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A STUDY OF THE FISSION PRODUCT RELEASE FROM A BADLY DAMAGED WATER-COOLED REACTOR

(Thesis)

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ABSTRACT

A realistic model for fission product release from a badly damaged power reactor has been developed in this study. The vaporization of fission products by decay heat, the effects of the metal-water reaction, the deposition of particulate inventory in reactor vessels, and the leakage through the multiple containments are all considered in this model.

The calculation shows that the vaporization of fission products can lead to a 35 percent reduction of the decay heat retained within the core. This effect is greatest for low-vapor-pressure fission products. The metal-water reaction heat available to vaporize UO_2 is about 10 percent of the decay heat available. The reaction heat can produce a reducing atmosphere surrounding the fuel leading to an increase of Ba and Sr releases by a factor of 30 or more. The effect of containment on the fission product release depends on the deposition properties of the specific fission product. But even a badly damaged containment can lead to a reduction of the fission product release by more than two orders of magnitude. A recirculating filter-absorber inside the containment can lead to a reduction of the particulate fission product release by more than one order of magnitude.

CHAPTER I

INTRODUCTION

The objective of this study was to develop a model which could relate the accidental fission product release from a power reactor to the reactor configuration and postaccident situation.

The sequence of events following the reactor accident (Ergen, 1967) was summarized briefly in Table 1. Following the double-ended rupture of a large, primary-system pipe, there was a violent blowdown which took about ten seconds. Then the core temperature began to rise due to the decay heat, and the various fission products started to vaporize after 30 to 50 seconds. When the reactor core reached temperatures greater than 1100° C, the zirconium-steam reaction began to become a significant energy source. At the same time the vaporized fuel and fission products were released into the pressure vessel, and if they did not deposit, leaked into the various containments and finally into the environment. The pressure vessel melt-through was expected in from 30 to 120 minutes after the pipe rupture. The fission product release would continue after the pressure vessel melt-through, but it would be influenced by the interaction of the fuel with the containment atmosphere and materials presented in the containment.

In this study a vaporization model (Appendix VI of Auxier and Chester, 1973) was used to calculate the vaporization rates of various fission products, and an aerosol model (Davis, 1971) was used to calculate the deposition of particulate fission products.

TABLE 1

SEQUENCE OF EVENTS FOLLOWING THE REACTOR ACCIDENT

Time	Event	Cause
0	Reactor shutdown	Damage to the reactor vessel, to the reactor primary cooling system, and to the emergency core cooling systems. A double-ended, primary-coolant-system pipe break is assumed.
10 secs	Reactor blowdown completed	Rapid depressurization of pressure vessel and coolant systems
30-50 secs	Fission products and UO_2 start to vaporize	Fission product afterheat
40 sec-30 min	Zr-steam reaction	Fission product afterheat
30-120 min	Possible pressure vessel melt-through	Fission product afterheat and Zr-steam reaction heat

After the rapid depressurization and loss of coolant following damage to the reactor core and cooling system, some of the more volatile fission products were among the most energetic heat sources (Morrison et al., 1966). Since these fission products had higher vapor pressure, most of them vaporized from the core shortly after the accident. Hence, the decay heat available for vaporizing the remaining fission products is reduced. In this study this negative feedback effect, which could lead to a reduction of the releases of the less volatile fission products, was investigated.

In recent years, there has been more concern about the zirconium-steam reaction because of the increasing use of zircaloy as a cladding material and because of the use of a water spray as an emergency safety device. Hence, there were many papers dealing with this effect (see, for example, Baker and Ivins, 1965; Dietz, Nyer and Wilson, 1966; Morrison et al., 1966). But almost all of these reports emphasized the effects of zirconium-steam reaction on core temperature rather than the vaporization rate of fission products. In this study the magnitude of zirconium-steam reaction heat relative to the decay heat and its effect on fission product vaporization were investigated.

After a reactor accident, containment was the most important safety device to reduce the fission product release to the environment. In this study, the effect of multiple containments and the degree of damage to the containments on the fission product release was investigated.

CHAPTER II

DESCRIPTION OF THE FISSION PRODUCT RELEASE MODEL

I. BASIC ASSUMPTION OF THE VAPORIZATION MODEL

First, it was postulated that the rate of fission product vaporization from the reactor core was proportional to the sum of the fission product decay heat rate and zirconium-steam reaction heat. Secondly, it was postulated that UO_2 was vaporized by a constant fraction of the decay heat and a different constant fraction of the zirconium-steam reduction heat from 60 seconds after shutdown onward. The effect of fission product vaporization on decay heat generation was included and will be discussed in detail in Chapter III. Thirdly, it was postulated that each fission product vaporization rate was proportional to the ratio of the vapor pressure of the fission product to that of UO_2. The vaporization rate was assumed to be zero during a heatup period of ten seconds and to increase linearly from zero at ten seconds after shutdown to the value at 60 seconds. The ten-second heatup period assumption was taken from the core thermal history after a loss of coolant accident (Ergen, 1967) as mentioned in Chapter I.

The three postulates were reasonable. The third postulate was justified by R. J. Davis' work (Appendix VI of Auxier and Chester, 1973). He compared the calculated vaporized fraction of the core inventory of fission product with the observed inventory for several isotopes. The agreement was reasonably good. The second postulate was made for simplicity and the effects of changing this postulate are examined in this thesis. The first postulate states that the total heat source being considered is from two sources.

II. BASIC ASSUMPTION OF THE AEROSOL MODEL

There are many aerosol models reported in recent years. R. J. Davis' model (Davis, 1971) was adopted in this study because it was simple but reasonably accurate.

Loss of airborne material in a container was assumed to occur due to agglomeration and settling of aerosol particles. In the settling process a time-independent particle size distribution was assumed to describe the complete size spectrum from a minimum particle volume to a maximum particle volume. The maximum and minimum particle volumes were also assumed to be independent of time. These particles were presumed to be completely mixed so that the concentration was everywhere the same except in a stagnant boundary layer along the floor. Particles that fall into the boundary layer did not return. The settling velocity was obtained by using Stokes' law together with the assumed particle size distribution. By a mathematical analysis, the following differential equation was obtained to describe the settling process.

$$dn(t)/dt = -K_s\ (Vmax,\ Vmin,\ \rho,\ h,\ \eta,\ \lambda,\ a,\ g)\ n(t) \qquad (1)$$

where $n(t)$ is the total particle number concentration at time t, K_s is a settling rate constant, Vmax, Vmin are the maximum and minimum particle volumes respectively, ρ is the particle density, h is the height of the container, η is the viscosity of the air, λ is the mean free path of the molecules of the gaseous medium, a is the Cunningham correction constant, and g is the acceleration due to gravity.

The kinetics of the agglomeration process have been worked out by Smoluchowski (1916, 1917). Additional mathematical treatment of the theory has been developed by Fuchs (1934) and Chandrasekhar (1943). It was presumed that any particle that becomes larger than Vmax by coagulation falls instantaneously. In other words, they were presumed to disappear at the same rate as they are formed by coagulation. Hence, the decrease in total number concentration by this process is

$$dn(t)/dt = -K_c\, n^2(t) \qquad (2)$$

where K_c is a coagulation rate constant. An additional expression can be written for the formation of particles:

$$dn(t)/dt = S(t) \qquad (3)$$

where S(t) is the rate of aerosol formation which is obtained by the vaporization model. Hence, the equation for the change in aerosol particle number concentration with time has the form

$$dn(t)/dt = -K_c\, n^2(t) - K_s\, n(t) + S(t) \qquad (4)$$

III. MATHEMATICAL FORMULATION

<u>List of Symbols</u>

- B — total inventory of one fission product airborne in the reactor building, curies
- BWR — Boiling water-cooled reactor
- C — total inventory of one fission product airborne in the containment, curies
- E_b — fractional removal efficiency of the reactor building

filter-absorber for a PWR

E_c fractional removal efficiency of the containment filter-absorber for a PWR

F' ratio of vapor pressures: fission product/UO_2

F_b flow rate through the reactor building filter absorber, cm^3/sec

F_c flow rate through the containment filter absorber, cm^3/sec

F_u fraction of core which has vaporized

H fraction of fission product decay heat available to vaporize UO_2

H' decay heat correction factor

H_{sub} heat of sublimation of UO_2, joules/g

K'_c constant in aerosol agglomeration term, $cm^3\ curie^{-1}\ sec^{-1}$

K_{sp} constant in aerosol settling term (in pressure vessel), sec^{-1}

K_{sc} constant in aerosol settling term (in containment), sec^{-1}

K_{sb} constant in aerosol settling term (in reactor building), sec^{-1}

K_{st} constant in aerosol settling term (in access tunnel), sec^{-1}

L_b leakage rate of gas between the reactor building and the next containment, cm^3/sec

L_c leakage rate of gas between the containment and the reactor building, cm^3/sec

L_p leakage rate of gas in and out of the pressure vessel, cm^3/sec

L_t leakage rate of gas between the access tunnel and the environment, cm^3/sec

M_o — M_u at reactor shutdown, g

M_u — mass of the core, g

P — total inventory of one fission product airborne in the pressure vessel, curies

P' — total amount of heat available to vaporize UO_2, watts

P_{dh} — fission product decay heating rate, watts

P_o — reactor operating power level, watts

PWR — pressurized water-cooled reactor

Q — inventory of one fission product in the fuel, curies

Q_o — Q at reactor shutdown, curies

R — total inventory of one fission product airborne in the environment, curies

t — time after shutdown, sec

T — total inventory of one fission product airborne in the access tunnel, curies

V — rate of one fission product vaporization from the core, curies/sec

V_b — volume of the reactor building, cm^3

V_c — volume of the containment, cm^3

V_p — volume of pressure vessel, cm^3

V_t — volume of the access tunnel, cm^3

V_u — rate of vaporization of UO_2, g/sec

λ — one fission product decay constant, sec^{-1}

Heat Generation

The fission product decay heating rate is taken to be approximately that for a core which has operated for infinite time (Remley, 1973),

$$P_{dh}(t) = 0.140 \ P_0 t^{-0.291} \tag{5}$$

Equation (5) is empirical and is approximately correct in the time range from 60 seconds after shutdown to 1 year after shutdown. Under the condition that all the fission products remain in the core.

The magnitude of the heat generated by zirconium-water reaction is estimated in Chapter IV. Although the heat generated by zirconium-water reaction is significant, its affect on the fission product release is much less than that of decay heat due to several other reasons which will be discussed later. Hence, the metal-water reaction heat is neglected in the present formulation.

Vaporization of UO_2

During the first 10 seconds after cessation of fissioning, no vaporization was assumed to occur

$$P' = 0 \quad \text{for } t < 10. \tag{6}$$

It was assumed that heatup of the core takes about one minute. Therefore, from 60 seconds after shutdown onward, it was assumed that a constant fraction H of the decay heat generated in that fraction of the core which had not yet vaporized, went to vaporize UO_2. Hence,

$$P'(t) = 0.140 \ H \ H'(t) P_0 t^{-0.291} \quad \text{for } t > 60 \tag{7}$$

For times between 10 and 60 seconds after shutdown, it was assumed that the decay heating to cause vaporization of UO_2 increased linearly from zero at 10 seconds to the heat rate given in Equation (5) at 60 seconds. Hence,

$$P'(t) = 0.140 \times 60^{-0.291} H H'(t)P_0 (t-10)/50 \quad \text{for} \quad 10 \leq t \leq 60 \tag{8}$$

The H value in Equations (7) and (8) depends on the heat transfer properties of the various material in the core, the geometric and mechanical situations after the accident and the amount of the emergency cooling water available. This value can not be predicted before the accident and is difficult to be determined even after a reactor accident has started. The effect of this value on the fission product release will be discussed in the next section of this chapter.

The H' value in Equations (7) and (8) depends on the fuel material and also on the assumed H value. In Chapter III, a method to calculate H' as a function of time is described and discussed. The result shows that H' is not sensitive to the change of the assumed H value.

The rate of vaporization of UO_2 is

$$V_u = P'/\Delta H_{sub}. \tag{9}$$

The heat sublimation of UO_2 at 1800°K is 137.1 kcal/mole (Belle, 1961) or 2150 joules/g. V_u is the rate of decrease in the mass of the core, M_u. Hence,

$$-V_u = dM_u/dt \quad . \tag{10}$$

From Equations (7), (8), (9), and (10), M_u can be obtained as a function of time by numerical methods.

Fission Product Vaporization and Inventory

The rates of vaporization of fission products are assumed to be proportional to the fractional rate of vaporization of UO_2, the ratio of vapor pressure of the fission product to that of UO_2, the amount of fission product not yet vaporized. Hence,

$$V = V_u F' Q/M_u \tag{11}$$

In general, the inventory of any fission product in the fuel will be given by integration of an equation of the form

$$dQ/dt = -V - \lambda Q \quad . \tag{12}$$

solving for Q and integrating gives

$$Q/Q_o = \exp(-\lambda t) \quad (M_u/M_o)^{F'} . \tag{13}$$

Release of Vaporized Fission Products

The vaporized fuel and fission products were released into the pressure vessel and, if they did not deposit, found their way into the containment, the reactor building, any access tunnel associated with the power plant and finally the environment.

The inventory in the pressure vessel increased due to vaporization from the core at a rate of V curies per second. The inventory will decrease due to leakage from the pressure vessel to the containment and radioactive decay. A leakage flow proportional to the density of fission products from the pressure vessel to the containment and a similar flow from the containment to the pressure vessel were assumed.

Loss of particulate fission products is also due to agglomeration and settling of aerosol particles. It was assumed that particulate fission products would be associated with UO_2 particles and therefore that the fractional rate of deposition of particulate fission products would equal that of UO_2 particles. The "aerosol model" described in the last section is used to calculate the loss due to deposition.

The fission products were divided into four classes according to their deposition properties. The four classes are refractories, noble gases, volatiles, and halogens. Refractory fission products were assumed to condense, along with UO_2, soon after vaporization, hence to be particulate in each containment, including the pressure vessel. Noble gases were assumed to be molecular throughout the containment system. The volatile fission products were assumed to include all other fission products except the halogens. The volatile fission products were assumed to be molecular in the pressure vessel and particulate in each successive containment. Half of the halogens were assumed to remain molecular throughout like the noble gases, the other half was assumed to be molecular in the pressure vessel and particulate in each successive containment, like the volatile fission products. The typical fission products of the four classes are listed in Table 2.

We can now write an expression for the rate of change in the inventory in the pressure vessel.

$$dP/dt = V_u F' \, Q/M_u - L_p(P/V_p - C/V_c) - \lambda P - K_c' \, P^2 - K_{sp} P \tag{14}$$

where the K'_c is different from the K_c in Equation (2) in that K'_c is expressed in the units $cm^3 curie^{-1} sec^{-1}$, while K_c is expressed in the units $cm^3 sec^{-1}$. As mentioned above, K'_c and K_{sp} are equal to zero for those fission products which are molecular in the pressure vessel.

In the containment, provision was made to account for removal of particles by filtration or of iodine by charcoal absorption and the loss rate by filtration-adsorption is $(F_c E_c/V_c)C$. Of course, this term is zero for noble gas isotopes. The differential equation for the fission product inventory in the containment can therefore be written:

$$dC/dt = L_p (P/V_p - C/V_c) - L_c (C/V_c - B/V_b) - \lambda C - F_c E_c C/V_c - K_c' C^2 - K_{sc} C \tag{15}$$

If the containment is enclosed by a building and if the reactor building is enclosed with a berm containment (Appendix VII of Auxier and Chester, 1973), then the equation which described the inventory in the reactor building and access tunnel is entirely analogous to those above for the containment.

TABLE 2

FOUR CLASSES OF FISSION PRODUCTS

Class Number	Description	Nuclei
I	Noble Gases	Kr, Xe
II	Halogens	I, Br
III	Volatiles	Ge, Se, Rb, Sr, As, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, Cs, Ba
IV	Refractories	Y, Zr, Nb, La, Ce, Pr, Nd, Pm, Sm

$$dB/dt = L_c(C/V_c - B/V_b) - L_b\,(B/V_b - T/V_t) - \lambda B - F_bE_bB/V_b - K_c{}'B^2 - K_{sb}B \quad (16)$$

$$dT/dt = L_b(B/V_b - T/V_t) - L_t\,T/V_t - \lambda T - F_tE_tT/V_t - K_c{}'T^2 - K_{st}T\,. \quad (17)$$

Consider these cases: an unenclosed containment, a containment enclosed in a reactor building and a containment enclosed in a building which is enclosed in an underground or berm containment so that the building leaks only to an access tunnel which in turn leaks to the environment. All these cases are shown in Figures 1 through 4.

With an unenclosed containment, the release R changes according to

$$dR/dt = (L_c/V_c)\;C - \lambda R\,. \quad (18)$$

With a containment enclosed in a building, the differential equation becomes

$$dR/dt = (L_b/V_b)\;B - \lambda R\,. \quad (19)$$

If the building is enclosed, then the leak to the environment from the access tunnel of the underground containment becomes

$$dR/dt = (L_t/V_t)\;T - \lambda R\,. \quad (20)$$

The three equations are analogous to one another; they pertain respectively to single, double, and triple containment systems.

