLGLNT (MAKY,ISIZE)
      IF (NPTS.GE.0.AND.INC.LT.0) CALL DLNLGT (MAKX,ISIZE)
      IF (NPTS.GE.0.AND.INC.GE.0) CALL DLNLNT (MAKX,MAKY,ISIZE)
      IF (NPTS.LT.0) GO TO 110
      IF (NSYM.GT.0) CALL SBLN (MAJX,KKX,ISIZ)
      GO TO 120
  110 IF (NSYM.GT.0) CALL SBLG (ISIZ)
  120 IF (INC.LT.0) GO TO 130
      IF ((LSIZE.GT.0).A.(NSYM.GT.0)) CALL SLLN (MAJY,KKY,ISIZ)
      IF ((LSIZE.LT.0).A.(ISIZE.LT.0)) CALL SRLN (MAJY,KKY,ISIZ)
      GO TO 140
  130 CALL SLLG (ISIZ)
      IF (ISIZE.LT.0) CALL SRLG (ISIZ)
  140 CALL EXL
      IF (NSYM.LT.0) GO TO 230
      KSZ=LSZ
      IF (NYL.GE.0) GO TO 220
      KSZ=-KSZ
      IF (MZM.EQ.0) GO TO 160
      DO 150 K=1,MZM
      CALL FETCH (K,LABELZ,KK)
      IF (KK.GE.608) MZM=MZM+1
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  150 CONTINUE
  160 IF (NXM.EQ.0) GO TO 180
      DO 170 K=1,NXM
      CALL FETCH (K,LABELX,KK)
      IF (KK.GE.60B) NXM=NXM+1
  170 CONTINUE
  180 IF (NYM.EQ.0) GO TO 200
      DO 190 K=1,NYM
      CALL FETCH (K,LABELY,KK)
      IF (KK.GE.60B) NYM=NYM+1
  190 CONTINUE
  200 IF (NRM.EQ.0) GO TO 220
      DO 210 K=1,NRM
      CALL FETCH (K,LABELR,KK)
      IF (KK.GE.60B) NRM=NRM+1
  210 CONTINUE
  220 CONTINUE
      IF (NXN.NE.0) CALL DLCH (MAX0(IXL/2,IXL+(IXR-IXL-ISZ(LSZ)*NXN)/2),
     1IYB+5*IVSZ(ISIZ)/3+IVSZ(LSZ)/2,NXM,LABELX,KSZ)
      IF (NYN.NE.0) CALL DLCV (0,MIN0((IYB+1023)/2,IYB-(IYB-IYT-ISZ(LSZ)
     1*NYN)/2),NYM,LABELY,KSZ)
      IF (NZL.NE.0) CALL DLCH (MAX0(IXL/2,IXL+(IXR-IXL-ISZ(LSZ)*MZL)/2),
     10,MZM,LABELZ,KSZ)
      IXX=IXR
      IF (ISIZE.LT.0) IXX=IXX+4*ISZ(ISIZ)
      IF (NRN.NE.0) CALL DLCV (IXX+IVSZ(LSZ)/2+ISZ(ISIZ)/2,MIN0((IYB+102
     13)/2,IYB-(IYB-IYT-ISZ(LSZ)*NRN)/2),NRM,LABELR,KSZ)
      CALL EXH
  230 IF (NZL.LT.0) GO TO 320
C     PLOT POINTS AND/OR LINE
      MPTS=MPTS*KINC
      DO 310 NXP=1,MPTS,KINC
      XTWO=X(NXP)
      YTWO=Y(NXP)
      IF (NPTS.LT.0) XTWO=ALOG10(XTWO)
      IF (INC.LT.0) YTWO=ALOG10(YTWO)
      CALL CONVRT (XTWO,NXTWO,XMN,XMX,IXL,IXR)
      CALL CONVRT (YTWO,NYTWO,YMN,YMX,IYB,IYT)
      IF (NXP.EQ.1) GO TO 290
      IF (LIN.GE.0) GO TO 280
  240 IF (MOD(((NXP-1)/KINC),IABS(LIN)).NE.0) GO TO 250
      CALL EXL
      CALL DLCH (NXTWO,NYTWO,0,KSYM,1)
      CALL EXH
      GO TO 300
  250 IF (B.EQ.0.) GO TO 300
  260 DO 270 IB=1,4
  270 CALL PLT (NXTWO,NYTWO,42)
      GO TO 300
  280 IF (B.EQ.0.) CALL DRV (NXONE,NYONE,NXTWO,NYTWO)
  290 IF (LIN.NE.0) GO TO 240
      IF (B.NE.0.) GO TO 260
  300 NYONE=NYTWO
      NXONE=NXTWO
  310 CONTINUE
  320 RETURN
      END
      SUBROUTINE SLLN(NNY,NK,ISIZE)
      COMMON /CJE07/ IXL,IXR,IYT,IYB,XL,XR,YT,YB
      DIMENSION ISZ(4), IVSZ(4)
      DATA ISZ/12,18,24,30/
      DATA IVSZ/16,24,32,40/
      DATA MASK1/77000000000000000000B/
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      DATA MASK2/00777777777777777777B/
      NNK=NK
      NC=MAX0(INT(ALOG10(AMAX1(ABS(YT),ABS(YB)))+.00001)+1,1)
      IF (MIN0(YT,YB).LT.0) NC=NC+1
      IF (NNK.GT.0) NC=NC+1
   10 IF (ISZ(ISIZE)*(NC+NNK+.5).LT.IXL) GO TO 20
      IF (NNK.GT.0) NNK=NNK-1
      IF (NNK.GT.0) GO TO 10
   20 NC=MIN0(NC+NNK,4)
      IF (YT.GE..005) GO TO 30
      IF (NNY.LE.5) GO TO 30
      NC=NC+1
      NNK=NNK+1
   30 CONTINUE
      ENCODE (6,50,FMT)NC,NNK
      ENCODE (10,FMT,OUT)YB
      IF ((OUT.AND.MASK1).EQ.1L*) OUT=(OUT.AND.MASK2).OR.1L.
C     THIS CHANGE SHOULD REPLACE * BY . AT LEFT OF FIELD
C     WE COULD HAVE USED CALL PUT (1,OUT,1R.)