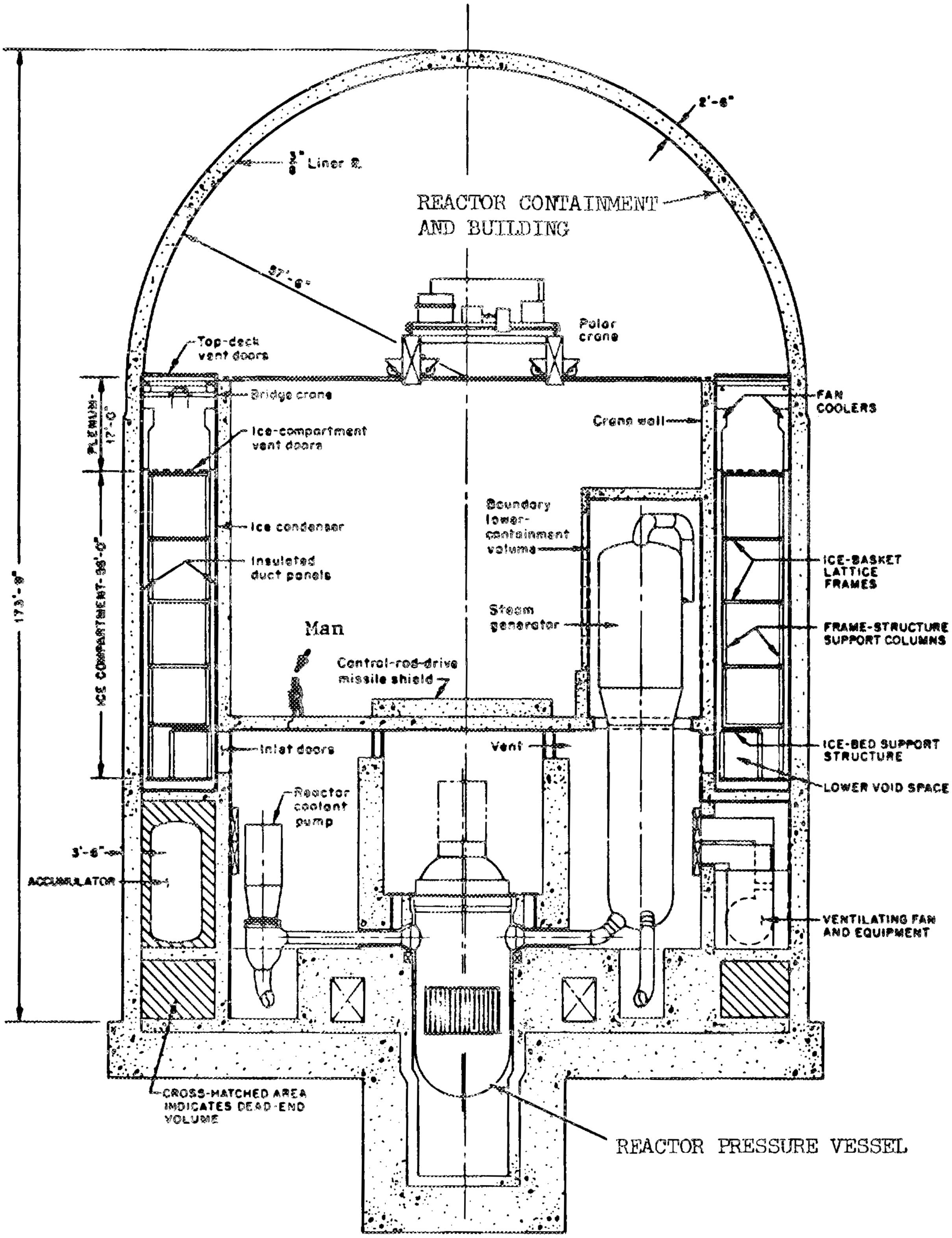

Fig. 1. A Section Through a Typical Primary Coolant System and Containment for a Large PWR System

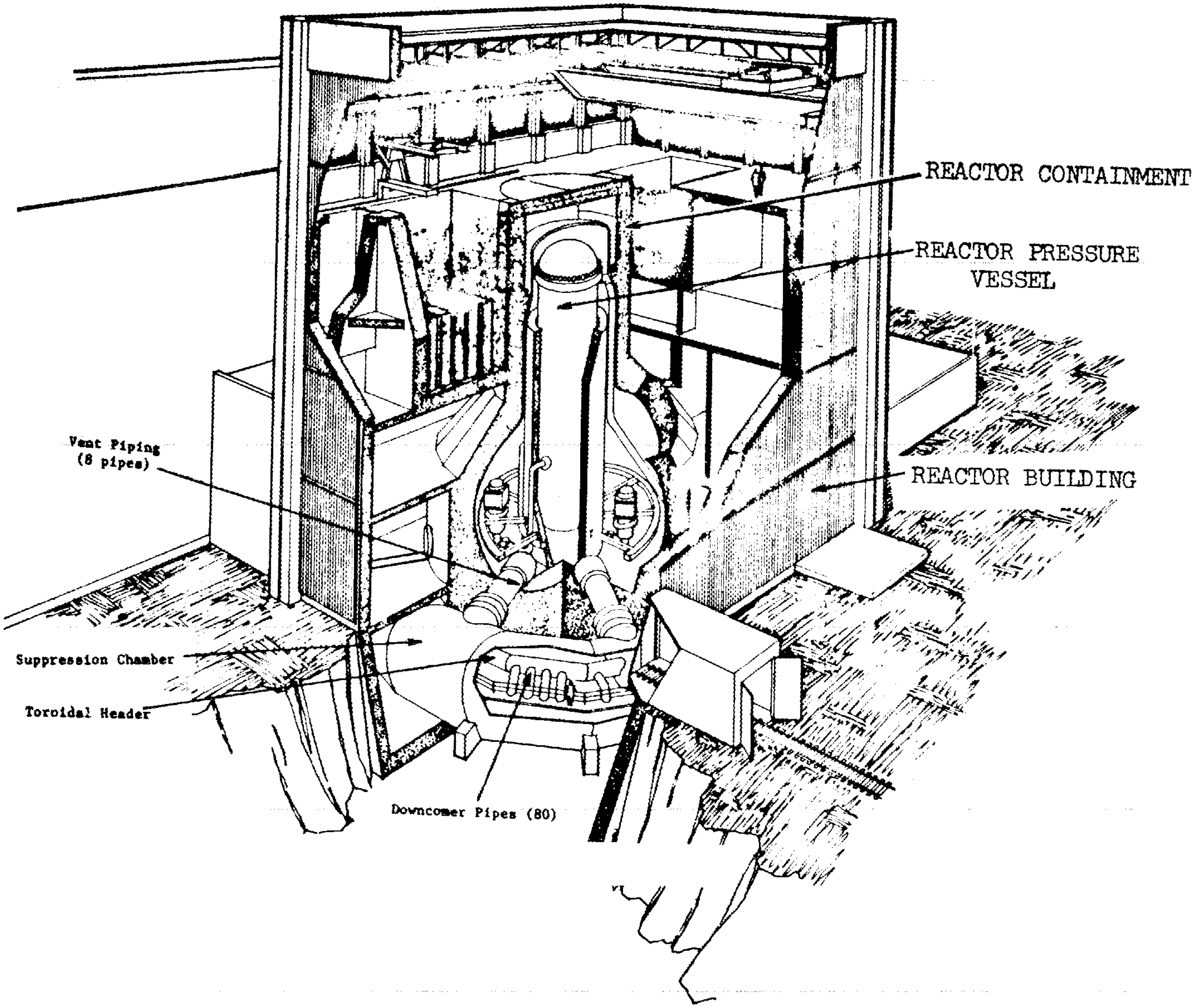

Fig. 2. Cutaway View of a BWR Secondary Containment Building Showing Primary Containment System Enclosed

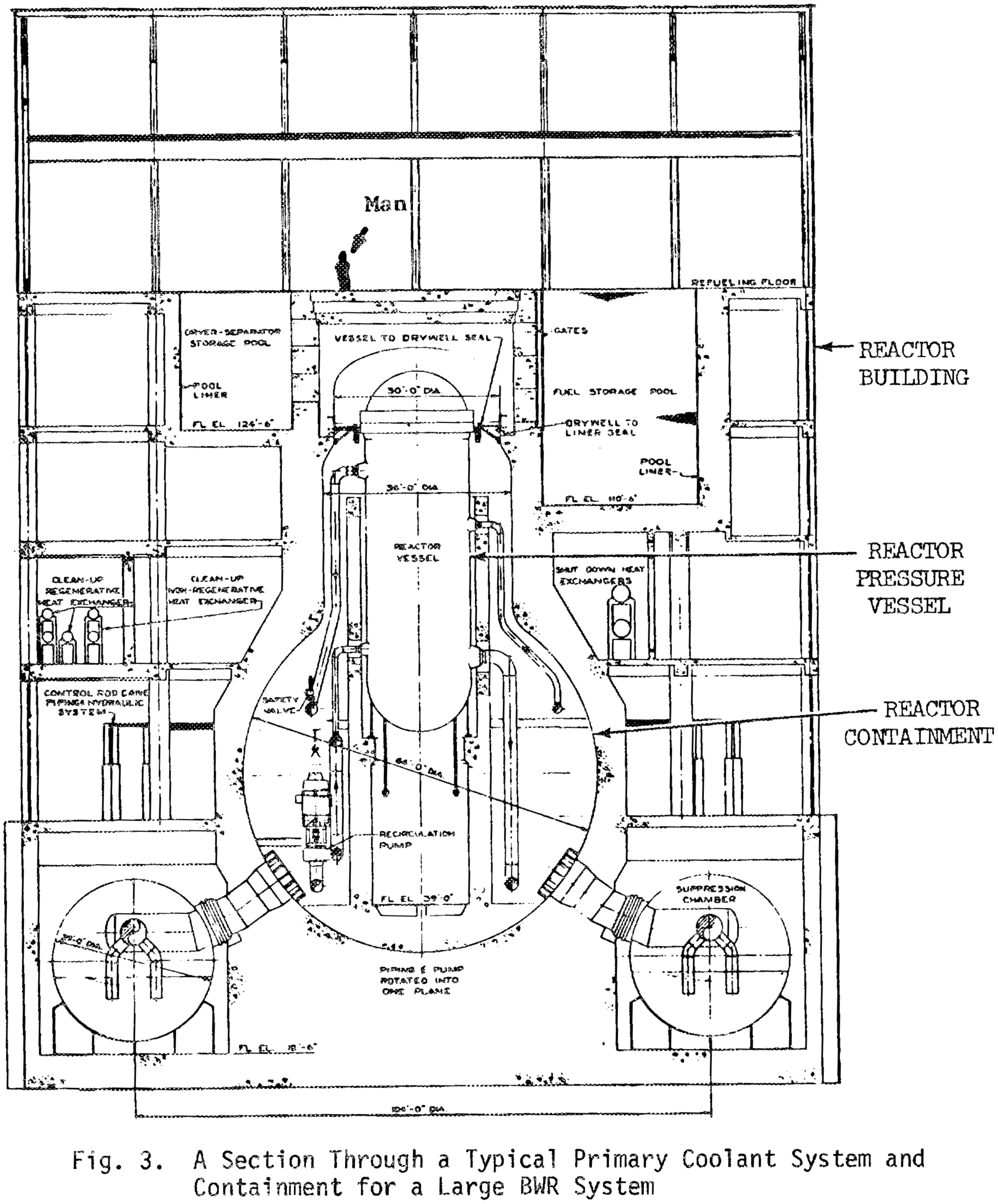

Fig. 3. A Section Through a Typical Primary Coolant System and Containment for a Large BWR System

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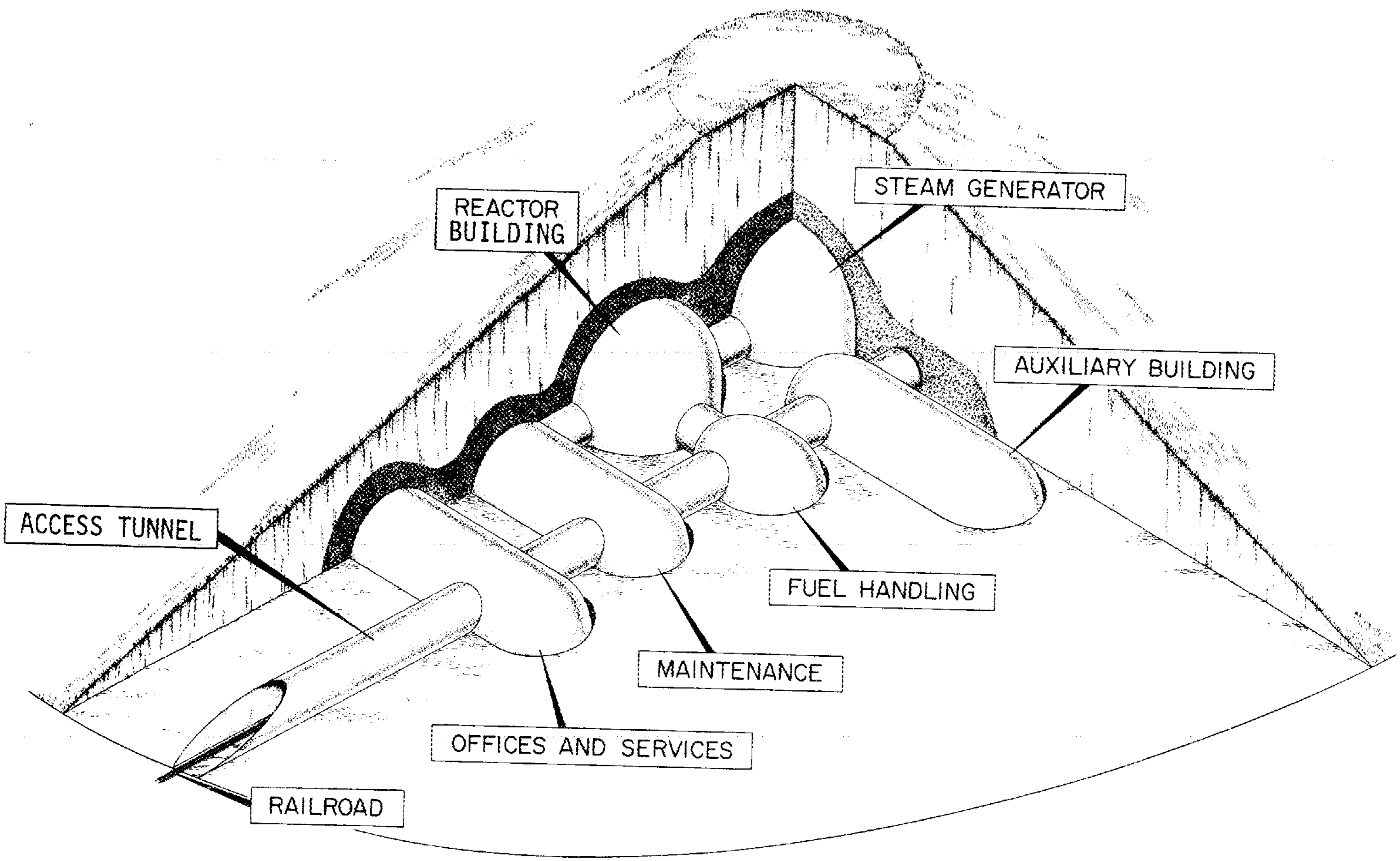

Fig 4. Cutaway View of a Berm Containment for a Large FBR System

Equations (14) through (20) are solved by means of a finite difference technique.

IV. THE RELATIVE EFFECTS OF VARIOUS PARAMETERS ON THE FISSION PRODUCT RELEASE

A damaged BWR (boiling water reactor) was chosen to be the normal case in calculating the relative effects of various parameters on fission product release. The values of parameters used are shown in the Appendix, Table 8, Table 9, and Table 10. In each case, one of the parameters is decreased or increased with respect to the normal case to see its effect on release.

Since the effects of parameter variation are different for the four different classes of fission products, ^{133}Xe, ^{131}I, ^{90}Sr, ^{91}Y were chosen to represent the noble gases, halogens, volatiles, and refractories respectively. The effects of various parameters on the releases of these four fission products are shown in Figures 5, 6, 7, and 8 respectively.

Figure 5 shows that varying vaporization rate has small effect on ^{133}Xe release at times shortly after reactor blowdown, and negligible effect at longer times. The effect of a longer blowdown time is to reduce the ^{133}Xe release at short times. But this effect is negligible at longer times. Since noble gases were presumed to be molecular through the containment system, the release is not affected by changing aerosol parameters.

Figure 6, page 22, shows that the effect of a longer blowdown time on the ^{131}I release is the same as that on the ^{133}Xe release. Changing the vaporization rate or using a larger particle fall

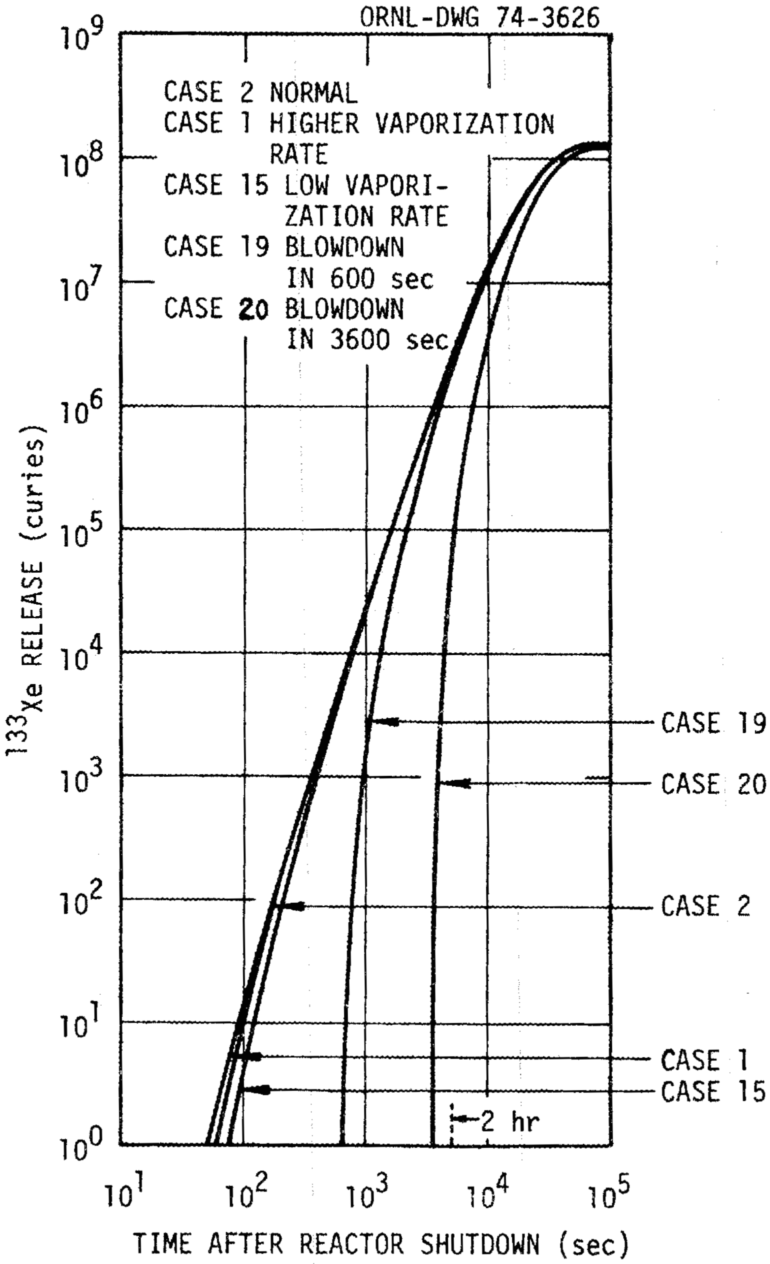

Fig. 5. Effects of Various Parameters on ^{133}Xe Release

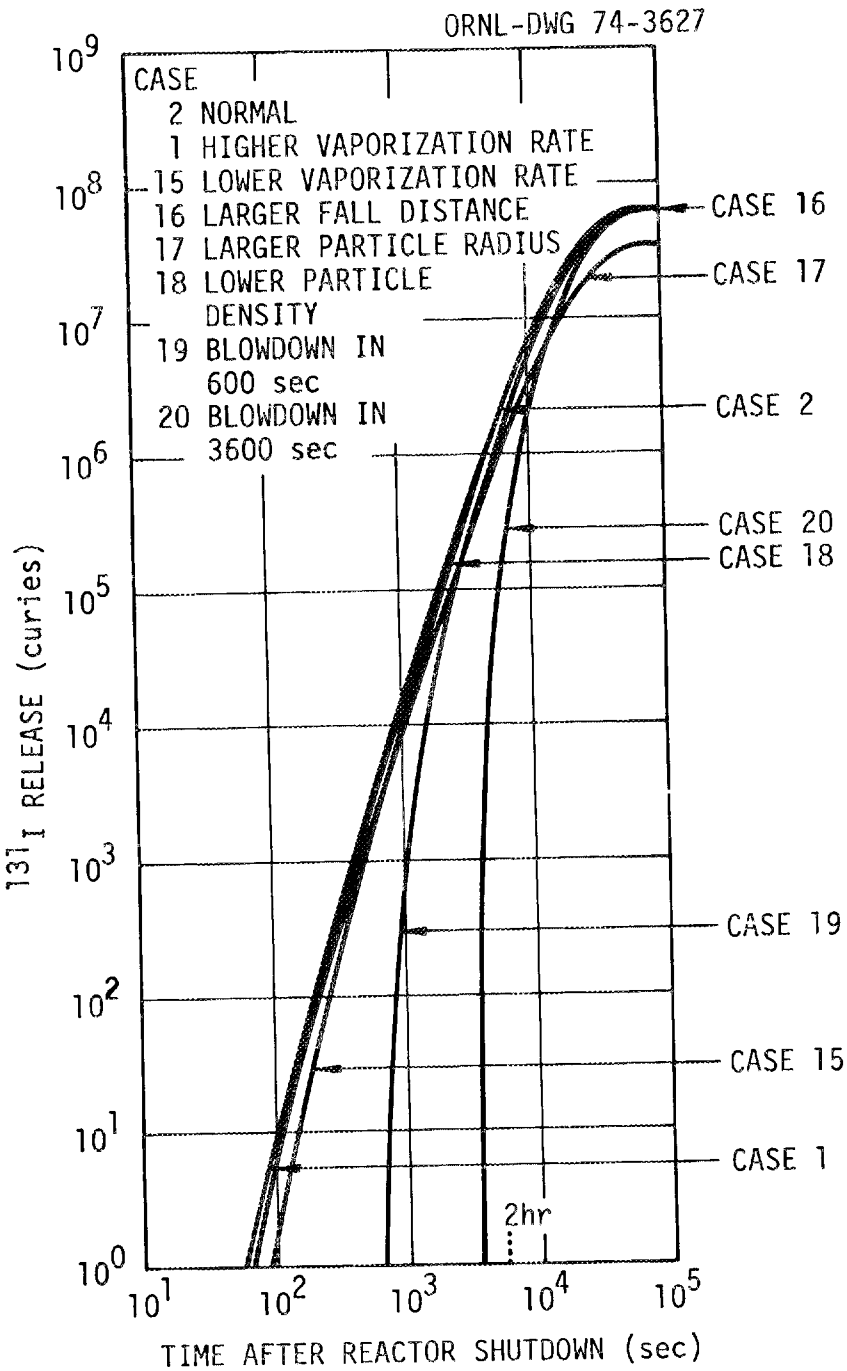

Fig. 6. Effects of Various Parameters on ^{131}I Release

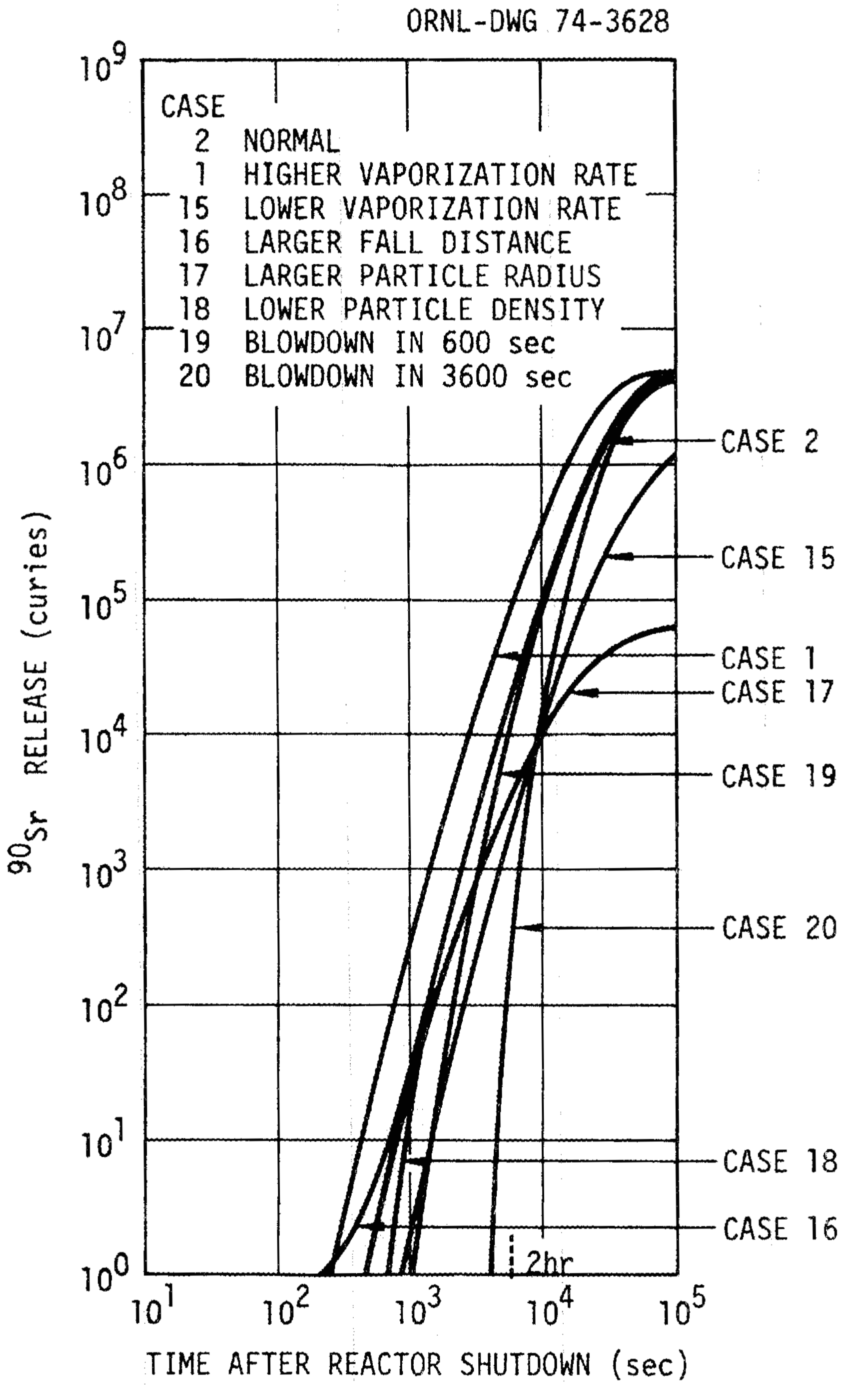

Fig. 7. Effects of Various Parameters on ^{90}Sr Release

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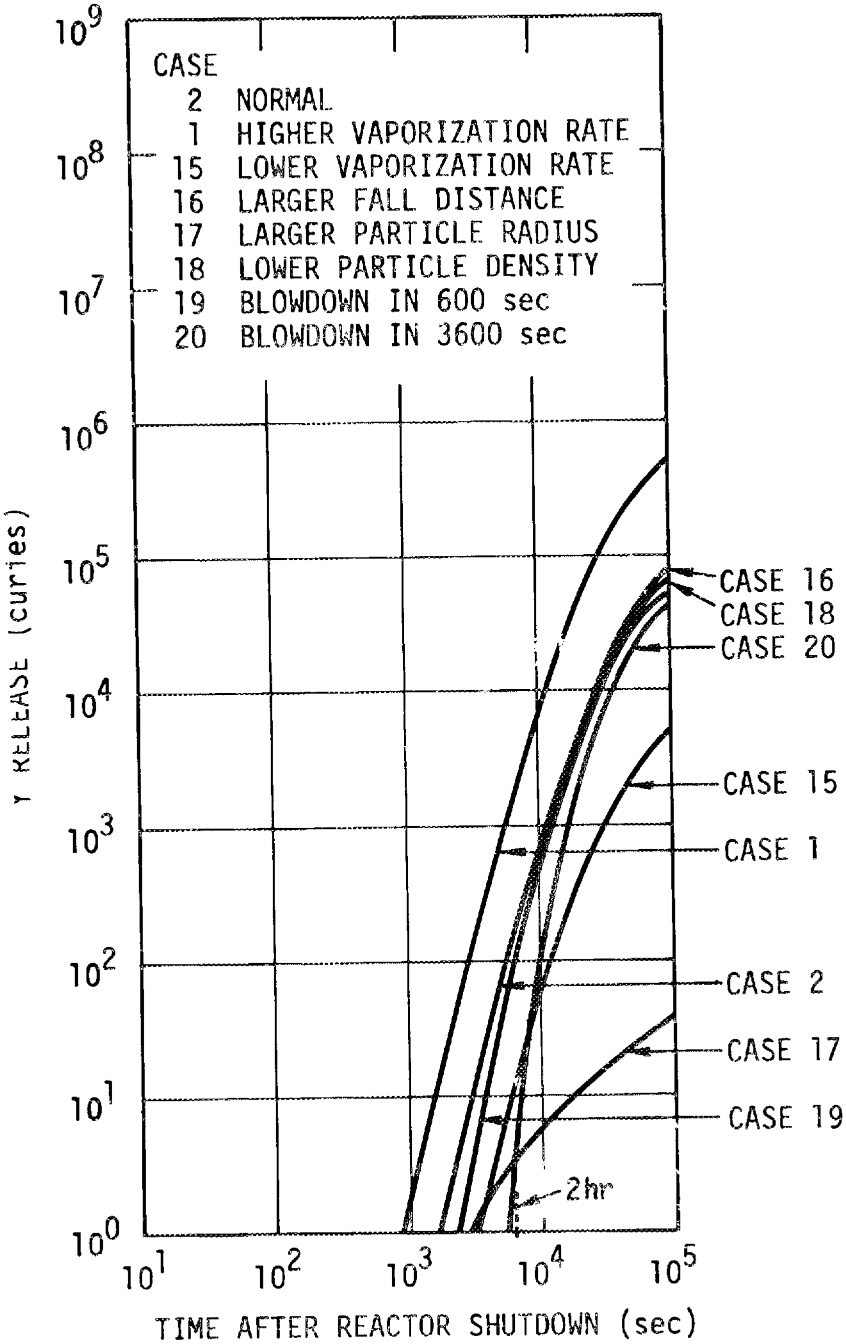

Fig. 8. Effects of Various Parameters on ^{91}Y Release

distance or lower particle density has no significant effect on the ^{131}I release.But increasing the minimum particle radius leads to a significant reduction of the ^{131}I release at longer times.

Figure 7, page 23, shows that the effect of increasing the minimum particle radius on the ^{90} Sr release is very large. Increasing the UO_2 vaporization rate leads to an increase of the ^{90}Sr release. Decreasing the UO_2 vaporization rate changed the magnitude of the ^{90}Sr release more than increasing the UO_2 vaporization rate did. This is also true for ^{131}I release. Although particle fall distance does not appear to be an important parameter, it leads to a slight increase of the ^{90}Sr release at short times. Longer blowdown time leads to a reduction of ^{90}Sr release at times shortly after blowdown but this effect is less important for the ^{90}Sr release than for the ^{131}I and ^{133}Xe release.

Figure 8 shows that the effects of changing the vaporization rate and changing the aerosol parameters are more significant for ^{91}Y release than for the other three fission products. On the other hand, the effect of a longer blowdown time is relatively unimportant for ^{91}Y release.

In summary, the minimum particle radius is the most important parameter in determining the magnitude of the release of particulate fission products. For refractories an increase of the minimum particle radius by a factor of ten can lead to a three orders of magnitude reduction of release at the end of 10^5 sec after reactor shutdown.

The assumed fraction of decay heat available to vaporize UO_2, which determines the vaporization rate, is important for fission products with vapor pressure equal or lower than that of ^{90}Sr but is not important for fission products with higher vapor pressure. The reason is that high vapor pressure fission products were released from the core much faster than they were leaked through the containments; hence, the release rate was not controlled by the vaporization rate. This reasoning also explains why decreasing the vaporization rate had more effect on the ^{90}Sr release than on the ^{131}I release.

The various parameter changes and effects are briefly summarized in Table 3.

V. CONTAINMENT EFFECTS

Our calculation shows that the effects of containment systems on the four different classes of fission product releases are similar. Hence only the effect on the ^{91}Y release is shown here.

Figure 9 shows that the addition of even a damaged access tunnel reduces the release by two orders of magnitude. And the fission product release of a BWR with damaged reactor building and damaged access tunnel is about the same as that of a BWR with design basis reactor building but with no access tunnel.

The effect of containment filter on the ^{91}Y release of a PWR is also shown in Figure 9. The calculation shows that the filter can lead to a reduction of the release to the environment by two orders of magnitude. In other words, the effect of adding a containment filter is about the same as replacing a damaged access tunnel by a design basis access tunnel.

TABLE 3

VARIOUS PARAMETER CHANGES AND EFFECTS

Parameter Change	Effect on Magnitude of Release (at 10^5 sec)
Higher Vaporization Rate	Increases
Greater Fall Distance	Increases Slightly
Greater Minimum Particle Radius	Decreases Greatly
Lower Particle Density	Increases Slightly
Blowdown in 600 sec	Remains Unchanged
Blowdown in 3600 sec	Remains Unchanged

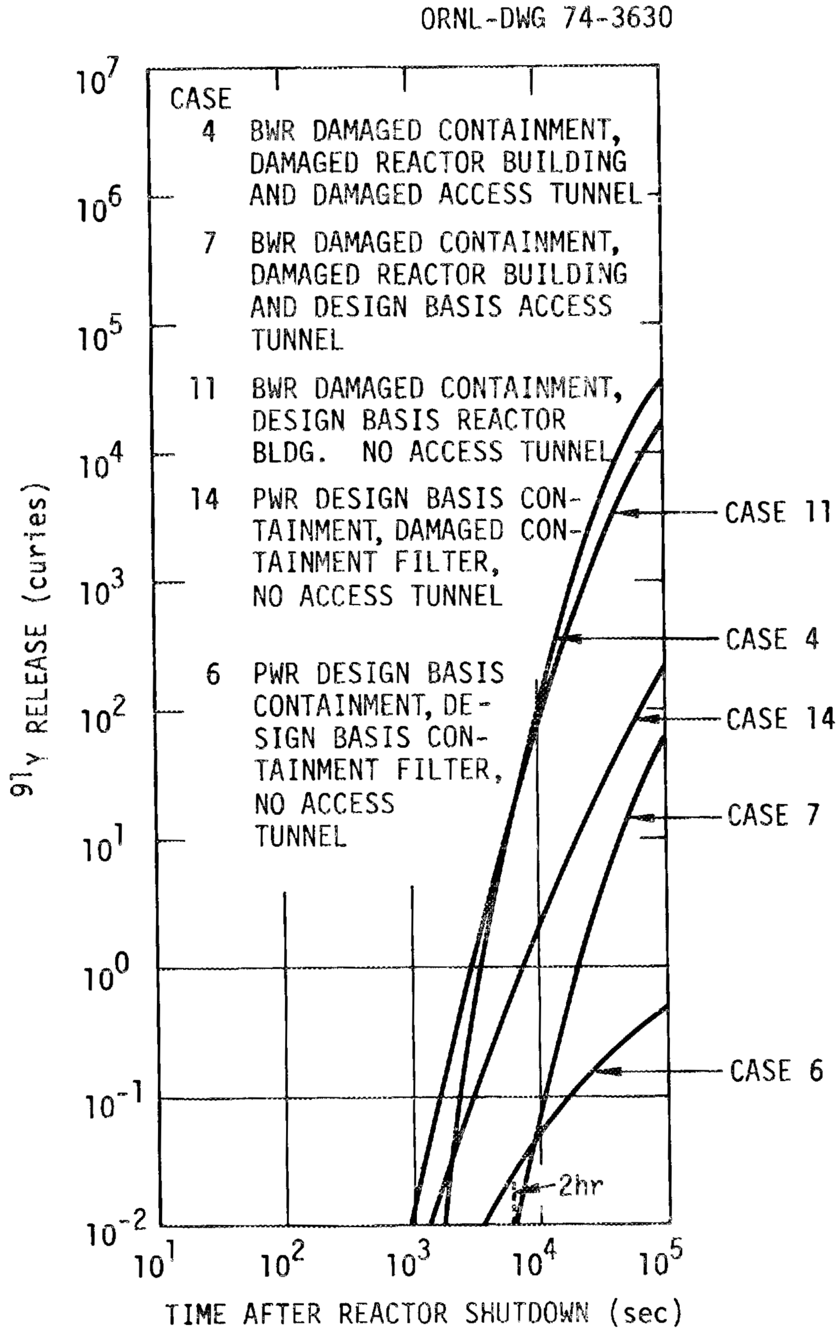

Fig. 9. Effects of Various Containment Systems on ^{91}Y Release

CHAPTER III

THE EFFECT OF THE FISSION-PRODUCT VAPORIZATION ON DECAY HEAT AVAILABILITY

I. STAGES OF CALCULATION

At the first stage of our calculation, the fission products were divided into four classes: noble gases, halogens, volatiles, and refractories. And it was assumed that the fractions of each fission product remaining in the core as a function of time are the same for all fission products in the same classification, and ^{133}Xe, ^{131}I, ^{90}Sr, ^{91}Y were selected to represent the four classes of fission products, respectively.

First, H'(t) in Equations (7) and (8) was set equal to one. The fraction of ^{133}Xe remaining in the core as a function of time was obtained by using Equations (5) through (13) with the aid of the computer. Then this fraction was multiplied by the fraction of the total decay heat attributable to all noble gases. The latter fraction is also a function of time. The same calculation was also done for ^{90}Sr, ^{131}I, and ^{91}Y.

Then, the results for the four fission product classifications were summed. The sum was the first approximation to the fraction of decay heat remaining in the core and was to be used as the value of H'(t) in the calculation of the second approximation.

Because this effect, as mentioned before, is a negative feedback effect, and also because the result obtained in the first approximation is quite different from unity, this procedure was iterated for ten runs to get the final convergent result. The final convergent value is defined as the decay heat "correction factor".