      IXT=IXL-ISZ(ISIZE)*(NC+.5)
      IVS=IVSZ(ISIZE)/2
      CALL DLCH (IXT,IYB-IVS,NC,OUT,ISIZE)
      CALL TSP (IXL,IYB,1,1H+)
      IF (NNY.LE.0) RETURN
      NY=MIN0((IYB-IYT)/IVSZ(ISIZE),NNY)
      DY=(YT-YB)/NY+YT*1E-12
      DDY=FLOAT(IYT-IYB)/NY
      DO 40 I=1,NY
      YC=YB+I*DY
      IYC=IYB+I*DDY
      ENCODE (10,FMT,OUT)YC
      CALL DLCH (IXT,IYC-IVS,NC,OUT,ISIZE)
   40 CALL TSP (IXL,IYC,1,1H+)
      RETURN
C
   50 FORMAT (2H(F,I1,1H.,I1,1H))
      END
      SUBROUTINE SLLIN(NNY,NK)
      COMMON /CJE07/ IXL,IXR,IYT,IYB,XL,XR,YT,YB
      DIMENSION FMT(14), OUT(2)
      DATA (FMT(K),K=1,14)/6H(F7.0),6H(F8.1),6H(F9.2),7H(F10.3),7H(F11.4
     1),7H(F12.5),7H(F13.6),8H(1PE7.0),8H(1PE8.1),8H(1PE9.2),9H(1PE10.3)
     2,9H(1PE11.4),9H(1PE12.5),9H(1PE13.6)/
      IF (NK.GT.6) GO TO 10
      K=MIN0(6,MAX0(0,NK))+1
      NC=K+6
      GO TO 20
   10 K=MIN0(16,MAX0(10,NK))-2
      NC=K-1
   20 A=FMT(K)
      ENCODE (20,A,OUT)YB
      IXT=IXL-12*NC-6
      CALL WLCH (IXT,IYB,NC,OUT,1)
      CALL TSP (IXL,IYB,1,1H+)
      IF (NNY.LE.0) RETURN
      NY=MIN0(128,NNY)
      IYC=IYB
      DY=(YT-YB)/NY
      DDY=FLOAT(IYT-IYB)/NY
      DO 30 I=1,NY
      YC=YB+I*DY
      IYC=IYB+I*DDY
      ENCODE (20,A,OUT)YC
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      CALL WLCH (IXT,IYC,NC,OUT,1)
   30 CALL TSP (IXL,IYC,1,1H+)
      RETURN
      END
      SUBROUTINE SRLIN(NNY,NK)
      COMMON /CJE07/ IXL,IXR,IYT,IYB,XL,XR,YT,YB
      DIMENSION FMT(12), OUT(2)
      DATA (FMT(K),K=1,12)/2H(F,1H ,1H.,1H ,1H),8H(1PE7.0),8H(1PE8.1),9H
     1(1PE9.2),9H(1PE10.3),9H(1PE11.4),9H(1PE12.5),9H(1PE13.6)/
      IF (NK.GT.9) GO TO 10
      NC=MAX0(INT(ALOG10(AMAX1(ABS(YT),ABS(YB))))+1,1)
      IF (MIN0(YT,YB).LT.0) NC=NC+1
      IF (NK.GT.0) NC=NC+1
      NC=NC+NK
      ENCODE (10,40,FMT(2))NC
      ENCODE (10,40,FMT(4))NK
      K=1
      GO TO 20
   10 K=MIN0(16,MAX0(0,NK))-4
      NC=K+1
   20 ENCODE (20,FMT(K),OUT)YB
      CALL TSP (IXR,IYB,1,1H+)
      CALL TCP (NC,OUT)
      IF (NNY.LE.0) RETURN
      NY=MIN0(128,NNY)
      IYC=IYB
      DDY=FLOAT(IYT-IYB)/NY
      DY=(YT-YB)/NY
      DO 30 I=1,NY
      YC=YB+I*DY
      IYC=IYB+I*DDY
      ENCODE (20,FMT(K),OUT)YC
      CALL TSP (IXR,IYC,1,1H+)
   30 CALL TCP (NC,OUT)
      RETURN
C
   40 FORMAT (I2)
      END
      SUBROUTINE SBLIN(NNX,NK)
      COMMON /CJE07/ IXL,IXR,IYT,IYB,XL,XR,YT,YB
      DIMENSION FMT(12), OUT(2)
      DATA (FMT(K),K=1,12)/2H(F,1H ,1H.,1H ,1H),8H(1PE7.0),8H(1PE8.1),9H
     1(1PE9.2),9H(1PE10.3),9H(1PE11.4),9H(1PE12.5),9H(1PE13.6)/
      IY=IYB
      IYDEL=12
      GO TO 10
      ENTRY STLIN
      IY=IYT
      IYDEL=-12
   10 IF (NK.GT.9) GO TO 20
      NC=MAX0(INT(ALOG10(AMAX1(ABS(XL),ABS(XR)))+.00001)+1,1)
      IF (MIN0(XL,XR).LT.0) NC=NC+1
      IF (NK.GT.0) NC=NC+1
      NC=NC+NK
      ENCODE (10,50,FMT(2))NC
      ENCODE (10,50,FMT(4))NK
      K=1
      GO TO 30
   20 K=MIN0(16,MAX0(10,NK))-4
      NC=K+1
   30 ENCODE (20,FMT(K),OUT)XL
      CALL TSP (IXL,IY,1,1H+)
      IXTT=IXL-6*NC+6
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      IYC=IY+IYDEL
      CALL WLCH (IXTT,IYC,NC,OUT,1)
      IF (NNX.LE.0) RETURN
      NX=MIN0(NNX,128)
      IXC=IXL
      DDX=FLOAT(IXR-IXL)/NX
      DX=(XR-XL)/NX
      DO 40 I=1,NX
      XC=XL+I*DX
      IXT=IXT+I*DDX
      IXC=IXL+I*DDX
      ENCODE (20,FMT(K),OUT)XC
      CALL TSP (IXC,IY,1,1H+)
   40 CALL WLCH (IXT,IYC,NC,OUT,1)
      RETURN
C
   50 FORMAT (I2)
      END
      SUBROUTINE SBLOG
      COMMON /CJE07/ IXL,IXR,IYT,IYB,XL,XR,YT,YB
      DIMENSION XY(4), IXY(4)
      EQUIVALENCE (XY,XL), (IXY,IXL)
      DATA TEN/2H10/
      IY=IYB
      IYDEL=20
   10 IX=IXL
      IXDEL=-8
      I1=1
      I2=2
      GO TO 30
      ENTRY STLOG
      IY=IYT
      IYDEL=-12
      GO TO 10
      ENTRY SRLOG
      IX=IXR
      IXDEL=8
      GO TO 20
      ENTRY SLLOG
      IX=IXL
      IXDEL=-48
   20 IY=IYB
      IYDEL=0
      I1=4
      I2=3
   30 X1=XY(I1)
      X2=XY(I2)
      XMIN=AMIN1(X1,X2)
      XMAX=AMAX1(X1,X2)
      XMIN=AMIN1(AINT(XMIN),SIGN(AINT(ABS(XMIN)+.999),XMIN))
      XMAX=AMAX1(AINT(XMAX),SIGN(AINT(ABS(XMAX)+.999),XMAX))
      X1=XMIN
      X2=XMAX
      NY=ABS(X1-X2)
      IF (NY.NE.0) GO TO 40
      YTT=X1+1.
      IF (X2.LT.X1) YTT=X1-1.
      NY=1
      X1=YTT
   40 XY(I1)=X1
      XY(I2)=X2
      IXYV=XY(I1)
      NH=MAX1(ABS(XY(I1)),ABS(XY(I2)))
```

```
      NL=MINT(XY(I1),XY(I2))
      NC=MIN0(INT(ALOG10(FLOAT(NH))+.00001)+2,4)
      IF (NL.GE.0) GO TO 60
      IF (IABS(NL).EQ.NH) GO TO 50
      IF (INT(ALOG10(ABS(FLOAT(NL)))).LT.INT(ALOG10(FLOAT(NH)))) GO TO 6
     10
   50 NC=MIN0(NC+1,4)
   60 ENCODE (4,100,FMT)NC
      NX=AMIN1(ABS(XY(I1)-XY(I2)),25.)