Since the vapor pressure of different fission products in the same classification varied over several orders of magnitude (Bedford and Jackson, 1965), it was decided that the second stage was to classify the fission products into more than four classes according to their vapor pressure. The reclassification of fission products into ten groups is shown in Table 4.

In Table 4, it is worth noting that although the theoretical value of Te vapor pressure is high, a lower value from experimental work (Parker, et al., 1967) is used in our classification since Te can be dissolved in Zr cladding (Appendix VI of Auxier and Chester, 1973). The results obtained by using ten fission product groups rather than four will be shown and discussed in the next section.

The decay heat available for vaporizing fission products is reduced appreciably. But the most important thing after the accident is the fission product release rather than the decay heat itself. Hence, the final stage was to use the modified decay heat to calculate the fission product release. The results are compared with some available data. The comparison will be given in the last section of this chapter.

The three stages of calculation described above are illustrated by Figures 10 and 11.

There is one thing that should be pointed out here. Although ten groups of fission products were used in calculating the fraction of decay heat remaining in the core, the original four classifications

TABLE 4

FISSION PRODUCT GROUPS WITH THE RATIO OF THEIR VAPOR PRESSURE TO THAT OF UO_2

Group Number	Nuclei	Ratio of their vapor pressure to that of UO_2
1	As, Se, Br, Kr, Rb, Cd, I, Xe, Cs	1.0×10^{6}
2	Ge, Sr, Pd, Sn	8.0×10^{2}
3	Ag, In	1.0×10^{4}
4	Sb, Ba	1.5×10^{5}
5	La, Nd, Pm	70.0
6	Ge, Pr, Te	8.0
7	Rh, Sm	1.0
8	Y, Nb	0.25
9	Zr, Ru	3.0×10^{-2}
10	Mo, Tc	7.0×10^{-3}

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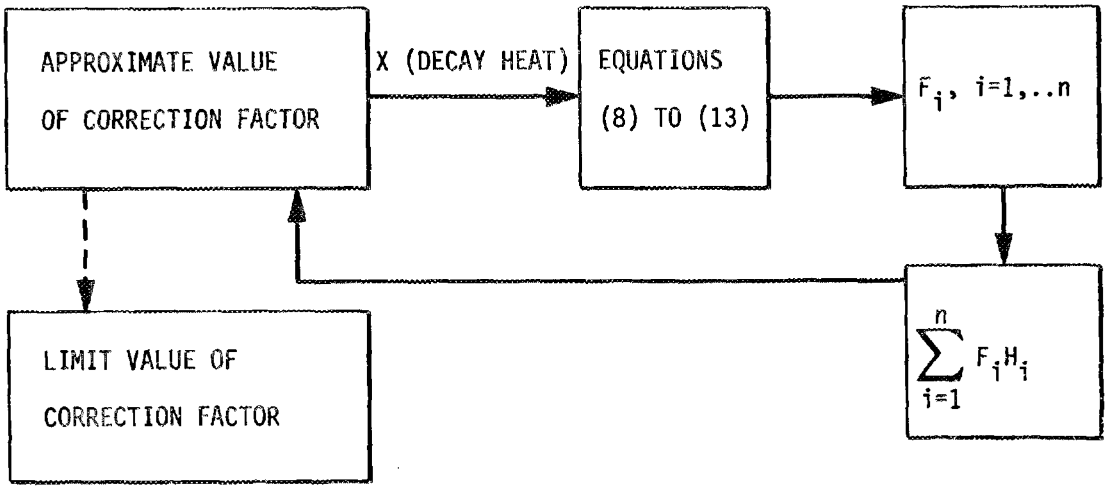

where:

F_i = fraction of class i fission products not vaporized

H_i = fraction of decay heat contributed by class i fission products

n = 4 in the first stage of calculation

n = 10 in the second stage of calculation

Fig. 10. The First and Second Stages of Calculation of Effect of Fission Product Loss on Decay Heat

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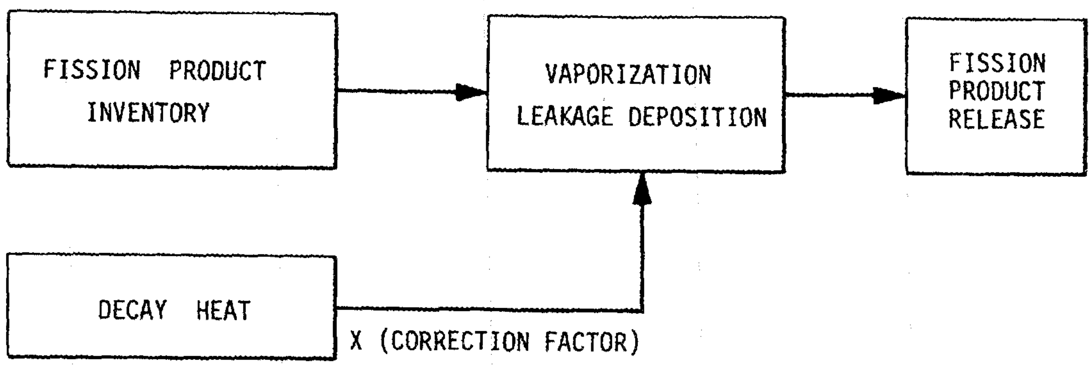

Fig. 11. The Third Stage Calculation of Effect of Fission Product Loss on Decay Heat

were used to calculate the fission product release. This is due to the fact that the original classifications were based on the rate of deposition of the fission products. In other words, in calculating the decay heat escape fraction the fission products were classified into ten groups according to their vapor pressures, but in calculating the fission product release the fission products were classified into four classes according to their deposition properties.

II. RESULTS AND INTERPRETATION

The decay heat correction factors obtained in stage one and stage two calculations with an H value of 10^{-3} are shown in Figure 12. The higher correction factor of curve A (in Figure 12) shortly after blowdown, the monotonic decrease of curve A (in Figure 12) after 10^3 seconds, and the continued increase of curve B (in Figure 12) after 100 seconds are explained by the following reasoning.

The decay heat fractions contributed by the four and ten classes of fission products are shown in Figure 13 and Table 5, respectively, which are based on the work of R. O. Chester (1973). From Figure 13, it is clear that shortly after blowdown the volatiles contribute to most of the decay heat. By reexamining the vapor pressures of volatiles, it is found that using Sr to represent the volatiles makes the vapor pressure lower than the actual value. This reduces the fission product vaporization, which, in turn, leads to a higher correction factor.

The monotonic decrease with time of curve A (in Figure 12, page 35) after 10 seconds is also due to using Sr to represent the entire group of volatiles. Before 10^3 seconds most of the volatiles escaped

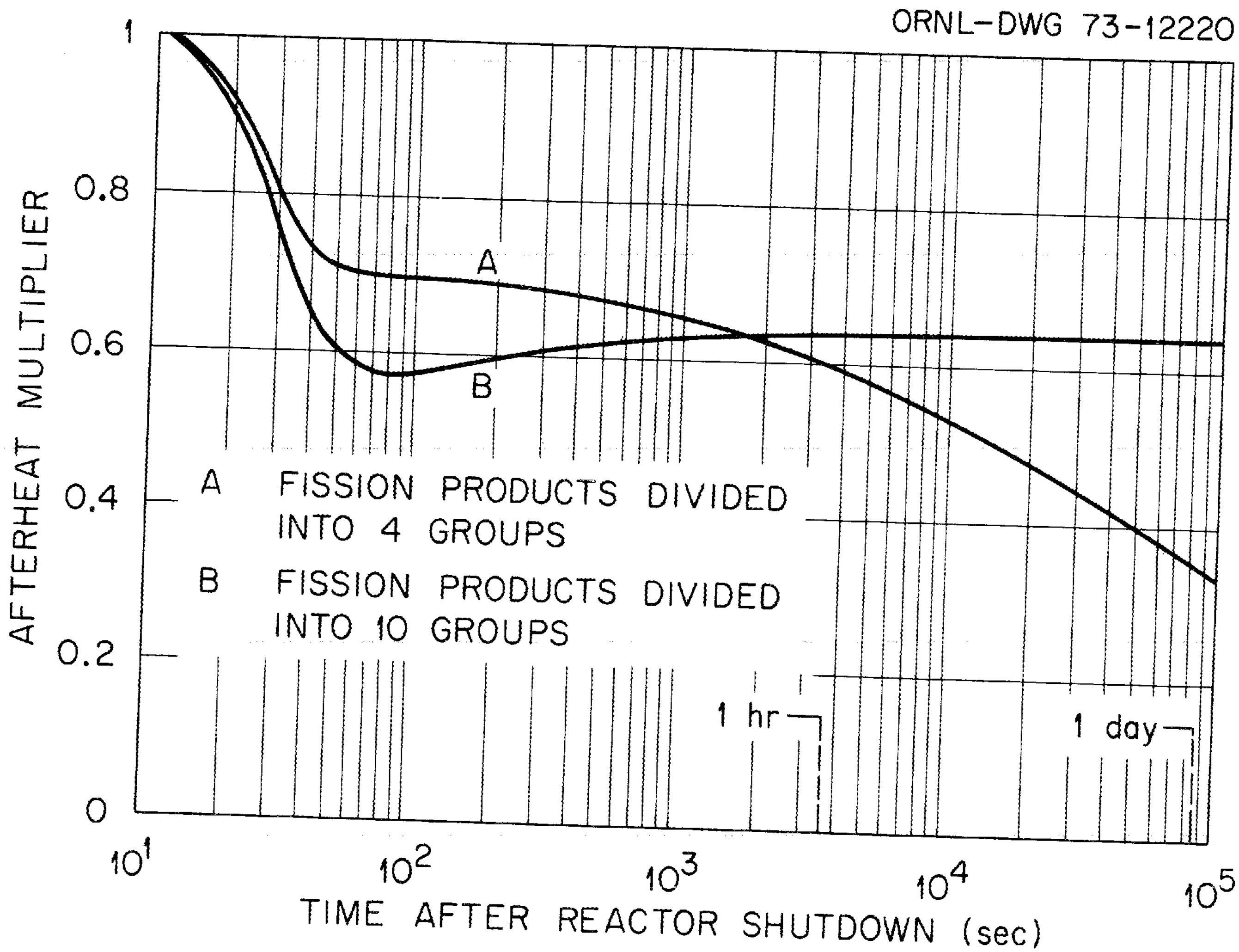

Fig. 12. Calculated Correction Factor Due to Volatized Fission Products for Reactor Core Afterheat

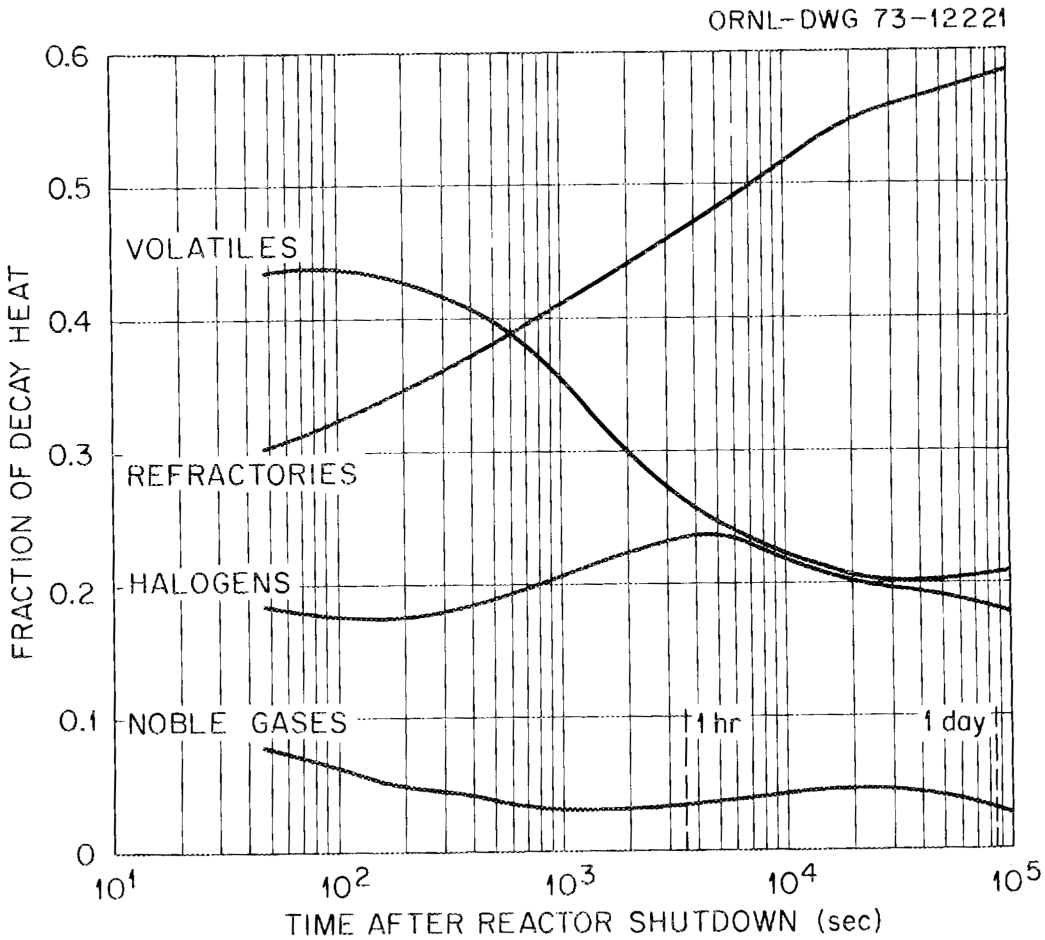

Fig. 13. Decay Heat Contribution Due to Fission Products in Each Classification

TABLE 5

DECAY HEAT FRACTIONS ATTRIBUTABLE TO THE

TEN FISSION PRODUCT GROUPS

Group Number	Fractions at 100 Seconds	Fractions at 10^5 Seconds
1	0.356	0.214
2	0.061	0.050
3	0.000	0.000
4	0.067	0.041
5	0.152	0.197
6	0.145	0.172
7	0.003	0.008
8	0.097	0.169
9	0.040	0.110
10	0.079	0.038

from the core due to the high vapor pressure. But the fraction of Sr which escaped from the core was only 0.167 at 10^3 seconds and 0.995 at 10^5 seconds.

Although at 10^5 seconds the refractories contributed approximately 60 percent of the decay heat (by Figure 13, page 36), they do not contribute too much to the change of correction factor since only a very small fraction of the refractories have vaporized. On the other hand, at 10^5 seconds the volatiles still contribute approximately 20 percent of the decay heat (by Figure 13); and since most of Sr vaporized between 10^3 seconds and 10^5 seconds, the escape of Sr was the primary contributor of the decreasing of correction factor after 10^3 seconds. This fact leads to the decrease of curve A (in Figure 12). The continued increase of curve B (in Figure 13) was due to the smaller escape fraction of refractories.

As mentioned in the third section of Chapter II, the decay heat correction factor also depends on the value assumed for H in Equations (7) and (8). The decay heat correction factors obtained by setting H equal to 10^{-4}, 10^{-3}, 10^{-2} are shown in Figure 14. From Figure 14 it is clear that the correction factor is not sensitive to the change in the value of H, since the correction factor changes by less than a factor of two while H changes by two orders of magnitude.

The effect of fission product escape on the UO_2 vaporization is shown in Figure 15. From Figure 15, the escape of fission products can lead to a 35 percent reduction in the UO_2 vaporization after 10^3 seconds.