      ENCODE (10,FMT,OUT)IXYV
      CALL TSP (IX,IY,1,1H+)
      IF ((I1.EQ.4).A.(IX.EQ.IXL)) IXDEL=IXDEL+8*(4-NC)
      IXC=IX+IXDEL
      IYC=IY+IYDEL
      IXX=IXC+8
      IYX=IYC-8
      CALL TSP (IXC,IYC,2,TEN)
      CALL WICH (IXX-8,IYX-12,4,OUT,1)
      IF (NX.EQ.0) RETURN
      IDXYV=ISIGN(1,IFIX(XY(I2)-XY(I1)))
      DO 90 I=1,NX
      IXYV=IXYV+IDXYV
      ENCODE (10,FMT,OUT)IXYV
      IF (I1.EQ.1) GO TO 70
      IYC=IY+IYDEL+(I*(IXY(I2)-IXY(I1)))/NX
      IYX=IYC-8
      CALL TSP (IX,IYC,1,1H+)
      GO TO 80
   70 IXC=IX+IXDEL+(I*(IXY(I2)-IXY(I1)))/NX
      IXX=IXC+8
      CALL TSP (IXX,IY,1,1H+)
   80 CALL TSP (IXC,IYC,2,TEN)
      CALL WICH (IXX-8,IYX-12,4,OUT,1)
   90 CONTINUE
      RETURN
C
  100 FORMAT (2H(I,I1,1H))
      END
      SUBROUTINE PLNOW(FLUX,IX,JY,XPLT,YPLT,VECP,ILVECP,ITITLE)
      LOGICAL ITOP,JTOP,NFOUND,IPR
      COMMON /CNTRCOM/ ISYM(50),SCFAC
      COMMON /CJE07/ IXL,IXR,IYT,IYB,XNM,XMX,YMX,YMN
      DIMENSION FLUX(1), XPLT(1), YPLT(1), VECP(1), ITITLE(1)
      DATA TIGER/5LLARC1/
C     LCP  LT  0      WE COMPUTE CONTOUR INTERVALS
C     LCP EQ  0      NO CONTOURS
C     LCP GT 0      CONTOUR ROUTINE COMPUTES INTERVALS
C     PARAMETERS FOR COMPUTING REGIONS TO BE CONTOURED
      NCL=I0
      LABELX=ITITLE(9)
      LABELY=ITITLE(10)
      LABELZ=ITITLE(11)
      LCP=-20
      FF=.04
      CINT=-1.0
      IGRID=5
      IMT=IX
      JMT=JY
      IMJMT=IMT*JMT
      SCALE=20.0
      ANGT=1.0471976
      ANGF=0.0
      AMULX=1.0
```

```
      AMULX=YPLT(JY)/XPLT(IX)
C     THIS SHOULD PRODUCE A SQUARE BASE FOR THE 3-D PLOT
      AMULY=1.0
      IDXA=1
      IDXL=MAX0(IMT,JMT,21)
      IDXB=IDXA+IDXL
      IDXC=IDXB+IDXL
      IDXD=IDXC+IDXL
      IDXL=IDXD+IDXL-1
      IF (IDXL.LE.ILVECP) GO TO 10
      PRINT 190, IDXL,ILVECP
      RETURN
C     COMPUTE ZERO ORIGIN.
   10 CONTINUE
      XMIN=XPLT(1)
      XMAX=XPLT(IMT)
      YMIN=YPLT(1)
      YMAX=YPLT(JMT)
      TEMX=FLUX(1)
      TEMPM=TEMX
      DO 20 IDY=1,IMJMT
      TEMPI=FLUX(IDY)
      TEMX=AMAX1(TEMX,TEMPI)
      TEMPM=AMIN1(TEMPM,TEMPI)
C     END OF IDY LOOP.
   20 CONTINUE
      TEMP=0.0
      IF (TEMX.GT.TEMPM) TEMP=SCALE/(TEMX-TEMPM)
      IF (TEMP.EQ.0.0) GO TO 40
C     SCALE VALUES TO BE PLOTTED
      DO 30 IDY=1,IMJMT
      FLUX(IDY)=TEMP*FLUX(IDY)
   30 CONTINUE
   40 CONTINUE
      ENCODE (20,230,ITITLE(5))XMIN,XMAX
      ENCODE (20,240,ITITLE(7))YMIN,YMAX
      CMAX=TEMX
      CMIN=TEMPM
      IF (TEMP.NE.0.0) CMAX=CMAX*TEMP
      IF (TEMP.NE.0.0) CMIN=CMIN*TEMP
      SCMAX=TEMX
      SCMIN=TEMPM
      IF (CMAX.LE.CMIN) GO TO 160
C     RELATE R AND Z VALUES TO ORIGIN
      DO 50 IDY=1,IMT
      XPLT(IDY)=XPLT(IDY)-XMIN
   50 CONTINUE
      DO 60 IDY=1,JMT
      YPLT(IDY)=YPLT(IDY)-YMIN
   60 CONTINUE
      PRINT 200, LABELZ
      CALL PLTXYZ (FLUX,XPLT,YPLT,IMT,JMT,ANGT,ANGF,AMULX,AMULY,VECP(IDX
     1A),VECP(IDXB),VECP(IDXC),VECP(IDXD),IRA,IRB,ICR,ICC)
C     RESTORE R AND Z VALUES
      DO 70 IDY=1,IMT
      XPLT(IDY)=XPLT(IDY)+XMIN
   70 CONTINUE
      DO 80 IDY=1,JMT
      YPLT(IDY)=YPLT(IDY)+YMIN
   80 CONTINUE
C     WRITE JOB IDENTIFICATION
      CALL DLCH (154,992,4,4HJOB=,1)
      CALL DLCH (206,992,10,ITITLE,1)
```

```
C     WRITE DATE
      CALL OLCH (400,992,5,5HDATE=,1)
      CALL DLCH (464,992,10,ITITLE(2),1)
C     WRITE ID
      CALL DLCH (154,952,60,ITITLE(31),1)
C     WRITE FUNCTION RANGE
      ENCODE (20,220,ITITLE(3))SCMIN,SCMAX
      CALL DLCH (696,952,7,7HRANGE--,1)
      CALL DLCH (780,952,20,ITITLE(3),1)
C     WRITE X RANGE
      CALL DLCH (780,972,20,ITITLE(5),1)
C     WRITE Y RANGE
      CALL DLCH (780,992,20,ITITLE(7),1)
      CALL DLCH (154,972,60,ITITLE(12),1)
C     LABEL THE AXES
      IRA72=IRA-72
      IRA72=MAX0(IRA72,0)
      CALL OLCH (ICC,IRA72,NCL,LABELX,1)
      CALL DLCH (ICB,IRB-11,NCL,LABELY,1)
      CALL DLCH (270,80,NCL,LABELZ,2)
      CALL DLCH (200,4,5,TIGER,2)
      CALL ADV (1)
      DIVIS=ABS(CMAX)
      IF (DIVIS.EQ.0.0) DIVIS=ABS(CMIN)
      IF ((CMAX-CMIN)/DIVIS.LE.1.0E-6) GO TO 160
      IF (LCP.EQ.0) GO TO 160
      IF (LCP.GT.0) GO TO 100
C
C     COMPUTE PLOT INTERVALS GIVEN FF AND NC
      NC=IABS(LCP)
      ANC=NC
      VNC=1.0/ANC
      VNCM=1.0/(ANC-1.0)
      EONE=2.7182818
      ALPH=VNCM*(ANC*EXP(FF)-EONE)
      BETA=ANC*VNCM*(EONE-EXP(FF))
      CDIF=CMAX-CMIN
      DO 90 N=1,NC
      VECP(N)=CDIF*ALOG(ALPH+FLOAT(N)*VNC*BETA)+CMIN
   90 CONTINUE
      CMIN=(1.0-FF)*VECP(1)
  100 CONTINUE
      II=0
      IM1=IMT
      IMX=1
      JM1=JMT
      JMX=1
      JTOP=.F.
      DO 140 J=1,JMT
      NFOUND=.T.
      ITOP=.F.
      DO 120 I=1,IMT
      II=II+1
      IF (FLUX(II).LT.CMIN) GO TO 120
      NFOUND=.F.
      IF (ITOP) GO TO 110
      ITOP=.T.
      IM1=MIN0(IM1,I)
      IMX=MAX0(IMX,I)
      GO TO 120
  110 IMX=MAX0(IMX,I)
  120 CONTINUE
      IF (NFOUND) GO TO 140
```

```
      IF (JTOP) GO TO 130
      JTOP=.T.
      JM1=MIN0(JM1,J)
      GO TO 140
  130 JMX=MAX0(JMX,J)
  140 CONTINUE
C     IF NO REGION FOUND GO TO ERROR PRINT AND SKIP CONTOUR PLOT
      IPR=.FALSE.
      IF (IM1.GE.IMX) IPR=.TRUE.
      IF (JM1.GE.JMX) IPR=.TRUE.
      IF (.NOT.IPR) GO TO 150
      PRINT 210, IM1,IMX,JM1,JMX,SCMIN,SCMAX
      GO TO 160
  150 TOPX=XPLT(IMX)-XPLT(IM1)
      TOPY=YPLT(JMX)-YPLT(JM1)
      IJ=(JM1-1)*IX+IM1
      NJY=JMX-JM1+1
      NIX=IMX-IM1+1
C     TO PASS SCALE FACTOR VIA CNTRCOM TO CNTRJB FOR CONTOUR LABELS
      SCFAC=TEMP
      CALL ADV (1)
      CALL CNTRJB (XPLT(IM1),NIX,YPLT(JM1),NJY,FLUX(IJ),IX,JY,ICP,CMIN,C
     1MAX,CINT,VECP,TOPX,TOPY,IGRID,IDRW,LABELX,10,LABELY,10)
      KX=IXR+10
      KX=MAX0(KX,IXL+480)
      KX=MIN0(KX,780)
C     WRITE JOB IDENTIFICATION
      CALL DLCH (KX-168,30,4,4HJOB=,1)
      CALL DLCH (KX-120,30,10,ITITLE,1)
C     WRITE DATE
      CALL DLCH (KX+36,30,5,5HDATE=,1)
      CALL DLCH (KX+96,30,10,ITITLE(2),1)
C     WRITE FUNCTION RANGE
      CALL DLCH (KX-90,IDRW,7,7HRANGE--,1)
      ENCODE (20,220,ITITLE(3))SCMIN,SCMAX
      CALL DLCH (KX,IDRW,20,ITITLE(3),1)
      IDRW1=IDRW+20
C     WRITE R AND Z RANGE
      XMINC=XPLT(IM1)
      XMAXC=XPLT(IMX)
      ENCODE (20,230,ITITLE(27))XMINC,XMAXC
      CALL DLCH (KX,IDRW1,20,ITITLE(27),1)
      IDRW2=IDRW1+20
      YMINC=YPLT(JM1)
      YMAXC=YPLT(JMX)
      ENCODE (20,240,ITITLE(29))YMINC,YMAXC
      CALL DLCH (KX,IDRW2,20,ITITLE(29),1)
C     WRITE ID
      CALL DLCH (IXL,IDRW1,60,ITITLE(31),1)
      IDRW3=IDRW2+20
      CALL DLCH (IXL,IDRW3,60,ITITLE(12),1)
C     LABEL THE FUNCTION AXIS
      CALL DLCH (110,30,10,LABEL7,1)
      CALL DLCH (50,4,5,TIGER,2)
      CALL ADV (1)
C     END OF IDX LOOP.
  160 CONTINUE
C     RESTORE FUNCTION VALUES
      IF (TEMP.EQ.0.0) GO TO 180
      TEMPI=1.0/TEMP
      DO 170 IDY=1,IMJMT
  170 FLUX(IDY)=FLUX(IDY)*TEMPI
  180 RETURN
```

```
C
  190 FORMAT (*0 NOT ENOUGH STORAGE AVAILABLE FOR PLOTTING*/20X,* REQUIR
     1ED =*I6,4X,* AVAILABLE =*I6)
  200 FORMAT (*      PLOT MADE OF *A10)
  210 FORMAT (*0      ERROR IN CONTOUR VALUES--PLOTS CANNOT BE MADE*/*
     1  IMI, IMA, JM1, JMX, SCMIN, SCMAX     *,4I5,1P2F14.6)
  220 FORMAT (1X,1PE9.2,*,*,1PE9.2)
  230 FORMAT (*X=*,F8.3,*, *,F8.3)
  240 FORMAT (*Y=*,F8.3,*, *,F8.3)
      END
      SUBROUTINE CNTRJB(X,NNX,Y,NNY,Z,NZX,NZY,NC,ZMN,ZMX,DLZ,ZPLAN,DMPX,
     1DMPY,IGRD,IDRW,LABELX,NXLBL,LABELY,NYLBL)
      COMMON /CJE07/ IXL,IXR,IYT,IYB,XMN,XMX,YMX,YMN
      COMMON /CNTRCON/ ISYM(50),SCFAC
      DIMENSION XSCALE(2), YSCALE(2)
      EQUIVALENCE (XMIN,XSCALE(1)), (XMAX,XSCALE(2))
      EQUIVALENCE (YMIN,YSCALE(1)), (YMAX,YSCALE(2))
      DIMENSION X(1), Y(1), Z(NZX,1), ZPLAN(1)
      DIMENSION FMT(2)
      LOGICAL TEST
      NOC=MIN0(IABS(NC),50)
      ZMIN=ZMN
      ZMAX=ZMX
      DELZ=DLZ
      DMAPX=DMPX
      DMAPY=DMPY
      NOX=IABS(NNX)
      NOY=IABS(NNY)
      DO 10 I=1,50
   10 ISYM(I)=0
C     ESTABLISH SCALES
      XMIN=X(1)
      XMAX=X(NOX)
      YMIN=Y(1)
      YMAX=Y(NOY)
      FGRD=0.
      IF (IGRD.GT.0) FGRD=-IGRD
      CALL PLJB (XSCALE,YSCALE,2,1,1,1,FGRD,DMAPX,DMAPY,LABELX,NXLBL,LAB
     1ELY,NYLBL,-1)
      IF (NC.LT.0) GO TO 50
      IF (NNX.LE.0) CALL MINM (Z,NZX,NOX,NOY,I,J,ZMIN)
      IF (NNY.LE.0) CALL MAXM (Z,NZX,NOX,NOY,I,J,ZMAX)
      IF (DELZ.GT.0) GO TO 20
      DELZ=(ZMAX-ZMIN)/(NOC-1.)
   20 IF (NZY.GT.0) GO TO 30
      ZMAX=ZMAX-AMOD(ZMAX,DELZ)
      ZMIN=ZMIN-AMOD(ZMIN,DELZ)
      NOC=MIN0(NOC,IFIX((ZMAX-ZMIN)/DELZ+1.01))
   30 ZPLAN(1)=ZMIN
      DO 40 I=2,NOC
   40 ZPLAN(I)=ZPLAN(I-1)+DELZ
   50 CONTINUE
      DO 90 NY=2,NOY
      IX=MOD(NY,2)
      DY=Y(NY)-Y(NY-1)
      DO 90 INX=2,NOX
      NX=INX
      IF (IX.NE.0) NX=NOX-INX+2
      ZT1=Z(NX-1,NY-1)
      ZT2=Z(NX,NY-1)
      ZT3=Z(NX,NY)
      ZT4=Z(NX-1,NY)
      DX=X(NX)-X(NX-1)
```

```
      IF (ABS(ZT3-ZT1)-ABS(ZT4-ZT2)) 70,60,60
   60 CALL TRCUB (X(NX),Y(NY),-DX,-DY,NOC,ZPLAN,ZT4,ZT3,ZT2)
      CALL TRCUB (X(NX-1),Y(NY-1),DX,DY,NOC,ZPLAN,ZT2,ZT1,ZT4)
      GO TO 80
   70 CALL TRCUB (X(NX-1),Y(NY),DX,-DY,NOC,ZPLAN,ZT3,ZT4,ZT1)
      CALL TRCUB (X(NX),Y(NY-1),-DX,DY,NOC,ZPLAN,ZT1,ZT2,ZT3)
   80 CONTINUE
   90 CONTINUE
      IDRW=IYB+40
      IDRW=MINO(IDRW,945)
C     USE DLCH IF SPACE PERMITS
C     DLCH USES 12SP/H.CHAR - 15SP /V.CHAR
C     TSP USES 8SP/H.CHAR - 12SP/V.CHAR
      TEST=.F.