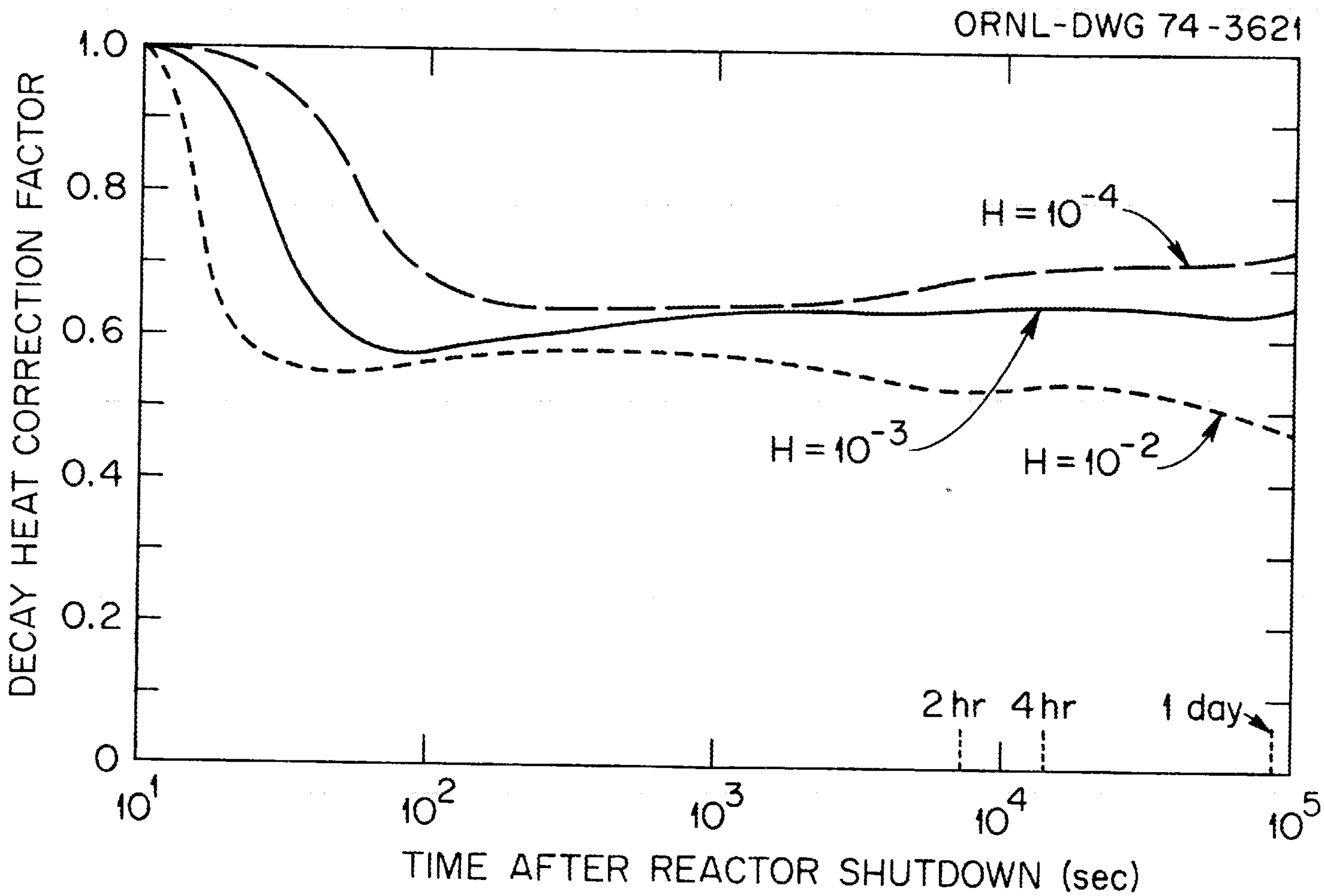

Fig. 14. Decay Heat Correction Factor for Three Different H Values

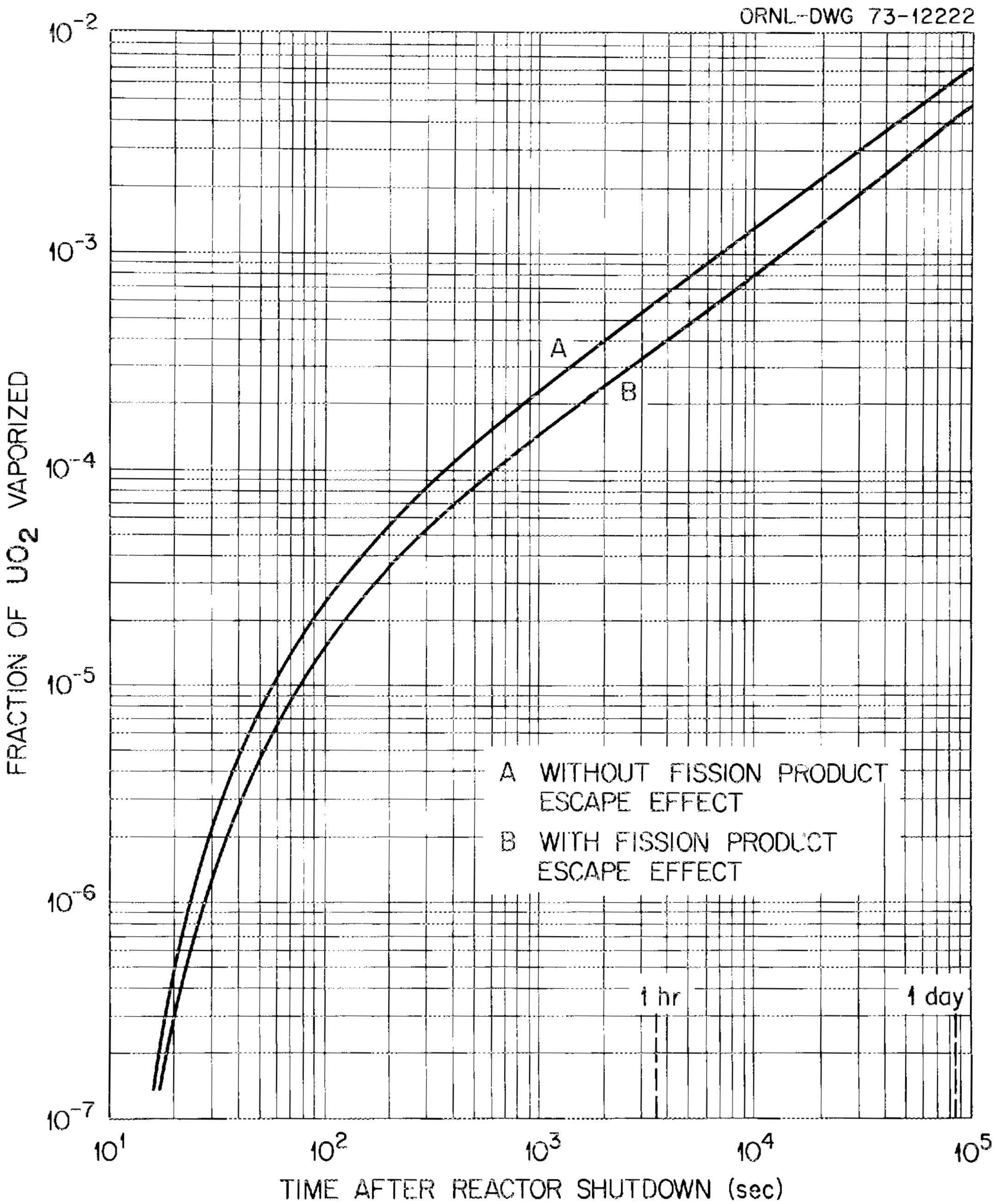

Fig. 15. Fraction of UO_2 Vaporized Under Two Different Conditions

The calculated releases of various fission products for the case including the fission product vaporization effect are compared with those which were obtained without including this effect. This comparison is shown in Table 6. Table 6 shows that fission product vaporization has negligible effect on the release of high vapor pressure fission products, but it can lead to appreciable reduction of the low vapor pressure fission product release.

III. COMPARISON OF THE CALCULATED VALUES WITH THE AEC SUGGESTED VALUES

The AEC regulatory staff (DiNunno et al., 1962) suggests typical values of the amount of radioactivity which leaves a PWR reactor core and reaches the reactor building. The AEC values are essentially the total airborne release from the core. They include natural deposition processes but not the effects of washdown or filtering from protective safeguards. Next, leakage to the environment is assumed to occur at a constant rate of 0.1 percent per day.

In order to compare the calculated values with the AEC suggested values, three numerical values must be examined: First, the fission product inventories in pressure vessel, containment, reactor building and the releases into the environment are summed. Doing the summation in this way, the deposition process was included but the effect of leakage was excluded. The summed values can be compared directly with the AEC suggested values. Parker (1967) suggested values for Cs and Ru based on his experimental work. These values are also included in the comparison which is shown in Table 7. Table 7 shows that the AEC suggested values compared to the calculated values of Zr and Nb

TABLE 6

FISSION PRODUCT RELEASE AT 10^5 SECONDS AFTER A DESIGN BASIS ACCIDENT (WITH AND WITHOUT FISSION PRODUCT ESCAPE EFFECT)

Nuclei	Without FPEE (Ci)	With FPEE (Ci)
Xe-133	0.21×10^6	0.21×10^6
I-131	0.87×10^5	0.87×10^5
Sr-90	0.44×10^4	0.38×10^4
Y-91	0.54×10^2	0.34×10^2
Nb-95	0.60×10^2	0.38×10^2
Zr-95	0.72×10^1	0.46×10^1
Ru-103	0.79×10^1	0.50×10^1
Ru-106	0.27×10^1	0.16×10^1
Te-129m	0.23×10^3	0.15×10^3
Cs-137	0.69×10^4	0.69×10^4
Ba-140	0.10×10^6	0.10×10^6

TABLE 7

COMPARISON OF THE CALCULATED FISSION PRODUCT SOURCE TERM WITH SUGGESTED VALUES

Fission Product	Suggested Value Percent of Inventory in Bldg.	Suggested Value Percent of Inventory to Envir*	Calculated Value†† Sum	Calculated Value†† Percent of Inventory in Bldg	Calculated Value†† Percent of Inventory to Envir
Xe	100*	.012	47	30	.01
I	50*	.003	46†	28†	.0098†
Zr	1*	1.2×10^{-4}	2×10^{-3}	9×10^{-4}	2×10^{-7}
Nb	1*	1.2×10^{-4}	2×10^{-2}	7×10^{-3}	2×10^{-6}
Ba	1*	1.2×10^{-4}	36	22	7×10^{-3}
Sr	1*	1.2×10^{-4}	36	15	4×10^{-3}
Cs	50**	.006	3.8	2.3	8×10^{-4}
Ru	5**	6×10^{-4}	2×10^{-3}	1×10^{-3}	2×10^{-7}
Gross Activity	15*	1.8×10^{-3}	16	10	3.5×10^{-3}

*These values are suggested by AEC in TID-14844 (1962).

**These values are suggested by Parker, et al. (1967).

†In this particular calculation, 50 percent of the core inventory of iodine is considered to have aerosol properties similar to the rare gases. As such, these numbers may be an overestimate of the release.

††The calculated values are obtained at 10^4 sec, and assume 10^{-3} of the decay heat available for the evaporation of UO_2. Radiological decay of all isotopes is included in these values.

overestimated the release by at least a factor of 50, but the values for Ba and Sr were underestimated by a factor of 36. Iodine was slightly overestimated. Xenon was overestimated by a factor of two. The higher calculated values of Sr and Ba releases can be explained by the following reasoning: because of the zirconium-steam reaction, the atmosphere surrounding the fuel changed from oxidizing condition to reducing condition. Hence, the vapor pressure of Sr and Ba increased by more than two orders of magnitude (Bedford and Jackson, 1965). Further, it should be noted that the calculated values are a nonlinear function of time. The time chosen for comparison is 10^4 seconds after shutdown. This is approximately three hours, the longest time realistically estimated before back-up emergency assistance will have arrived at the reactor site (Auxier and Chester, 1973). Also, in many circumstances in three hours the pressure vessel will not yet have melted through requiring a basic geometry change in the calculation. Second, the calculated airborne inventory in the reactor building at 10^4 seconds is listed in Table 7. Third, the calculated total release to the environment at 10^4 seconds is listed.

There is another interesting thing which should be pointed out here. By intuition, one might guess that the release source term of high vapor pressure fission products is greater than that of low vapor pressure fission products. But the values of Cs, Ba, and Sr in Table 7 show that the intuition is wrong. This is because a higher concentration produces a more than compensating higher deposition rate.

CHAPTER IV

ESTIMATION OF THE MAGNITUDE OF THE EFFECTS OF METAL-STEAM REACTION

If the heat released from the zirconium-steam reaction as a function of time is to be determined very accurately, the detailed mechanical and geometrical changes following the reactor accident are needed. Since the objectives of this study were to investigate the effect of zirconium-steam reaction on the fission product release rather than the reaction itself and the general characteristics of this effect rather than that of a single and unique accident, an assumption was used to avoid this complexity which is based on the results obtained by Louis Baker and R. O. Ivins (1965).

It was assumed that the zirconium-steam reaction starts at 40 sec after the reactor shutdown and 20 percent of the total zirconium reacts within the first half hour at a constant rate. This constant rate is determined by the following calculations.

The zirconium-steam reaction heat at 1800 ^{o}K is 137,780 cal/mole or 6.359 x 10^{3} joules/g (Lemmon, et al., 1959). And the total mass of zirconium is 137.172 pounds or 0.6 x 10^{8} g (see, for example, USAEC Docket No. 50-259/260/296, 1973). Hence

$$\text{Total reaction heat} = 6.359 \times 10^{3} \text{ joules/g} \times 0.6 \times 10^{8} \text{ g}$$

$$= 3.815 \times 10^{11} \text{ joules}$$

The assumed constant reaction heat rate

$$= 3.815 \times 10^{11} \text{ joules} \times 0.2 \div 1800 \text{ sec}$$

$$= 4.24 \times 10^{7} \text{ joules/sec} .$$

Since the decay heat is distributed within the fuel rod where the fission products are stored while the zirconium-steam reaction heat is distributed outside the fuel rod, the fraction of zirconium-steam reaction heat available for the vaporization of the fission products, which is denoted by H_1 in the following calculations, should be less than that of the decay heat. And if there is some cooling water left in the core, the water should be in contact with zirconium-cladding rather than the inside of the fuel rod. Hence the fraction of heat used to vaporize the water should be greater for zirconium-steam reaction heat than for decay heat. Both effects lead to the conclusion that H_1 should be less than H. Hence in our calculation, H_1 was assumed to be one order of magnitude less than H.

Incorporating the zirconium-water reaction to the decay heat by combining Equations (7), (8), and (21), the following equations are obtained:

$$P'(t) = 0.140 \times 60^{-0.291}\ H\ H'(t)P_o(t-10)/50$$

$$\text{for } 10 \leq K < 40 \qquad (22)$$

$$P'(t) = 0.140 \times 60^{-0.291}\, H\, H'(t)\, P_o (t-10)/50 + 4.24 \times 10^7\, H_1$$

$$\text{for } 40 \leq t < 60 \qquad (23)$$

$$P'(t) = 0.140\, H\, H'(t) P_o t^{-0.291} + 4.24 \times 10^7\, H_1$$

$$\text{for } 60 \leq t < 2200 \qquad (24)$$

$$P'(t) = 0.140\, H\, H'(t) P_o t^{-0.291}$$

$$\text{for } t \geq 2200 \, . \qquad (25)$$

Inserting Equations (22), (23), and (24) into Equations (9) and (10),

$$-dM_u/dt = A60^{-0.291}\,(t - 10)/50 \qquad \text{for } 10 \leq t < 40$$

$$= A60^{-0.291}\,(t - 10)/50 + B \qquad \text{for } 40 \leq t < 60$$

$$= At^{-0.291} + B \qquad \text{for } 60 \leq t < 2200$$

$$= At^{-0.291} \qquad \text{for } t \geq 2200$$

where

$$A = 6.511 \times 10^{-5}\, H\, H'(t)\, P_o$$

$$B = 1.971 \times 10^4\, H_1 \, . \qquad (26)$$

In order to compare the importance of the zirconium-steam reaction heat to that of the decay heat, the first and second terms in the right side of Equation (26) were calculated separately. In this calculation, P_o is set equal to 3.44×10^9 watts and H is set equal to 10^{-3}. From Figure 10, H'(60) equals 0.588 and H'(1800) equals 0.564.

At $t = 60$ seconds

$$\text{the first term} = 6.511 \times 10^{-5} \times (60)^{-0.291} \times 10^{-3} \times 0.588 \times 3.44 \times 10^{9} = 4.001 \times 10^{1} \text{ g/sec}$$

$$\text{the second term} = 1.971 \times 10^{4} \times 10^{-4} = 1.971 \text{ g/sec}$$

At $t = 1800$ seconds

$$\text{the first term} = 6.511 \times 10^{-5} \times (1800)^{-0.291} \times 10^{-3} \times 0.564 \times 3.44 \times 10^{9} = 1.426 \times 10^{1} \text{ g/sec}$$

$$\text{the second term} = 1.971 \times 10^{4} \times 10^{-4} = 1.971 \text{ g/sec}$$

The ratio of the second term to the first term equals 4.93 percent at 60 seconds and 13.82 percent at 1800 seconds.

From the results of the above calculation, it is evident that while the contribution of zirconium-steam reaction heat to the vaporization of fission products is significant, it is not as large as the contribution from decay heat.

CHAPTER V

SUMMARY

The reactor accident in this study was assumed to be a double-ended break of a large primary-system water pipe and concurrent failure of the emergency core cooling system. Following the reactor blowdown, the decay heat raised the core temperature. A certain fraction of the decay heat was assumed to vaporize UO_2 . The vaporization of various fission products was assumed to be controlled by their vapor pressure relative to that of UO_2. The airborne fission products were then subjected to decay, deposition and leakage processes, and finally released to the environment.

In this study the transport of fission products after release was not treated. Only agglomeration and gravitational settling were considered in the airborne fission product deposition process. The pressure vessel melt-through which may occur as soon as 2 hours after pipe rupture was not considered.

The assumption of a constant fraction of decay heat available to vaporize UO_2 was investigated in this study by taking into account the decay heat loss due to vaporization of fission products and by changing the assumed fraction.

The effect on fission product release of adding the metal-water reaction heat to the heat source was investigated.

The effect of multiple containments, the effect of a containment filter, and the effect of various parameters (particle fall distance, minimum particle radius and particle density) in the aerosol model on fission product release were studied also.

The results showed that the vaporization of fission products would lead to a 20 percent to 50 percent reduction (depending on the value of other parameters) in the decay heat available to vaporize UO_2.

The release of low vapor pressure fission products is approximately proportional to the assumed fraction of decay heat available to vaporize UO_2. But the release of fission products with vapor pressure higher than that of Sr is almost independent of the assumed fraction.

The metal-water reaction heat available to vaporize UO_2 is about one order of magnitude less than that of decay heat. Its effect on the fission product release is small. But the zirconium-steam reaction changed the atmosphere surrounding the fuel from an oxidizing condition to a reducing condition, thus changing the vapor pressure of various fission products. This can lead to an increase of Sr and Ba releases by a factor of 30 or more.

The addition of even a damaged access tunnel can reduce the fission product release by more than two orders of magnitude. The containment filter can lead to a reduction of the refractories' releases by more than one order of magnitude at the end of 2 hours after reactor shutdown.

The minimum particle radius is the most important parameter in the aerosol model. For refractory fission products, increasing the minimum particle radius by a factor of ten can lead to a reduction of release by two orders of magnitude at the end of 2 hours after reactor shutdown.

The particle fall distance and particle density have no significant effects on the fission product release.

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APPENDIX

COMPUTER PROGRAMS FOR THE ESTIMATION OF THE FISSION PRODUCT FROM A WATER-COOLED REACTOR

The program "RELEASE" is written to calculate the following variables as a function of time:

1. the fraction of UO_2 core vaporized.
2. the fraction of specific fission product vaporized.
3. the airborne inventories of the specific fission product in the pressure vessel, containment, reactor building, and access tunnel.
4. the fraction, the amount and the rate of the specific fission product released to the environment.

Another program "FEED" is written to calculate the effect of fission product vaporization on the decay heat. The correction factor of the decay heat as a function of time obtained by program "FEED" is used as part of the input of program "RELEASE". In this report, the program "RELEASE" is discussed first, then followed by a discussion of program "FEED".

I. THE DESCRIPTION OF THE USAGE OF THE PROGRAM "RELEASE"

The fission product release after a reactor accident depends upon the reactor type and the degree of damage to the reactor containments. Twenty representative cases are built in this code. In all the cases except cases 1, 15, 16, 17, 18, 19, and 20, the standard parametric values are used. The standard parametric values are determined by specifying whether the reactor is a PWR or BWR, to what degree the reactor containments are damaged, and how many containments the reactor has. Those standard parametric values are listed in Table 8, while the descriptions of the thirteen standard cases are tabulated in Table 9. Cases 1, 15, 16, 17, 18, 19, and 20, nonstandard parametric values, are listed in Table 10. Descriptions of the corresponding nonstandard cases are given in Table 11. In other words, these seven cases are used to investigate the relative effects of the various parameters of the model by comparing the results of those cases with that of case 2.

The notation of some parameters in this code are described briefly in the following and can be changed by the user to get the results of a specific case which is not included in the twenty representative cases.

a. EMU = total mass of UO_2 core ($1 = 1.48 \times 10^8$ gm in this code).

b. PWR = the reactor operating power level (= 3040 MW in this code).

c. IC = the number of reactor containments.

d. H = assumed fraction of decay heat available for the vaporization of UO_2 and fission products.

e. VP, VC, VB, VT = volumes of pressure vessel, containment, reactor building, and access tunnel.

f. HP, HC, HB, HT = fall distance of aerosol particles in pressure vessel, containment, reactor building, and access tunnel.

g. FLTIC, FLTIB, FLTIT = flow rates through iodine absorber in containment, reactor building, and access tunnel.