      ITOP=50
C     IXR = RIGHT BOUNDARY
C     NOC = NUMBER OF CONTOURS
C     ITOP = SPACES DOWN FROM TOP LEFT FOR LABEL
      ITST=IXR+142
      IF (ITST.GE.1024) TEST=.T.
      ITST=NOC*15+ITOP
      IF (ITST.GE.1024) TEST=.T.
      KX=IXR+10
      KC=KX+150
      IF (TEST) KC=KX+80
      KY=ITOP
      DO 110 I=1,NOC
      ZTEM=ZPLAN(I)/SCFAC
      ENCODE (10,120,FMT)ZTEM
      IF (TEST) GO TO 100
      CALL DLCH (KX,KY,10,FMT,1)
      CALL DLCH (KC,KY,0,I,1)
      KY=KY+25
      GO TO 110
  100 FMT(2)=SHIFT(I,54)
      CALL TSP (KX,KY,11,FMT)
      KY=KY+12
  110 CONTINUE
      RETURN
C
  120 FORMAT (1PE9.2,1X)
      END
      SUBROUTINE PLJ8(X,Y,NPTS,INC,LNN,NSYM,C,XAA,YAA,LABELX,NXL,LABELY,
     1NYL,NZL)
      COMMON /CJE07/ IXL,IXR,IYT,IYB,XMN,XMX,YMX,YMN
      DIMENSION X(1), Y(1)
      INTEGER GRIDF
      B=AMAX1(AMAX1(C,0.)*(LNN+1),0.)
      LIN=LNN
      KSYM=IABS(NSYM)
      KINC=MAX0(IABS(INC),1)
      MPTS=IABS(NPTS)
      XXA=ABS(XAA)
      YYA=ABS(YAA)
      NXN=IABS(NXL)
      NYN=IABS(NYL)
      GRIDF=AMAX1(1.,ABS(C))
      IF (NSYM.LT.0) GO TO 130
      CALL MAXV (X,KINC,MPTS,ISUB,XMX)
      CALL MAXV (Y,KINC,MPTS,ISUB,YMX)
      CALL MINV (X,KINC,MPTS,ISUB,XMN)
      CALL MINV (Y,KINC,MPTS,ISUB,YMN)
C     ALSO THE LOG AXES WILL BE FULL CYCLES.
```

```
C       IF XXA AND/OR YYA ARE NON-ZERO THE LENGTHS
C       WILL BE CONSIDERED AS RATIOS WHERE THE LONGEST
C       SIDE IS FITTED ON A 860 POINT LINE.
        IF (XXA.EQ.0) XXA=6.
        IF (YYA.EQ.0) YYA=10.
        IF (NPTS.LT.0) GO TO 20
        IF (XMN.NE.XMX) GO TO 10
        DXM=.001*ABS(XMX)
        IF (DXM.EQ.0) DXM=.0001
        XMN=XMN-DXM
        XMX=XMX+DXM
     10 CALL ASCL (5,XMN,XMX,MAJX,MINX,KKX)
        GO TO 30
     20 XMN=ALOG10(XMN)
        XMX=ALOG10(XMX)
     30 IF (INC.LT.0) GO TO 50
        IF (YMN.NE.YMX) GO TO 40
        DYM=.001*ABS(YMX)
        IF (DYM.EQ.0) DYM=.0001
        YMN=YMN-DYM
        YMX=YMX+DYM
     40 CALL ASCL (5,YMN,YMX,MAJY,MINY,KKY)
        GO TO 60
     50 YMN=ALOG10(YMN)
        YMX=ALOG10(YMX)
     60 IF (ISIGN(1,NYL).LT.0.AND.INC.GT.0) YYA=(YMX-YMN)/YYA
        IF (ISIGN(1,NXL).LT.0.AND.NPTS.GT.0) XXA=(XMX-XMN)/XXA
        MAKX=GRIDF*MAJX
        MAKY=GRIDF*MAJY
        FACT=860./AMAX1(XXA,YYA)
        IXL=66
        IYT=50
        IXR=IXL+860.
        IYB=IYT+860.
        CALL FRAME (IXL,IXR,IYT,IYB)
        IF (SIGN(1.,XAA).GT.0) GO TO 70
        SWAP=XMN
        XMN=XMX
        XMX=SWAP
     70 IF (SIGN(1.,YAA).GT.0) GO TO 80
        SWAP=YMN
        YMN=YMX
        YMX=SWAP
     80 CALL DGA (IXL,IXR,IYT,IYB,XMN,XMX,YMX,YMN)
        IF (NPTS.LT.0.AND.INC.LT.0) CALL DLGLG
        IF (NPTS.LT.0.AND.INC.GE.0) CALL DLGLN (MAKY)
        IF (NPTS.GE.0.AND.INC.LT.0) CALL DLNLG (MAKX)
        IF (NPTS.GE.0.AND.INC.GE.0) CALL DLNLN (MAKX,MAKY)
        IF (NPTS.LT.0) GO TO 90
        CALL SBLIN (MAJX,KKX)
        GO TO 100
     90 CALL SBLOG
    100 IF (INC.LT.0) GO TO 110
        CALL SLLIN (MAJY,KKY)
        GO TO 120
    110 CALL SLLOG
    120 CALL EXL
        INXN=25
        IF (NXN.NE.0) CALL DLCH (MAX0(54,IXL+(IXR-IXL-12*NXN)/2),IYB+INXN,
       1NXN,LABELX,1)
        INCX=10
        IF (NYN.NE.0) CALL DLCV (INCX,MIN0(IYB+52,IYB-(IYB-IYT-12*NYN)/2),
       1NYN,LABELY,1)
```

```
      CALL EXH
      IF (NZL.LT.0) GO TO 220
C     PLOT POINTS AND/OR LINE
  130 MPTS=MPTS*KINC
      DO 210 NXP=1,MPTS,KINC
      XTWO=X(NXP)
      YTWO=Y(NXP)
      IF (NPTS.LT.0) XTWO=ALOG10(XTWO)
      IF (INC.LT.0) YTWO=ALOG10(YTWO)
      CALL CONVRT (XTWO,NXTWO,XMN,XMX,IXL,IXR)
      CALL CONVRT (YTWO,NYTWO,YMN,YMX,IYB,IYT)
      IF (NXP.EQ.1) GO TO 190
      IF (LIN.GE.0) GO TO 180
  140 IF (MOD(((NXP-1)/KINC),IABS(LIN)).NE.0) GO TO 150
      CALL EXL
      CALL DLCH (NXTWO,NYTWO,0,KSYM,1)
      CALL EXH
      GO TO 200
  150 IF (B.EQ.0.) GO TO 200
  160 DO 170 IB=1,4
  170 CALL PLT (NXTWO,NYTWO,42)
      GO TO 200
  180 IF (B.EQ.0.) CALL DRV (NXONE,NYONE,NXTWO,NYTWO)
  190 IF (LIN.NE.0) GO TO 140
      IF (B.NE.0.) GO TO 160
  200 NYONE=NYTWO
      NXONE=NXTWO
  210 CONTINUE
  220 RETURN
      END
      SUBROUTINE TRCJB(X,Y,DX,DY,NOC,ZPLAN,ZX,ZV,ZY)
      COMMON /CNTRCOM/ ISYM(50),SCFAC
      DIMENSION XP(2,50), YP(2,50), ZT(4), ZPLAN(1)
      ZT(1)=ZX
      ZT(2)=ZV
      ZT(3)=ZY
      ZT(4)=ZX
      ZTMIN=AMIN1(ZT(1),ZT(2),ZT(3))
      ZTMAX=AMAX1(ZT(1),ZT(2),ZT(3))
      IMIN=NOC+1
      IMAX=0
      DO 10 K=1,NOC
      J=NOC-K+1
      IF (ZPLAN(J).GE.ZTMIN) IMIN=J
      IF (ZPLAN(K).LE.ZTMAX) IMAX=K
   10 CONTINUE
      INT=IMAX-IMIN
      IF (INT.LT.0.OR.ZTMIN.EQ.ZTMAX) GO TO 130
      12=1
      DO 110 K=1,3
      ZTMAX=AMAX1(ZT(K),ZT(K+1))
      ZPMIN=AMIN1(ZT(K),ZT(K+1))
      MIN=NOC+1
      MAX=0
      DO 20 J=1,NOC
      INZ=NOC-J+1
      IF (ZPLAN(INZ).GT.ZPMIN.OR.(ZPLAN(INZ).EQ.ZPMIN.AND.ZTMIN.EQ.ZPMIN
     1)) MIN=INZ
      IF (ZPLAN(J).LE.ZTMAX) MAX=J
   20 CONTINUE
      INZ=MAX-MIN
      IF (INZ.LT.0.OR.ZTMAX.EQ.ZPMIN) GO TO 110
      IF (INZ-INT) 40,30,40
```

```
 30 GO TO (50,40), I2                                                   PLOTS
 40 I2=1                                                                PLOTS
    GO TO 60                                                            PLOTS
 50 I2=2                                                                PLOTS
 60 DO 100 J=MIN,MAX                                                    PLOTS
    GO TO (70,80,90), K                                                 PLOTS
 70 XP(I2,J)=X+DX*(ZPLAN(J)-ZT(2))/(ZT(1)-ZT(2))                        PLOTS
    YP(I2,J)=Y                                                          PLOTS
    GO TO 100                                                           PLOTS
 80 XP(I2,J)=X                                                          PLOTS
    YP(I2,J)=Y+DY*(ZPLAN(J)-ZT(2))/(ZT(3)-ZT(2))                        PLOTS
    GO TO 100                                                           PLOTS
 90 XP(I2,J)=X+DX*(ZPLAN(J)-ZT(3))/(ZT(1)-ZT(3))                        PLOTS
    YP(I2,J)=Y+DY*(ZPLAN(J)-ZT(1))/(ZT(3)-ZT(1))                        PLOTS
100 CONTINUE                                                            PLOTS
110 CONTINUE                                                            PLOTS
    DO 120 J=IMIN,IMAX                                                  PLOTS
    ISYM(J)=ISYM(J)+I                                                   PLOTS
    L=3                                                                 PLOTS
    IF (MOD(ISYM(J),10).NE.1) L=0                                       PLOTS
    CALL PLJB (XP(1,J),YP(1,J),2,1,L,-J,0,0,0,0,0,0,0,0)                PLOTS
120 CONTINUE                                                            PLOTS
130 RETURN                                                              PLOTS
    END                                                                 PLOTS
    SUBROUTINE PLTXYZ(F,X,Y,IX,JY,ANGT,ANGF,AMULX,AMULY,AA,AB,RA,RB,IR  PLOTS
   1A,IRB,ICB,ICC)                                                      PLOTS
    DIMENSION F(1), X(1), Y(1), AA(1), AB(1), RA(1), RB(1)              PLOTS
    YT=SIN(ANGT)*AMULX                                                  PLOTS
    XT=COS(ANGT)*AMULX                                                  PLOTS
    YP=SIN(ANGF)*AMULY                                                  PLOTS
    XP=COS(ANGF)*AMULY                                                  PLOTS
    YTB=YT*X(IX)                                                        PLOTS
    XTB=XT*X(IX)                                                        PLOTS
    YPB=YP*Y(JY)                                                        PLOTS
    XPB=XP*Y(JY)                                                        PLOTS
    XA=XTB+XPB                                                          PLOTS
    EA=0.                                                               PLOTS
    EB=1000.                                                            PLOTS
    DO 10 I=1,IX                                                        PLOTS
    L=I                                                                 PLOTS
    DO 10 J=I,JY                                                        PLOTS
    E=F(L)-X(I)*YT-Y(J)*YP                                              PLOTS
    EA=AMAX1(EA,E)                                                      PLOTS
    EB=AMIN1(EB,E)                                                      PLOTS
 10 L=L+IX                                                              PLOTS
    YC=YTB+YPB                                                          PLOTS
    IF (EB) 20,40,40                                                    PLOTS
 20 DIF=YC+EB                                                           PLOTS
    IF (DIF) 30,40,40                                                   PLOTS
 30 YB=-DIF                                                             PLOTS
    GO TO 50                                                            PLOTS
 40 YB=0.                                                               PLOTS
 50 YA=YC+YB+EA                                                         PLOTS
    CALL DGA (123,1023,0,900,0.0,XA,YA,0.0)                             PLOTS
    CALL FRAME (123,1023,0,900)                                         PLOTS
    YO=YB+YTB                                                           PLOTS
    IA=IX+1                                                             PLOTS
    DO 60 I=1,IX                                                        PLOTS
    L=IA-I                                                              PLOTS
    AA(I)=XTB-XT*X(L)                                                   PLOTS
    AB(I)=XPB+AA(I)                                                     PLOTS
    RB(I)=YO-YT*X(L)                                                    PLOTS
 60 RA(I)=YPB+RB(I)                                                     PLOTS
```

```
      CALL PLOT (IX,AA,1,RA,1,32,0)
      CALL PLOT (IX,AB,1,RB,1,32,1)
      YE=YB+YPB
      DO 70 J=1,JY
      AA(J)=XP*Y(J)
      AB(J)=XTB+AA(J)
      RA(J)=YE-YP*Y(J)
   70 RB(J)=YTB+RA(J)
      CALL PLOT (JY,AA,1,RA,1,32,1)
      CALL PLOT (JY,AB,1,RB,1,32,0)
      ZH=.05*EA
      YF=YC+YB
      DO 80 L=1,21
      AA(L)=XTB
      RA(L)=YF+ZH*FLOAT(L-1)
   80 CONTINUE
      CALL PLOT (21,AA,1,RA,1,32,1)
      DO 100 I=1,IX
      L=I
      DO 90 J=1,JY
      AA(J)=XTB-X(I)*XT+Y(J)*XP
      RA(J)=YF-X(I)*YT-Y(J)*YP+F(L)
   90 L=L+IX
      CALL PLOT (JY,AA,1,RA,1,42,1)
  100 CONTINUE
      L=1
      DO 120 J=1,JY
      DO 110 I=1,IX
      AA(I)=XTB-X(I)*XT+Y(J)*XP
      RA(I)=YF-X(I)*YT-Y(J)*YP+F(L)
  110 L=L+1
      CALL PLOT (IX,AA,1,RA,1,42,1)
  120 CONTINUE
      CA=22.+(XPB+.5*XTB)*113./XA
      CA=AMIN1(CA,116.0)
      CB=2.+XPB*56.5/XA
      CC=XTB*113./XA
      RB=57.*(1.-(.5*YPB+YB)/YA)+1.
      RA=57.*(1.-(.5*YTB+YB)/YA)+1.
      TIY=RB*16.0-8.0
      IRB=IFIX(TIY)
      TIY=RA*16.0-8.0
      IRA=IFIX(TIY)
      TIX=CC*8.0-4.0
      ICC=IFIX(TIX)
      TIX=CB*8.0-4.0
      ICB=IFIX(TIX)
C     RETURN WITHOUT ADVANCE OF THE FRAME.
      RETURN
      END
```

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APPENDIX E

COMPARISON OF FRACTION IN COOLANT AND CUMULATIVE RELEASE AT TWO HOURS

Calculations for ^{131}I were made for the Ft. St. Vrain fuel model (MFUEL = 1) with an average age of 2.5 yr (AGE = 2.5) and the fuel was not aged (LAGE = F). A BISO-TRISO mixture (0.06, 0.04) was used (FRAC = 0.6). Six partitions of the core volume IC = 1, 5, 10, 25, 100, 200 and five partitions of the 20-h time period IT = 20, 40, 100, 300, 500 were used. The four temperature models SORS, CORCON, AYER, and AYER Fu-Cort (ITEMP = 1, 2, 3, 4) and the four equation models, Simplified Model Equation-Renormalized, Constant Release-Renormalized, Linear Release-Renormalized, Intact-Failed Self-Consistent fuel transition (NEQ = 1, 2, 3, 4) were used. The most sensitive test of these 320 calculations was the comparison of the fraction in the coolant and the cumulative release at 2-h time.