TABLE 8

STANDARD PARAMETRIC VALUES USED IN THE CODE

Description of the Reactor and Accident Type →	Design Basis BWR	Damaged BWR	Design Basis PWR	Damaged PWR
Containment Volume (cm^3)				
Pressure Vessel	$5x10^8$	$5x10^8$	$5x10^8$	$5x10^8$
Containment	$5x10^9$	$5x10^9$	$6x10^{10}$	$6x10^{10}$
Reactor Building	$5x10^{10}$	$5x10^{10}$	--	--
Access Tunnel	$5x10^{10}$	$5x10^{10}$	$5x10^{10}$	$5x10^{10}$
Filter Adsorber				
Flow Rate (containment volume/sec)	10^{-2}	10^{-2}	10^{-2}	10^{-2}
Fractional Remove Efficiency	95%	95%	95%	95%
Aerosol Parameters				
Max. Particle Radius (mμ)	10	10	10	10
Min. Particle Radius (mμ)	0.09	0.09	0.09	0.09
Particle Density (g/cm^3)	11	11	11	11
Particle Fall Distance (cm)				
in Pressure Vessel	$1x10^2$	$1x10^2$	$1x10^2$	$1x10^2$
in Containment	$2x10^2$	$2x10^2$	$1x10^3$	$1x10^3$
in Reactor Building	$1x10^3$	$1x10^3$	--	--
in Access Tunnel	$6x10^2$	$6x10^2$	$6x10^2$	$6x10^2$
Fraction of Decay Heat which Vaporizes UO_2 Core	10^{-3}	10^{-3}	10^{-3}	10^{-3}

TABLE 8 (continued)

Description of the Reactor and Accident Type	Design Basis BWR	Damaged BWR	Design Basis PWR	Damaged PWR
Blowdown-Core Heat Up Schedule				
Time for Blowdown (sec)	10	10	10	10
Time for Heat Up (sec)	50	50	50	50
Leak Rate (volume/sec)				
from Pressure Vessel	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}
from Containment	6×10^{-8}	1×10^{-4}	6×10^{-8}	1×10^{-4}
from Reactor Building	1×10^{-5}	1×10^{-4}	--	--
from Access Tunnel	6×10^{-8}	1×10^{-4}	6×10^{-8}	1×10^{-4}

TABLE 9

STANDARD REACTOR ACCIDENT TYPES

Case Number	Reactor Type	Pressure Vessel	Containment	Containment Filter	Building	Access Tunnel
2	BWR	B	B	---	B	---
3	BWR	B	G	---	G	---
4	BWR	B	B	---	B	B
5	PWR	B	B	B	---	---
6	PWR	B	G	G	---	---
7	BWR	B	B	---	B	G
8	BWR	B	G	---	G	B
9	BWR	B	G	---	G	G
10	PWR	B	G	G	---	G
11	BWR	B	B	---	G	---
12	BWR	B	G	---	B	---
13	PWR	B	B	G	---	---
14	PWR	B	G	B	---	---

Where: G = design basis containment

B = damaged containment

--- = does not apply

TABLE 10

THE NONSTANDARD PARAMETERS USED IN CASES

1, 15, 16, 17, 18, 19, AND 20

Case Number	Description	Nonstandard Parameter	Parameter Value
1	Higher vaporization rate	Fraction of decay heat which vaporized UO_2 core	10^{-2}
15	Lower vaporization rate	Same as in case 1	10^{-4}
16	Larger fall distance	Fall distance (cm) in pressure vessel	10^3
		In containment	2×10^3
		In reactor building	10^4
17	Larger particle	Minimum particle radius (mμ)	0.9
18	Lower particle density	Particle density (g/cm^3)	5
19	Longer blowdown time	Blowdown time (sec)	600
20	Same as case 19	Same as case 19	3600

TABLE 11

NONSTANDARD REACTOR ACCIDENT TYPES

Case Number	Reactor Type	Pressure Vessel	Containment	Containment Filter	Reactor Building	Access Tunnel
1	BWR	B	B	---	B	---
15	BWR	B	B	---	B	---
16	BWR	B	B	---	B	---
17	BWR	B	B	---	B	---
18	BWR	B	B	---	B	---
19	BWR	B	B	---	B	---
20	BWR	B	B	---	B	---

Where: B = damaged containment

--- = does not apply

h. FLTRC, FLTRB, FLTRT = flow rates through particulate filters in containment, reactor building, and access tunnel.

i. ELP, ELC, ELB, ELT = leak rates from pressure vessel, containment, reactor building, and access tunnel.

Input of Program "RELEASE"

1. List = IPLOT

   Format = I10

   IPLOT = 0, no curve plotted.

   = 1, plot the curves of fission product inventories in core, pressure vessel, containment, reactor building, access tunnel and the environment as a function of time on a log-log scale.

2. List = ICOL, IROW, NDIM, EPS

   Format = (3I10, E10.2)

   ICOL = 1.

   IROW = number of times at which the correction factor of decay heat is available.

   NDIM = number of points used to interpolate the correction factor of decay heat at a given time. (NDIM = 2 means linear interpolation).

   EPS = an input constant which is used as the upper bound for the absolute error.

3. List = Z, F

   Format = (8D10.4)

   Z = values of time (with dimensions equal to IROW)

   F = correction factor of decay heat corresponding to the time in Z (with dimensions equal to IROW).

4. List = IM, XLAMDA, QZERO, G, FP, ATNO

   Format = (I10, 5E10.2)

   IM = the classification number of the specific fission product we want to calculate.

   = 1 for noble gases.

   = 2 for volatiles.

   = 3 for halogens.

   = 4 for refractories.

   XLAMDA = decay constant of the specific fission product, sec^{-1}

   QZERO = inventory of the specific fission product in fuel at time equal to 0.

   G = fraction of halogen fission products which remain gaseous.

   FP = ratio of the specific fission product vapor pressure to UO_2 vapor pressure.

   ATNO = atomic number of the fission product.

5. List = (TITLE(k), k = 1, 10)

   Format = (10A8)

   TITLE = consists of 20 cards, on each card print the name of the specific fission product followed by the case number. (For example, I-131 CASE 1). The case number must be in the order: 4, 7, 9, 8, 5, 14, 6, 13, 10, 15, 1, 12, 3, 11, 2, 16, 17, 18, 19, 20. These letters will be printed on the curve as the title of each case.

Output of Program "RELEASE"

1. The following results are printed out as a function of time at 40 points, i.e., with equal time interval on log scale from 10 sec to 10^5 sec.

a. the fraction of reactor core vaporized.

b. the fraction of fission products vaporized.

c. the fraction of fission products released.

d. the fission product inventories in each vessel.

e. the fission product release rate.

f. the sum of the fraction of fission products in each region under the condition without deposition and filtering.

2. If IPLOT equals to 1, the fission product inventories in each region are plotted as a function of time on a log-log scale.

Sample Calculation of Program "RELEASE"

The input data cards are shown in Figure 16. That is:

1st card = IPLOT

2nd card = ICOL, IROW, NDIM, EPS

3rd card to 13th card = Z, F

14th card = IM, XLAMDA, QZERO, G, FP, ATNO

15th card to 24th card = TITLE

The printed out results together with the plotted curve are shown in Figure 17 and Figure 18, respectively. (The total number of cases given by the output is twenty, but only four of them are shown here in order to save pages.)

```
          1
           1          42          2     1.E-5
0.0          0.1000D 020.1259D 020.1585D 020.1995D 020.2512D 020.3162D 020.3981 D02
0.5012D 020.6310D 020.7943D 020.1000D 030.1259D 030.1585D 030.1995D 030.2512 D03
0.3162D 030.3981D 030.5012D 030.6310D 030.7943D 030.1000D 040.1259D 040.1585 D04
0.1995D 040.2515D 040.3162D 040.3981D 040.5012D 040.6310D 040.7943D 040.1000 D05
0.1259D 050.1585D 050.1995D 050.2515D 050.3162D 050.3981D 050.5012D 050.6310 D05
0.7943D 050.1000D 060.0        0.1000D 010.9936D 000.9684D 000.9154D 000.8313 D00
0.7300D 000.6448D 000.6000D 000.5843D 000.5789D 000.5781D 000.5805D 000.5852 D00
0.5915D 000.5984D 000.6054D 000.6119D 000.6179D 000.6228D 000.6270D 000.6302 D00
0.6327D 000.6343D 000.6353D 000.6358D 000.6357D 000.6356D 000.6358D 000.6366 D00
0.6384D 000.6408D 000.6433D 000.6450D 000.6451D 000.6441D 000.6422D 000.6403 D00
0.6393D 000.6394D 000.6405D 000.6423D 00
           4   6.38E-9    1.20E+7          1.         70.        147.
                         PM-147  CASE  4
                         PM-147  CASE  7
                         PM-147  CASE  9
                         PM-147  CASE  8
                         PM-147  CASE  5
                         PM-147  CASE 14
                         PM-147  CASE  6
                         PM-147  CASE 13
                         PM-147  CASE 10
                         PM-147  CASE 15
                         PM-147  CASE  1
                         PM-147  CASE 12
                         PM-147  CASE  3
                         PM-147  CASE 11
                         PM-147  CASE  2
                         PM-147  CASE 16
                         PM-147  CASE 17
                         PM-147  CASE 18
                         PM-147  CASE 19
                         PM-147  CASE 20
/*
//
```

Fig. 16. The Input Data Cards of Program "Release"

PM-147 CASE 9

CASE 9

DECAY CONSTANT, 1/SEC 0.838D-08
CORE INVENTORY AT ZERO TIME, CURIES 0.120D 08
RATIO OF FP VAPOR PRESSURE TO UO2 VAPOR PRESSURE 0.700D 02
FRACTION OF FP WHICH IS GASEOUS 0.100D 01
CLASS OF FISSION PRODUCT 4

TIME (SEC)	FRACTION OF CORE VAPORIZED	FRACTION OF FP VAPORIZED	FRACTION OF FP RELEASED	INVENTORIES (CURIES) IN CORE	IN PV	IN (2)	IN (3)	IN (4)	RELEASE (CURIES)	(CI/SEC)	
0.0	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.10D 02	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.13D 02	0.19D-07	0.13D-05	0.0	0.12D 08	0.13D 02	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.16D 02	0.97D-07	0.68D-05	0.0	0.12D 08	0.76D 02	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.20D 02	0.28D-06	0.20D-04	0.0	0.12D 08	0.23D 03	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.25D 02	0.65D-06	0.46D-04	0.0	0.12D 08	0.53D 03	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.32D 02	0.13D-05	0.93D-04	0.0	0.12D 08	0.11D 04	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.40D 02	0.25D-05	0.18D-03	0.0	0.12D 08	0.21D 04	0.61D 00	0.0	0.0	0.0	0.0	0.10D 01
0.50D 02	0.46D-05	0.32D-03	0.0	0.12D 08	0.38D 04	0.33D 01	0.0	0.0	0.0	0.0	0.10D 01
0.63D 02	0.78D-05	0.55D-03	0.0	0.12D 08	0.65D 04	0.97D 01	0.0	0.0	0.0	0.0	0.10D 01
0.79D 02	0.11D-04	0.80D-03	0.0	0.12D 08	0.96D 04	0.23D 02	0.0	0.0	0.0	0.0	0.10D 01
0.10D 03	0.16D-04	0.11D-02	0.0	0.12D 08	0.13D 05	0.46D 02	0.0	0.0	0.0	0.0	0.10D 01
0.13D 03	0.21D-04	0.15D-02	0.0	0.12D 08	0.17D 05	0.85D 02	0.0	0.0	0.0	0.0	0.10D 01
0.16D 03	0.27D-04	0.19D-02	0.0	0.12D 08	0.22D 05	0.15D 03	0.0	0.0	0.0	0.0	0.10D 01
0.20D 03	0.34D-04	0.24D-02	0.0	0.12D 08	0.28D 05	0.25D 03	0.0	0.0	0.0	0.0	0.10D 01
0.25D 03	0.43D-04	0.30D-02	0.0	0.12D 08	0.35D 05	0.41D 03	0.0	0.0	0.0	0.0	0.10D 01
0.32D 03	0.54D-04	0.38D-02	0.0	0.12D 08	0.43D 05	0.67D 03	0.0	0.0	0.0	0.0	0.10D 01
0.40D 03	0.67D-04	0.46D-02	0.0	0.12D 08	0.53D 05	0.11D 04	0.0	0.0	0.0	0.0	0.10D 01
0.50D 03	0.82D-04	0.57D-02	0.0	0.12D 08	0.64D 05	0.17D 04	0.0	0.0	0.0	0.0	0.10D 01
0.63D 03	0.99D-04	0.69D-02	0.0	0.12D 08	0.77D 05	0.26D 04	0.0	0.0	0.0	0.0	0.10D 01
0.79D 03	0.12D-03	0.84D-02	0.0	0.12D 08	0.92D 05	0.39D 04	0.0	0.0	0.0	0.0	0.10D 01
0.10D 04	0.14D-03	0.10D-01	0.0	0.12D 08	0.11D 06	0.59D 04	0.0	0.0	0.0	0.0	0.10D 01
0.13D 04	0.17D-03	0.12D-01	0.0	0.12D 08	0.13D 06	0.90D 04	0.0	0.0	0.0	0.0	0.10D 01
0.16D 04	0.21D-03	0.14D-01	0.0	0.12D 08	0.15D 06	0.13D 05	0.0	0.0	0.0	0.0	0.10D 01
0.20D 04	0.25D-03	0.17D-01	0.0	0.12D 08	0.17D 06	0.20D 05	0.0	0.0	0.0	0.0	0.10D 01
0.25D 04	0.29D-03	0.20D-01	0.0	0.12D 08	0.20D 06	0.29D 05	0.0	0.0	0.0	0.0	0.10D 01
0.32D 04	0.35D-03	0.24D-01	0.0	0.12D 08	0.22D 06	0.42D 05	0.0	0.0	0.0	0.0	0.10D 01
0.40D 04	0.41D-03	0.29D-01	0.0	0.12D 08	0.25D 06	0.60D 05	0.0	0.0	0.0	0.0	0.10D 01
0.50D 04	0.49D-03	0.34D-01	0.0	0.12D 08	0.27D 06	0.85D 05	0.0	0.0	0.0	0.0	0.10D 01
0.63D 04	0.58D-03	0.40D-01	0.0	0.12D 08	0.29D 06	0.12D 06	0.54D 01	0.0	0.0	0.0	0.10D 01
0.79D 04	0.69D-03	0.47D-01	0.0	0.11D 08	0.31D 06	0.16D 06	0.18D 02	0.0	0.0	0.0	0.10D 01
0.10D 05	0.81D-03	0.55D-01	0.0	0.11D 08	0.32D 06	0.21D 06	0.39D 02	0.0	0.0	0.0	0.10D 01
0.13D 05	0.96D-03	0.65D-01	0.71D-13	0.11D 08	0.32D 06	0.28D 06	0.75D 02	0.14D 00	0.86D-06	0.70D-08	0.10D 01
0.16D 05	0.11D-02	0.77D-01	0.24D-10	0.11D 08	0.32D 06	0.35D 06	0.13D 03	0.31D 01	0.29D-03	0.18D-06	0.10D 01
0.20D 05	0.13D-02	0.90D-01	0.15D-09	0.11D 08	0.31D 06	0.43D 06	0.22D 03	0.96D 01	0.18D-02	0.57D-06	0.10D 01

Fig. 17a. The Printed Out Results of Program "Release"

0.250 05	0.160-02	0.110 00	0.550-09	0.110 08	0.300 06	0.510 06	0.340 03	0.220 02	0.660-02	0.130-05	0.100 01
0.320 05	0.190-02	0.120 00	0.160-08	0.110 08	0.280 06	0.590 06	0.520 03	0.470 02	0.200-01	0.280-05	0.100 01
0.400 05	0.220-02	0.140 00	0.440-08	0.100 08	0.260 06	0.650 06	0.760 03	0.890 02	0.530-01	0.530-05	0.100 01
0.500 05	0.260-02	0.170 00	0.110-07	0.100 08	0.240 06	0.690 06	0.110 04	0.160 03	0.130 00	0.960-05	0.100 01
0.630 05	0.300-02	0.190 00	0.250-07	0.970 07	0.220 06	0.710 06	0.140 04	0.270 03	0.300 00	0.160-04	0.100 01
0.790 05	0.360-02	0.220 00	0.530-07	0.930 07	0.200 06	0.700 06	0.180 04	0.430 03	0.640 00	0.260-04	0.100 01
0.100 06	0.420-02	0.260 00	0.110-06	0.890 07	0.180 06	0.660 06	0.220 04	0.650 03	0.130 01	0.390-04	0.100 01

PM-147 CASE 2

CASE 2

DECAY CONSTANT, 1/SEC 0.8380-08
CORE INVENTORY AT ZERO TIME, CURIES 0.1200 08
RATIO OF FP VAPOR PRESSURE TO UO2 VAPOR PRESSURE 0.7000 02
FRACTION OF FP WHICH IS GASEOUS 0.1000 01
CLASS OF FISSION PRODUCT 4

TIME (SEC)	FRACTION OF CORE VAPORIZED	FRACTION OF FP VAPORIZED	FRACTION OF FP RELEASED	INVENTORIES (CURIES) IN CORE	IN PV	IN (2)	IN (3)	IN (4)	RELEASE (CURIES)	(CI/SEC)	
0.0	0.0	0.0	0.0	0.120 08	0.0	0.0	0.0	0.0	0.0	0.0	0.100 01
0.100 02	0.0	0.0	0.0	0.120 08	0.0	0.0	0.0	0.0	0.0	0.0	0.100 01
0.130 02	0.190-07	0.130-05	0.0	0.120 08	0.130 02	0.0	0.0	0.0	0.0	0.0	0.100 01
0.160 02	0.970-07	0.680-05	0.0	0.120 08	0.760 02	0.0	0.0	0.0	0.0	0.0	0.100 01
0.200 02	0.280-06	0.200-04	0.0	0.120 08	0.230 03	0.0	0.0	0.0	0.0	0.0	0.100 01
0.250 02	0.650-06	0.460-04	0.0	0.120 08	0.530 03	0.0	0.0	0.0	0.0	0.0	0.100 01
0.320 02	0.130-05	0.930-04	0.0	0.120 08	0.110 04	0.0	0.0	0.0	0.0	0.0	0.100 01
0.400 02	0.250-05	0.180-03	0.0	0.120 08	0.210 04	0.0	0.0	0.0	0.0	0.0	0.100 01
0.500 02	0.460-05	0.320-03	0.0	0.120 08	0.380 04	0.0	0.0	0.0	0.0	0.0	0.100 01
0.630 02	0.780-05	0.550-03	0.0	0.120 08	0.650 04	0.390 01	0.0	0.0	0.0	0.0	0.100 01
0.790 02	0.110-04	0.800-03	0.0	0.120 08	0.960 04	0.140 02	0.0	0.0	0.0	0.0	0.100 01
0.100 03	0.160-04	0.110-02	0.0	0.120 08	0.130 05	0.350 02	0.0	0.0	0.0	0.0	0.100 01
0.130 03	0.210-04	0.150-02	0.0	0.120 08	0.170 05	0.700 02	0.0	0.0	0.0	0.0	0.100 01
0.160 03	0.270-04	0.190-02	0.0	0.120 08	0.220 05	0.130 03	0.0	0.0	0.0	0.0	0.100 01
0.200 03	0.340-04	0.240-02	0.0	0.120 08	0.280 05	0.230 03	0.0	0.0	0.0	0.0	0.100 01
0.250 03	0.430-04	0.300-02	0.0	0.120 08	0.350 05	0.390 03	0.0	0.0	0.0	0.0	0.100 01
0.320 03	0.540-04	0.380-02	0.0	0.120 08	0.430 05	0.630 03	0.0	0.0	0.0	0.0	0.100 01
0.400 03	0.670-04	0.460-02	0.130-10	0.120 08	0.530 05	0.100 04	0.0	0.0	0.0	0.0	0.100 01
0.500 03	0.820-04	0.570-02	0.460-08	0.120 08	0.640 05	0.160 04	0.0	0.440 00	0.150-03	0.410-04	0.100 01
0.630 03	0.990-04	0.690-02	0.260-07	0.120 08	0.770 05	0.250 04	0.0	0.990 01	0.550-01	0.980-03	0.100 01
0.790 03	0.120-03	0.840-02	0.980-07	0.120 08	0.920 05	0.380 04	0.0	0.320 02	0.320 00	0.320-02	0.100 01
								0.770 02	0.120 01	0.770-02	0.100 01

Fig. 17b.