In Tables E.I through E.XXVIII we exhibit a summary of these results at 2 h. We note that the maximum variation between (IT, IC) of (100, 100) and 500,200) for the ^{131}I fraction release in the coolant is 20% for any temperature model, whereas the various temperature models differ by as much as a factor of 3.73 (NEQ = 4; ITEMP = 1,3; IT = 500, IC = 200).

A similar remark holds for the cumulative release where the maximum variation between (IT, IC) of (100,100) and (500,200) for the ^{131}I cumulative release is about 19%, whereas the various temperature models differ by as much as a factor of 3.03 (NEQ = 4, ITEMP = 1,3; IT = 100, IC = 100).

It should be noted that we are comparing the fraction at the 10^{-4} level and the release at less than the 1 Ci level here.

TABLE E.I

^{131}I FRACTION IN COOLANT x 10^4 at 2 h
ITEMP = 1, NEQ = 1, 2

IC \ IT	20	40	100	300	500
1	1.38	1.14	1.26	1.38	1.41
5	1.75	1.97	3.17	3.70	3.80
10	1.85	2.91	4.15	4.78	4.91
25	1.95	3.36	4.75	5.43	5.57
100	2.09	3.78	5.22	5.89	6.03
200	2.12	3.82	5.26	5.92	6.06

TABLE E.II

^{131}I FRACTION IN COOLANT x 10^4 at 2 h
ITEMP = 1, NEQ = 3

IC \ IT	20	40	100	300	500
1	1.38	1.14	1.26	1.38	1.41
5	1.75	1.97	3.17	3.70	3.80
10	1.85	2.91	4.15	4.78	4.91
25	1.95	3.36	4.75	5.43	5.57
100	2.09	3.78	5.22	5.89	6.03
200	2.12	3.81	5.26	5.92	6.06

TABLE E.III

^{131}I FRACTION IN COOLANT x 10^4 at 2 h
ITEMP = 1, NEQ = 4

IC \ IT	20	40	100	300	500
1	2.24	1.67	1.50	1.46	1.45
5	5.49	4.11	4.01	3.98	3.97
10	6.59	5.39	5.14	5.11	5.11
25	7.14	5.99	5.79	5.78	5.78
100	7.48	6.44	6.26	6.24	6.24
200	7.51	6.47	6.30	6.27	6.27

TABLE E.IV

^{131}I FRACTION IN COOLANT x 10^4 at 2 h
ITEMP = 2, NEQ = 1,2

IT / IC	20	40	100	300	500
1	0.85	0.76	0.74	0.74	0.74
5	1.03	0.98	1.02	1.05	1.06
10	1.08	1.10	1.24	1.32	1.34
25	1.14	1.25	1.42	1.51	1.53
100	1.20	1.37	1.57	1.68	1.70
200	1.21	1.38	1.58	1.69	1.71

TABLE E.V

^{131}I FRACTION IN COOLANT x 10^4 at 2 h
ITEMP = 2, NEQ = 3

IT / IC	20	40	100	300	500
1	0.85	0.76	0.74	0.74	0.74
5	1.03	0.98	1.02	1.05	1.06
10	1.08	1.10	1.24	1.32	1.34
25	1.14	1.25	1.42	1.51	1.53
100	1.20	1.37	1.57	1.68	1.70
200	1.21	1.38	1.58	1.69	1.71

TABLE E.VI

^{131}I FRACTION IN COOLANT x 10^4 at 2h
ITEMP = 2, NEQ = 4

IT / IC	20	40	100	300	500
1	0.85	0.76	0.74	0.74	0.74
5	1.36	1.16	1.10	1.08	1.08
10	1.69	1.44	1.37	1.38	1.37
25	1.89	1.64	1.58	1.36	1.56
100	2.05	1.81	1.75	1.74	1.74
200	2.06	1.82	1.76	1.75	1.75

TABLE E.VII

^{131}I FRACTION IN COOLANT x 10^4 at 2 h

ITEMP = 3, NEQ = 1,2

IC \ IT	20	40	100	300	500
1	0.93	0.81	0.78	0.78	0.78
5	1.08	0.95	1.05	1.14	1.16
10	1.11	1.05	1.24	1.36	1.38
25	1.13	1.10	1.35	1.48	1.51
100	1.14	1.18	1.44	1.59	1.62
200	1.14	1.18	1.45	1.60	1.63

TABLE E.VIII

^{131}I FRACTION IN COOLANT x 10^4 at 2 h

ITEMP = 3, NEQ = 3

IC \ IT	20	40	100	300	500
1	0.93	0.81	0.78	0.78	0.78
5	1.08	0.95	1.05	1.14	1.16
10	1.11	1.05	1.24	1.36	1.38
25	1.13	1.10	1.35	1.48	1.51
100	1.14	1.18	1.44	1.59	1.62
200	1.14	1.18	1.45	1.60	1.63

TABLE E.IX

^{131}I FRACTION IN COOLANT x 10^4 at 2h

ITEMP = 3, NEQ = 4

IC \ IT	20	40	100	300	500
1	1.02	0.87	0.81	0.79	0.79
5	1.69	1.33	1.21	1.20	1.20
10	1.95	1.55	1.44	1.43	1.42
25	2.09	1.66	1.58	1.56	1.56
100	2.20	1.78	1.69	1.67	1.67
200	2.21	1.79	1.69	1.68	1.68

TABLE E.X

^{131}I FRACTION IN COOLANT x 10^4 at 2 h

ITEMP = 4, NEQ = 1,2

IC \ IT	20	40	100	300	500
1	0.94	0.84	0.81	0.81	0.81
5	1.25	1.41	1.94	2.20	2.26
10	1.26	1.48	2.07	2.36	2.42
25	1.27	1.55	2.15	2.45	2.51
100	1.28	1.59	2.20	2.51	2.57
200	1.28	1.59	2.20	2.51	2.57

TABLE E.XI

^{131}I FRACTION IN COOLANT x 10^4 at 2 h

ITEMP = 4, NEQ = 3

IC \ IT	20	40	100	300	500
1	0.94	0.84	0.81	0.81	0.81
5	1.25	1.41	1.94	2.20	2.26
10	1.26	1.48	2.07	2.36	2.42
25	1.27	1.55	2.15	2.45	2.51
100	1.28	1.59	2.20	2.51	2.57
200	1.28	1.59	2.20	2.51	2.57

TABLE E.XII

^{131}I FRACTION IN COOLANT x 10^4 at 2 h

ITEMP = 4, NEQ = 3

IC \ IT	20	40	100	300	500
1	0.97	0.86	0.82	0.81	0.81
5	3.12	2.46	2.37	2.35	2.34
10	3.30	2.62	2.53	2.51	2.51
25	3.40	2.73	2.63	2.61	2.61
100	3.47	2.79	2.69	2.67	2.67
200	3.47	2.80	2.69	2.67	2.67

TABLE E.XIII

^{131}I CUMULATIVE RELEASE (Ci) AT 2 h
ITEMP = 1, NEQ = 1

IT \ IC	20	40	100	300	500
1	0.187	0.125	0.114	0.114	0.115
5	0.238	0.195	0.220	0.238	0.244
10	0.251	0.264	0.284	0.309	0.316
25	0.265	0.299	0.325	0.355	0.363
100	0.282	0.332	0.362	0.393	0.401
200	0.286	0.335	0.364	0.395	0.403

TABLE E.XIV

^{131}I CUMULATIVE RELEASE (Ci) AT 2 h
ITEMP = 1, NEQ = 2

IT \ IC	20	40	100	300	500
1	0.187	0.125	0.114	0.114	0.115
5	0.238	0.195	0.220	0.238	0.244
10	0.251	0.264	0.284	0.309	0.316
25	0.265	0.299	0.325	0.335	0.363
100	0.282	0.332	0.362	0.393	0.401
200	0.286	0.335	0.364	0.395	0.402

TABLE E.XV

^{131}I CUMULATIVE RELEASE (Ci) AT 2 h
ITEMP = 1, NEQ = 3

IT \ IC	20	40	100	300	500
1	0.151	0.115	0.112	0.113	0.115
5	0.191	0.177	0.215	0.238	0.243
10	0.201	0.237	0.277	0.308	0.316
25	0.212	0.266	0.317	0.354	0.362
100	0.226	0.295	0.353	0.391	0.400
200	0.228	0.298	0.355	0.394	0.403

TABLE E.XVI

^{131}I CUMULATIVE RELEASE (Ci) AT 2 h
ITEMP = 1, NEQ = 4

IT \ IC	20	40	100	300	500
1	0.263	0.151	0.122	0.117	0.116
5	0.566	0.309	0.265	0.254	0.253
10	0.677	0.411	0.341	0.329	0.328
25	0.720	0.461	0.389	0.378	0.377
100	0.756	0.501	0.429	0.416	0.415
200	0.760	0.505	0.432	0.419	0.418

TABLE E.XVII

^{131}I CUMULATIVE RELEASE (Ci) AT 2 h
ITEMP = 2, NEQ = 1

IT \ IC	20	40	100	300	500
1	0.129	0.102	0.096	0.095	0.095
5	0.157	0.127	0.121	0.121	0.122
10	0.163	0.138	0.136	0.139	0.140
25	0.172	0.151	0.151	0.155	0.156
100	0.179	0.161	0.164	0.169	0.171
200	0.180	0.162	0.165	0.171	0.172

TABLE E.XVIII

^{131}I CUMULATIVE RELEASE (Ci) AT 2 h
ITEMP = 2, NEQ = 2

IT \ IC	20	40	100	300	500
1	0.129	0.102	0.096	0.095	0.095
5	0.157	0.127	0.121	0.121	0.122
10	0.163	0.138	0.136	0.139	0.140
25	0.172	0.151	0.151	0.155	0.156
100	0.179	0.161	0.164	0.169	0.171
200	0.180	0.162	0.165	0.171	0.172

TABLE E.XIX

^{131}I CUMULATIVE RELEASE (Ci) AT 2 h
ITEMP = 2, NEQ = 3

IT \ IC	20	40	100	300	500
1	0.115	0.099	0.095	0.095	0.095
5	0.139	0.122	0.120	0.121	0.122
10	0.145	0.132	0.135	0.139	0.140
25	0.152	0.144	0.149	0.155	0.156
100	0.158	0.154	0.162	0.169	0.171
200	0.159	0.155	0.163	0.170	0.172

TABLE E.XX

^{131}I CUMULATIVE RELEASE (Ci) AT 2 h
ITEMP = 2, NEQ = 4

IT \ IC	20	40	100	300	500
1	0.129	0.102	0.096	0.095	0.095
5	0.186	0.137	0.125	0.123	0.122
10	0.217	0.158	0.144	0.142	0.142
25	0.238	0.177	0.161	0.159	0.158
100	0.255	0.192	0.177	0.174	0.174
200	0.257	0.194	0.178	0.175	0.175

TABLE E.XXI

^{131}I CUMULATIVE RELEASE (Ci) at 2 h
ITEMP = 3, NEQ = 1

IC \ IT	20	40	100	300	500
1	0.132	0.099	0.089	0.088	0.087
5	0.152	0.113	0.107	0.108	0.108
10	0.157	0.121	0.116	0.119	0.120
25	0.159	0.125	0.123	0.127	0.128
100	0.160	0.131	0.129	0.133	0.135
200	0.161	0.131	0.129	0.134	0.135

TABLE E.XXII

^{131}I CUMULATIVE RELEASE (Ci) at 2 h
ITEMP = 3, NEQ = 2

IC \ IT	20	40	100	300	500
1	0.132	0.099	0.089	0.088	0.087
5	0.153	0.113	0.107	0.108	0.108
10	0.157	0.121	0.116	0.119	0.120
25	0.159	0.125	0.123	0.127	0.128
100	0.161	0.131	0.129	0.133	0.135
200	0.161	0.131	0.129	0.134	0.135

TABLE E.XXIII

^{131}I CUMULATIVE RELEASE (Ci) at 2 h
ITEMP = 3, NEQ = 3

IC \ IT	20	40	100	300	500
1	0.111	0.093	0.088	0.087	0.087
5	0.127	0.106	0.106	0.108	0.108
10	0.131	0.114	0.115	0.119	0.120
25	0.132	0.116	0.121	0.127	0.128
100	0.134	0.122	0.127	0.133	0.135
200	0.134	0.122	0.127	0.134	0.135

TABLE E.XXIV

^{131}I CUMULATIVE RELEASE (Ci) at 2 h
ITEMP = 3, NEQ = 4

IC \ IT	20	40	100	300	500
1	0.140	0.102	0.090	0.088	0.088
5	0.207	0.132	0.113	0.110	0.110
10	0.231	0.147	0.126	0.122	0.122
25	0.244	0.155	0.135	0.131	0.131
100	0.254	0.164	0.142	0.138	0.138
200	0.255	0.165	0.142	0.138	0.138

TABLE E.XXV

^{131}I CUMULATIVE RELEASE (Ci) AT 2 h
ITEMP = 4, NEQ = 1

IC \ IT	20	40	100	300	500
1	0.139	0.110	0.102	0.100	0.100
5	0.182	0.162	0.170	0.181	0.183
10	0.184	0.167	0.178	0.189	0.192
25	0.185	0.172	0.183	0.195	0.198
100	0.186	0.175	0.186	0.198	0.202
200	0.186	0.175	0.186	0.198	0.202

TABLE E.XXVI

^{131}I CUMULATIVE RELEASE (Ci) AT 2 h
ITEMP = 4, NEQ = 2

IC \ IT	20	40	100	300	500
1	0.139	0.110	0.102	0.100	0.100
5	0.182	0.162	0.170	0.181	0.183
10	0.184	0.167	0.178	0.189	0.192
25	0.186	0.172	0.183	0.195	0.198
100	0.186	0.175	0.186	0.198	0.202
200	0.186	0.175	0.186	0.198	0.202

TABLE E.XXVII

^{131}I CUMULATIVE RELEASE (Ci) AT 2 h
ITEMP = 4, NEQ = 3

IC \ IT	20	40	100	300	500
1	0.120	0.105	0.101	0.100	0.100
5	0.156	0.152	0.168	0.180	0.183
10	0.157	0.156	0.176	0.189	0.192
25	0.158	0.161	0.180	0.195	0.198
100	0.159	0.163	0.183	0.198	0.201
200	0.159	0.163	0.183	0.198	0.202

TABLE E.XXVIII

^{131}I CUMULATIVE RELEASE (Ci) AT 2 h
ITEMP = 4, NEQ = 4

IC \ IT	20	40	100	300	500
1	0.142	0.111	0.102	0.101	0.100
5	0.346	0.220	0.194	0.189	0.189
10	0.362	0.231	0.204	0.199	0.198
25	0.372	0.240	0.210	0.205	0.204
100	0.378	0.244	0.214	0.208	0.208
200	0.378	0.244	0.214	0.208	0.208

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