0.10D 04	0.14D-03	0.10D-01	0.30D-06	0.12D 08	0.11D 06	0.57D 04	0.0	0.17D 03	0.36D 01	0.17D-01	0.10D 01
0.13D 04	0.17D-03	0.12D-01	0.84D-06	0.12D 08	0.13D 06	0.85D 04	0.0	0.34D 03	0.10D 02	0.34D-01	0.10D 01
0.16D 04	0.21D-03	0.14D-01	0.22D-05	0.12D 08	0.15D 06	0.13D 05	0.0	0.66D 03	0.26D 02	0.66D-01	0.10D 01
0.20D 04	0.25D-03	0.17D-01	0.54D-05	0.12D 08	0.17D 06	0.18D 05	0.0	0.12D 04	0.64D 02	0.12D 00	0.10D 01
0.25D 04	0.29D-03	0.20D-01	0.13D-04	0.12D 08	0.20D 06	0.26D 05	0.0	0.23D 04	0.15D 03	0.23D 00	0.10D 01
0.32D 04	0.35D-03	0.24D-01	0.30D-04	0.12D 08	0.22D 06	0.37D 05	0.0	0.41D 04	0.36D 03	0.41D 00	0.10D 01
0.40D 04	0.41D-03	0.29D-01	0.68D-04	0.12D 08	0.25D 06	0.52D 05	0.0	0.72D 04	0.82D 03	0.72D 00	0.10D 01
0.50D 04	0.49D-03	0.34D-01	0.15D-03	0.12D 08	0.27D 06	0.71D 05	0.0	0.12D 05	0.18D 04	0.12D 01	0.10D 01
0.63D 04	0.58D-03	0.40D-01	0.33D-03	0.12D 08	0.29D 06	0.94D 05	0.0	0.21D 05	0.39D 04	0.21D 01	0.10D 01
0.79D 04	0.69D-03	0.47D-01	0.69D-03	0.11D 08	0.31D 06	0.12D 06	0.0	0.33D 05	0.83D 04	0.33D 01	0.10D 01
0.10D 05	0.81D-03	0.55D-01	0.14D-02	0.11D 08	0.32D 06	0.15D 06	0.0	0.51D 05	0.17D 05	0.51D 01	0.10D 01
0.13D 05	0.96D-03	0.65D-01	0.28D-02	0.11D 08	0.32D 06	0.18D 06	0.0	0.75D 05	0.33D 05	0.74D 01	0.10D 01
0.16D 05	0.11D-02	0.77D-01	0.52D-02	0.11D 08	0.32D 06	0.20D 06	0.0	0.10D 06	0.62D 05	0.10D 02	0.10D 01
0.20D 05	0.13D-02	0.90D-01	0.93D-02	0.11D 08	0.30D 06	0.22D 06	0.0	0.13D 06	0.11D 06	0.13D 02	0.10D 01
0.25D 05	0.16D-02	0.11D 00	0.16D-01	0.11D 08	0.28D 06	0.23D 06	0.0	0.16D 06	0.19D 06	0.16D 02	0.10D 01
0.32D 05	0.19D-02	0.12D 00	0.25D-01	0.11D 08	0.26D 06	0.22D 06	0.0	0.18D 06	0.30D 06	0.18D 02	0.10D 01
0.40D 05	0.22D-02	0.14D 00	0.37D-01	0.10D 08	0.23D 06	0.21D 06	0.0	0.18D 06	0.45D 06	0.18D 02	0.10D 01
0.50D 05	0.26D-02	0.17D 00	0.52D-01	0.10D 08	0.21D 06	0.19D 06	0.0	0.17D 06	0.63D 06	0.17D 02	0.10D 01
0.63D 05	0.30D-02	0.19D 00	0.70D-01	0.97D 07	0.19D 06	0.16D 06	0.0	0.15D 06	0.84D 06	0.15D 02	0.10D 01
0.79D 05	0.36D-02	0.22D 00	0.89D-01	0.93D 07	0.17D 06	0.14D 06	0.0	0.13D 06	0.11D 07	0.13D 02	0.10D 01
0.10D 06	0.42D-02	0.26D 00	0.11D 00	0.89D 07	0.15D 06	0.13D 06	0.0	0.11D 06	0.13D 07	0.11D 02	0.10D 01

PP-147 CASE 17

CASE 17

DECAY CONSTANT, 1/SEC	0.838D-08
CORE INVENTORY AT ZERO TIME, CURIES	0.120D 08
RATIO OF FP VAPOR PRESSURE TO UO2 VAPOR PRESSURE	0.700D 02
FRACTION OF FP WHICH IS GASEOUS	0.100D 01
CLASS OF FISSION PRODUCT	4

TIME (SEC)	FRACTION OF CORE VAPORIZED	FRACTION OF FP VAPORIZED	FRACTION OF FP RELEASED	INVENTORIES (CURIES) IN CORE	IN PV	IN (2)	IN (3)	IN (4)	RELEASE (CURIES)	(CI/SEC)	
0.0	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.10D 02	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.13D 02	0.19D-07	0.13D-05	0.0	0.12D 08	0.16D 02	0.18D-01	0.0	0.0	0.0	0.0	0.10D 01
0.16D 02	0.97D-07	0.68D-05	0.0	0.12D 08	0.81D 02	0.18D-01	0.0	0.0	0.0	0.0	0.10D 01
0.20D 02	0.28D-06	0.20D-04	0.0	0.12D 08	0.23D 03	0.78D-01	0.0	0.0	0.0	0.0	0.10D 01
0.25D 02	0.65D-06	0.46D-04	0.0	0.12D 08	0.54D 03	0.27D 00	0.0	0.0	0.0	0.0	0.10D 01
0.32D 02	0.13D-05	0.93D-04	0.0	0.12D 08	0.11D 04	0.80D 00	0.0	0.0	0.0	0.0	0.10D 01
0.40D 02	0.25D-05	0.18D-03	0.0	0.12D 08	0.21D 04	0.20D 01	0.0	0.0	0.0	0.0	0.10D 01
0.50D 02	0.46D-05	0.32D-03	0.0	0.12D 08	0.37D 04	0.49D 01	0.0	0.0	0.0	0.0	0.10D 01

Fig. 17c.

0.63D 02	0.78D-05	0.55D-03	0.0	0.12D 08	0.62D C4	0.11D 02	0.0	0.0	0.0	0.0	0.10D 01
0.79D 02	0.11D-04	0.80D-03	0.0	0.12D 08	0.89D C4	0.23D 02	0.0	0.0	0.0	0.0	0.10D 01
0.10D 03	0.16D-04	0.11D-02	0.0	0.12C 08	0.12D C5	0.43D 02	0.0	0.0	0.0	0.0	0.10D 01
0.13D 03	0.21D-04	0.15D-02	0.12D-11	0.12C 08	0.15C C5	0.76D 02	0.0	0.40D-01	0.14D-04	0.40D-05	0.10D 01
0.16D 03	0.27D-04	0.19D-02	0.47D-10	0.12D 08	0.18D 05	0.13D 03	0.0	0.32D 00	0.56D-03	0.32D-04	0.10D 01
0.20D 03	0.34D-04	0.24D-02	0.25D-09	0.12D 08	0.22D C5	0.20D 03	0.0	0.92D 00	0.30D-02	0.92D-04	0.10D 01
0.25D 03	0.43D-04	0.30D-02	0.89D-C9	0.12D 08	0.25D C5	0.30D 03	0.0	0.21D 01	0.11D-01	0.21D-03	0.10D 01
0.32D 03	0.54D-04	0.38D-02	0.26D-08	0.12C 08	0.28D 05	0.43D 03	0.0	0.43D 01	0.31D-01	0.43D-03	0.10D 01
0.40D 03	0.67D-04	0.46D-02	0.68D-08	0.12D C8	0.31D 05	0.61D 03	0.0	0.82D 01	0.82D-01	0.82D-03	0.10D 01
0.50D 03	0.82D-04	0.57D-02	0.17D-07	0.12D 08	0.33D C5	0.82D 03	0.0	0.15D 02	0.20D 00	0.15D-02	0.10D 01
0.63D 03	0.99D-04	0.69D-02	0.38D-07	0.12C 08	0.33D C5	0.10D 04	0.0	0.25D 02	0.46D 00	0.25D-02	0.10D 01
0.79D 03	0.12D-03	0.84D-02	0.83D-07	0.12D 08	0.33D C5	0.13D 04	0.0	0.41D 02	0.10D 01	0.41D-02	0.10D 01
0.10D 04	0.14D-03	0.10D-01	0.17D-06	0.12D 08	0.32D 05	0.15D 04	0.0	0.63D 02	0.21D 01	0.63D-02	0.10D 01
0.13D 04	0.17D-03	0.12D-01	0.34D-06	0.12D 08	0.30D C5	0.16D 04	0.0	0.92D 02	0.41D 01	0.92D-02	0.10D 01
0.16D 04	0.21D-03	0.14D-01	0.63D-06	0.12C 08	0.28D C5	0.17D 04	0.0	0.12D 03	0.76D 01	0.12D-01	0.10D 01
0.20D 04	0.25D-03	0.17D-01	C.11D-05	0.12C 08	0.26D C5	0.17D 04	0.0	0.16D 03	0.13D 02	0.16D-01	0.10D 01
0.25D 04	0.29D-03	0.20D-01	0.19D-05	0.12D 08	0.24D C5	0.16D 04	0.0	0.19D 03	0.23D 02	0.19D-01	0.10D 01
0.32D 04	0.35D-03	0.24D-01	0.30D-05	0.12C 08	0.22D C5	0.15D 04	0.0	0.21D 03	0.36D 02	0.21D-01	0.10D 01
0.40D 04	0.41D-03	0.29D-01	0.44D-05	0.12D 08	0.21D 05	0.14D 04	0.0	0.22D 03	0.53D 02	0.22D-01	0.10D 01
0.50D 04	0.49D-03	0.34D-01	0.63D-05	0.12C 08	0.19D C5	0.12D 04	0.0	0.21D 03	0.76D 02	0.21D-01	0.10D 01
0.63D 04	0.58D-03	0.40D-01	0.85D-05	0.12D 08	0.18D 05	0.11D 04	0.0	0.20D 03	0.10D 03	0.20D-01	0.10D 01
0.79D 04	0.69D-03	0.47D-01	0.11D-04	0.11D 08	0.16D C5	0.10D 04	0.0	0.19D 03	0.13D 03	0.19D-01	0.10D 01
0.10D 05	0.81D-03	0.55D-01	0.14D-04	0.11D 08	0.15D 05	0.96D 03	0.0	0.17D 03	0.17D 03	0.17D-01	0.10D 01
0.13D 05	0.96D-03	0.65D-01	0.18D-04	0.11D 08	0.14D 05	0.88D 03	0.0	0.15D 03	0.21D 03	0.15D-01	0.10D 01
0.16D 05	0.11D-02	0.77D-01	0.22D-04	0.11D 08	0.13D 05	0.81D 03	0.0	0.14D 03	0.26D 03	0.14D-01	0.10D 01
0.20D 05	0.13D-02	0.90D-01	0.26D-04	0.11D 08	0.12D C5	0.75D 03	0.0	0.13D 03	0.31D 03	0.13D-01	0.10D 01
0.25D 05	0.16D-02	0.11D 00	0.31D-04	0.11C 08	0.11D 05	0.68D 03	0.0	0.11D 03	0.38D 03	0.11D-01	0.10D 01
0.32D 05	0.19D-02	0.12D 00	0.37D-04	0.11D 08	0.10D 05	0.62D 03	0.0	0.10D 03	0.45D 03	0.10D-01	0.10D 01
0.40D 05	0.22D-02	0.14D 00	0.44D-04	0.10D 08	0.91D 04	0.57D 03	0.0	0.94D 02	0.53D 03	0.94D-02	0.10D 01
0.50D 05	0.26D-02	0.17D 00	0.52D-04	0.10C 08	0.83D 04	0.52D 03	0.0	0.85D 02	0.62D 03	0.85D-02	0.10D 01
0.63D 05	0.30D-02	0.19D 00	0.60D-04	0.97D C7	0.75D 04	0.47D 03	0.0	0.77D 02	0.72D 03	0.77D-02	0.10D 01
0.79D 05	0.36D-02	0.22D 00	0.70D-04	0.93D 07	0.67D C4	0.42D 03	0.0	0.69D 02	0.84D 03	0.69D-02	0.10D 01
0.10D 06	0.42D-02	0.26D 00	0.81D-04	0.89D C7	0.60D 04	0.38D 03	0.0	0.62D 02	0.98D 03	0.62D-02	0.10D 01

Fig. 17d.

PM-147 CASE 20

CASE 20

DECAY CONSTANT, 1/SEC 0.838D-08
CORE INVENTORY AT ZERO TIME, CURIES 0.120D 08
RATIO OF FP VAPOR PRESSURE TO UO2 VAPOR PRESSURE 0.700D 02,
FRACTION OF FP WHICH IS GASEOUS 0.100D 01
CLASS OF FISSION PRODUCT 4

TIME	FRACTION	FRACTION	FRACTION	INVENTORIES (CURIES)					RELEASE		
	OF CORE	OF FP	OF FP								
(SEC)	VAPORIZED	VAPORIZED	RELEASED	IN CORE	IN PV	IN (2)	IN (3)	IN (4)	(CURIES)	(CI/SEC)	
0.0	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.10D 02	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.13D 02	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.16D 02	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.20D 02	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.25D 02	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.32D 02	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.40D 02	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.50D 02	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.63D 02	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.79D 02	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.10D 03	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.13D 03	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.16D 03	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.20D 03	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.25D 03	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.32D 03	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.40D 03	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.50D 03	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.63D 03	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.79D 03	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.10D 04	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.13D 04	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.16D 04	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.20D 04	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.25D 04	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.32D 04	0.0	0.0	0.0	0.12D 08	0.0	0.0	0.0	0.0	0.0	0.0	0.10D 01
0.40D 04	0.28D-04	0.19D-02	0.20D-08	0.12D 08	0.23D 05	0.40D 03	0.0	0.34D 01	0.24D-01	0.33D-03	0.10D 01
0.50D 04	0.10D-03	0.72D-02	0.72D-06	0.12D 08	0.79D 05	0.54D 04	0.0	0.24D 03	0.86D 01	0.24D-01	0.10D 01
0.63D 04	0.19D-03	0.13D-01	0.92D-05	0.12D 08	0.13D 06	0.17D 05	0.0	0.15D 04	0.11D 03	0.15D 00	0.10D 01
0.79D 04	0.30D-03	0.21D-01	0.53D-04	0.12D 08	0.18D 06	0.38D 05	0.0	0.54D 04	0.64D 03	0.54D 00	0.10D 01
0.10D 05	0.43D-03	0.29D-01	0.21D-03	0.12D 08	0.23D 06	0.66D 05	0.0	0.14D 05	0.25D 04	0.14D 01	0.10D 01

Fig. 17e.

0.13D 05	0.57D-03	0.39D-01	0.67D-03	0.12D 08	0.26D 06	0.10D 06	0.0	0.29D 05	0.80D 04	0.29D 01	0.10D 01
0.16D 05	0.75D-03	0.51D-01	0.18D-02	0.11D 08	0.28D 06	0.14D 06	0.0	0.53D 05	0.21D 05	0.53D 01	0.10D 01
0.20D 05	0.96D-03	0.65D-01	0.41D-02	0.11D 08	0.28D 06	0.17D 06	0.0	0.84D 05	0.50D 05	0.84D 01	0.10D 01
0.25D 05	0.12D-02	0.80D-01	0.85D-02	0.11D 08	0.27D 06	0.20D 06	0.0	0.12D 06	0.10D 06	0.12D 02	0.10D 01
0.32D 05	0.15D-02	0.98D-01	0.16D-01	0.11D 08	0.26D 06	0.21D 06	0.0	0.15D 06	0.19D 06	0.15D 02	0.10D 01
0.40D 05	0.18D-02	0.12D 00	0.27D-01	0.11D 08	0.24D 06	0.20D 06	0.0	0.16D 06	0.32D 06	0.16D 02	0.10D 01
0.50D 05	0.22D-02	0.14D 00	0.41D-01	0.10D 08	0.21D 06	0.19D 06	0.0	0.17D 06	0.49D 06	0.17D 02	0.10D 01
0.63D 05	0.26D-02	0.17D 00	0.58D-01	0.10D 08	0.19D 06	0.17D 06	0.0	0.15D 06	0.70D 06	0.15D 02	0.10D 01
0.79D 05	0.32D-02	0.20D 00	0.78D-01	0.96D 07	0.17D 06	0.15D 06	0.0	0.14D 06	0.93D 06	0.14D 02	0.10D 01
0.10D 06	0.38D-02	0.24D 00	0.99D-01	0.92D 07	0.15D 06	0.13D 06	0.0	0.12D 06	0.12D 07	0.12D 02	0.10D 01

Fig. 17f.

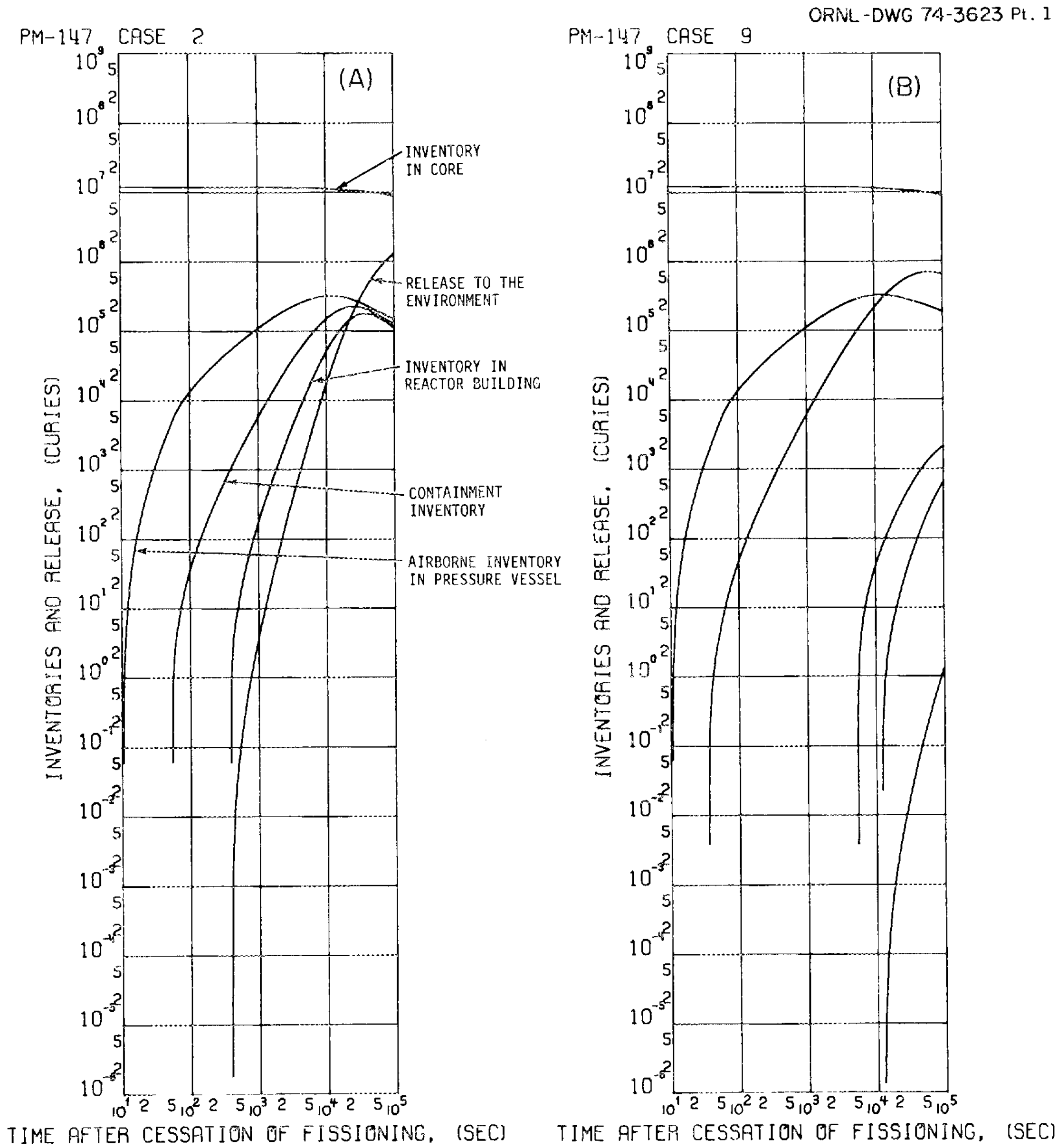

Fig. 18. The Plotted Curves of Program "Release"

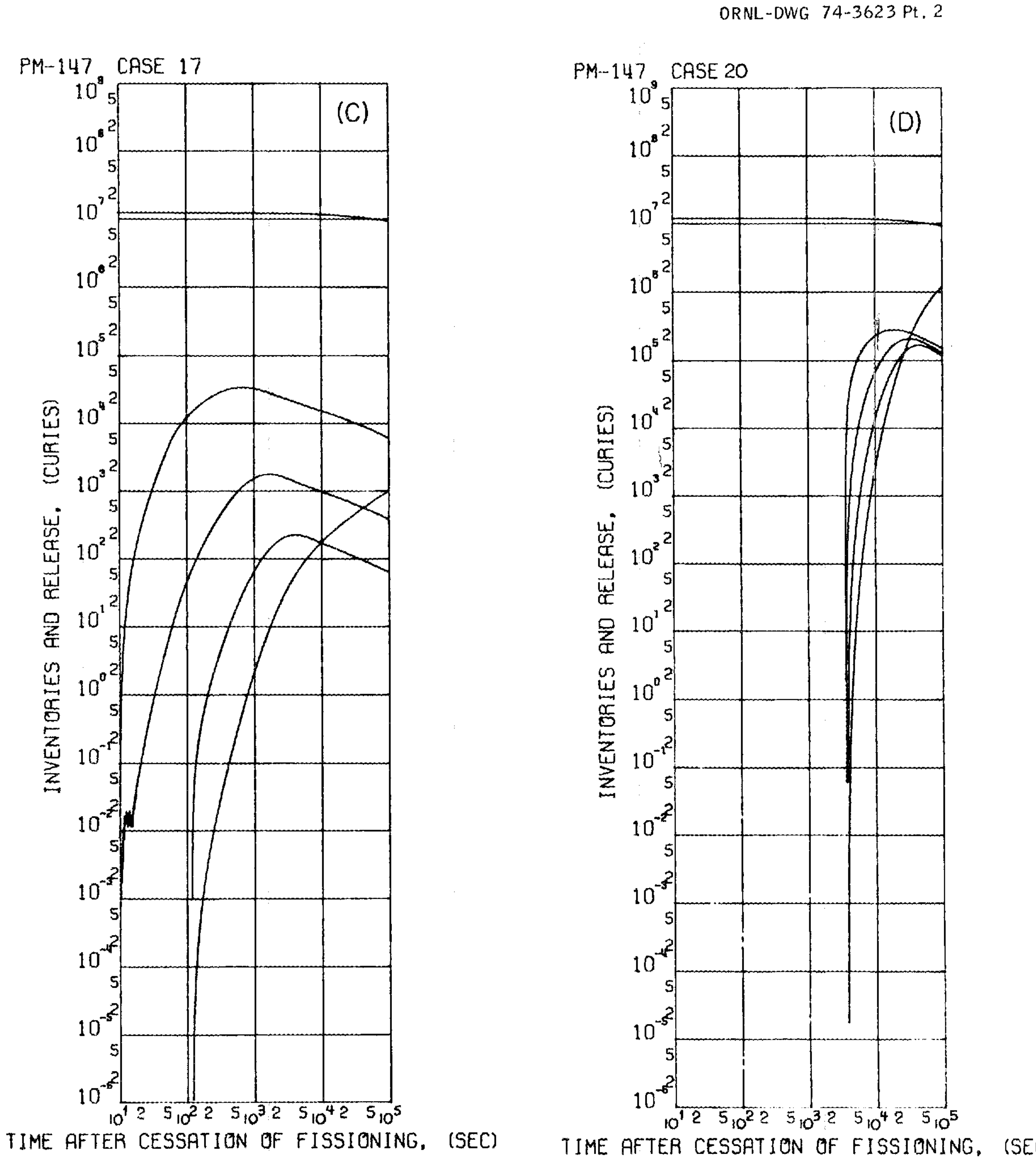

Fig. 19. The Input Cards of Program "Feed"

II. PROGRAM "FEED"

A. Input

1. List = ICOL, IROW, NDIM, EPS, ISET

   Format = (3I10, E10.2, I10)

   ICOL = 1

   IROW = number of times at which the F value (will be explained later) is available.

   NDIM = number of points used to interpolate the F value at a given time. (= 2 means linear interpolation).

   EPS = an input constant which is used as the upper bound for the absolute error.

   ISET = this value determines the total number of runs. In this code ISET must be less than 20. By our calculation, if $H = 10^{-2}$, ISET = 7 is enough to get the convergent result; for $H = 10^{-4}$, ISET = 4 is enough.

2. List = IM, XLAMDA, QZERO, FP

   Format = (I10, 3E10.2)

   IM = The group number of the specific fission product

   = 1 for As, Se, Br, Kr, Rb, Cd, I, Xe, Cs

   = 2 for Ge, Sr, Pd, Sn

   = 3 for Ag, In

   = 4 for Sb, Ba

   = 5 for La, Nd, Pm

   = 6 for Ge, Pr, Te

   = 7 for Rh, Sm

   = 8 for Y, Nb

= 9 for Zr, Ru

= 10 for Mo, Tc

XLAMDA = decay constant of the fission product, sec^{-1}

QZERO = can be set to arbitrary value.

FP = ratio of fission product vapor pressure to UO_2 vapor pressure. In our classification, the FP values for the ten groups are as follows:

group 1	1.0×10^6
group 2	8.0×10^2
group 3	1.0×10^4
group 4	1.5×10^5
group 5	70.0
group 6	8.0
group 7	1.0
group 8	0.25
group 9	3.0×10^{-2}
group 10	7.0×10^{-3}

3. List = Z

Format = (8E10,4)

Z = values of times at which the F value is available (with dimensions equal to IROW).

4. List = F

Format = (8Z10.4)

F = the fraction of total decay heat attributable to all the fission products in one classification at the corresponding time in Z.

The IM, XLAMDA, QZERO, FP, Z, F input data cards of fission product group one is followed by that of fission product group two and then followed by that of fission product group three and so on.

The most important parameter which is subjected to change in this code is the assumed fraction of decay heat available for the vaporization of UO_2 and fission products (denoted by H in the code). The other two parameters which are subjected to change are the total mass of UO_2 (denoted by EMU) and the reactor operation level (denoted by PWR), but both are not as important as the H value.

B. Output

For each run the fraction of fission products vaporized as a function of time is printed out for each of the ten fission product groups. Then the correction factor is printed out also as a function of time. All of these are printed out at equal time intervals (log scale) between 10 sec and 10^6 sec.

The notations on the output are explained as follows:

INDI = This number indicates the number of runs. For example, on the second run INDI = 2 is printed at the top of each page.

IM = The fission product group number.

MULTIPLIER = the correction factor.

C. Sample Calculation

The input data cards are shown in Figure 19. That is:

1st card = ICOL, IROW, NDIM, EPS, ISET

2nd card = IM, XLAMDA, QZERO, FP

3rd card to 7th card = Z of fission product group one

8th card to 12th card = F of fission product group one

The same pattern of input cards repeated for each of the ten fission product groups and the output is shown in Table 12. In order to save space only part of the 4th run is shown here.

A list of the computer programs "RELEASE" and "FEED" follows.

```
ICOL =            1
IROW =           34
NDIM =            2
EPS =   0.10E-03
ISET =           10

IM =            1
XLAMDA =   0.10E-06
QZERO =   0.10E 01
FP =   0.10E 07

Z

.4766E 020.6000E 020.7554E 020.9509E 020.1197E 030.1507E 030.1897E 030.2389E 03

.3007E 030.3786E 030.4766E 030.6000E 030.7554E 030.9509E 030.1197E 040.1507E 04

.1897E 040.2389E 040.3007E 040.3786E 040.4766E 040.6000E 040.7554E 040.9509E 04

.1197E 050.1507E 050.1897E 050.2389E 050.3007E 050.3786E 050.4766E 050.6000E 05

.7554E 050.9509E 05

F

.3806E 000.3756E 000.3698E 000.3633E 000.3560E 000.3481E 000.3397E 000.3311E 00

.3226E 000.3145E 000.3073E 000.3010E 000.2957E 000.2916E 000.2884E 000.2862E 00

.2848E 000.2840E 000.2837E 000.2833E 000.2823E 000.2800E 000.2760E 000.2706E 00

.2644E 000.2585E 000.2541E 000.2511E 000.2489E 000.2462E 000.2418E 000.2351E 00

.2258E 000.2142E 00
```

```
IM =            2
XLAMDA =    0.10E-06
QZERO =    0.10E 01
FP =    0.80E 03

Z

.4766E 020.6000E 020.7554E 020.9509E 020.1197E 030.1507E 030.1897E 030.2389E 03
.3007E 030.3786E 030.4766E 030.6000E 030.7554E 030.9509E 030.1197E 040.1507E 04
.1897E 040.2389E 040.3007E 040.3786E 040.4766E 040.6000E 040.7554E 040.9509E 04
.1197E 050.1507E 050.1897E 050.2389E 050.3007E 050.3786E 050.4766E 050.6000E 05
.7554E 050.9509E 05

F

.5856E-010.5897E-010.5943E-010.5997E-010.6059E-010.6128E-010.6206E-010.6293E-01
.6390E-010.6498E-010.6619E-010.6755E-010.6909E-010.7082E-010.7275E-010.7485E-01
.7710E-010.7944E-010.8175E-010.8392E-010.8580E-010.8724E-010.8811E-010.8821E-01
.8736E-010.8534E-010.8209E-010.7781E-010.7288E-010.6777E-010.6281E-010.5819E-01
.5397E-010.5031E-01
```

```
IM =            3
XLAMDA =    0.10E-06
QZERO =    0.10E 01
FP =    0.10E 05

Z

.4766E 020.6000E 020.7554E 020.9509E 020.1197E 030.1507E 030.1897E 030.2389E 03

.3007E 030.3786E 030.4766E 030.6000E 030.7554E 030.9509E 030.1197E 040.1507E 04

.1897E 040.2389E 040.3007E 040.3786E 040.4766E 040.6000E 040.7554E 040.9509E 04

.1197E 050.1507E 050.1897E 050.2389E 050.3007E 050.3786E 050.4766E 050.6000E 05

.7554E 050.9509E 05

F

.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

.0       0.0
```

IM = 4
XLAMDA = 0.10E-06
QZERO = 0.10E 01
FP = 0.15E 06

Z

.4766E 020.6000E 020.7554E 020.9509E 020.1197E 030.1507E 030.1897E 030.2389E 03

.3007E 030.3786E 030.4766E 030.6000E 030.7554E 030.9509E 030.1197E 040.1507E 04

.1897E 040.2389E 040.3007E 040.3786E 040.4766E 040.6000E 040.7554E 040.9509E 04

.1197E 050.1507E 050.1897E 050.2389E 050.3007E 050.3786E 050.4766E 050.6000E 05

.7554E 050.9509E 05

F

.6471E-010.6524E-010.6584E-010.6651E-010.6724E-010.6803E-010.6883E-010.6959E-01

.7026E-010.7076E-010.7101E-010.7093E-010.7044E-010.6949E-010.6802E-010.6601E-01

.6346E-010.6037E-010.5683E-010.5298E-010.4902E-010.4516E-010.4160E-010.3845E-01

.3580E-010.3375E-010.3240E-010.3183E-010.3209E-010.3308E-010.3463E-010.3655E-01

.3868E-010.4090E-01

IM = 5
XLAMDA = 0.10E-06
QZERO = 0.10E 01
FP = 0.70E 02

Z

```
.4766E 020.6000E 020.7554E 020.9509E 020.1197E 030.1507E 030.1897E 030.2389E 03

.3007E 030.3786E 030.4766E 030.6000E 030.7554E 030.9509E 030.1197E 040.1507E 04
.1897E 040.2389E 040.3007E 040.3786E 040.4766E 040.6000E 040.7554E 040.9509E 04

.1197E 050.1507E 050.1897E 050.2389E 050.3007E 050.3786E 050.4766E 050.6000E 05

.7554E 050.9509E 05

    F

.1454E 000.1467E 000.1483E 000.1502E 000.1523E 000.1546E 000.1571E 000.1598E 00

.1626E 000.1654E 000.1681E 000.1705E 000.1727E 000.1745E 000.1760E 000.1769E 00

.1774E 000.1773E 000.1765E 000.1751E 000.1730E 000.1701E 000.1668E 000.1631E 00

.1596E 000.1566E 000.1547E 000.1546E 000.1567E 000.1609E 000.1674E 000.1757E 00

.1857E 000.1969E 00

    IM =           6
    XLAMDA =    0.10E-06
    QZERO =   0.10E 01
    FP =   0.80E 01

    Z

.4766E 020.6000E 020.7554E 020.9509E 020.1197E 030.1507E 030.1897E 030.2389E 03

.3007E 030.3786E 030.4766E 030.6000E 030.7554E 030.9509E 030.1197E 040.1507E 04

.1897E 040.2389E 040.3007E 040.3786E 040.4766E 040.6000E 040.7554E 040.9509E 04

.1197E 050.1507E 050.1897E 050.2389E 050.3007E 050.3786E 050.4766E 050.6000E 05

.7554E 050.9509E 05
```

```
    F

.1404E 000.1414E 000.1425E 000.1437E 000.1449E 000.1462E 000.1476E 000.1488E 00

.1499E 000.1508E 000.1515E 000.1520E 000.1525E 000.1528E 000.1531E 000.1531E 00

.1527E 000.1516E 000.1496E 000.1467E 000.1432E 000.1398E 000.1370E 000.1355E 00

.1355E 000.1369E 000.1394E 000.1428E 000.1468E 000.1512E 000.1561E 000.1612E 00

.1664E 000.1716E 00

    IM =           7
    XLAMDA =    0.10E-06
    QZERO =   0.10E 01
    FP =   0.10E 01

    Z

.4766E 020.6000E 020.7554E 020.9509E 020.1197E 030.1507E 030.1897E 030.2389E 03

.3007E 030.3786E 030.4766E 030.6000E 030.7554E 030.9509E 030.1197E 040.1507E 04

.1897E 040.2389E 040.3007E 040.3786E 040.4766E 040.6000E 040.7554E 040.9509E 04

.1197E 050.1507E 050.1897E 050.2389E 050.3007E 050.3786E 050.4766E 050.6000E 05

.7554E 050.9509E 05

    F

.2613E-020.2638E-020.2668E-020.2702E-020.2741E-020.2786E-020.2835E-020.2889E-02

.2946E-020.3007E-020.3069E-020.3134E-020.3202E-020.3274E-020.3353E-020.3440E 00

.3540E-020.3656E-020.3790E-020.3945E-020.4128E-020.4340E-020.4586E-020.4863E-02
```

.5166E-020.5482E-020.5800E-020.6116E-020.6433E-020.6762E-020.7109E-020.7468E-02

.7829E-020.8178E-02

IM = 8
XLAMDA = 0.10E-06
QZERO = 0.10E 01
FP = 0.25E 00

Z

.4766E 020.6000E 020.7554E 020.9509E 020.1197E 030.1507E 030.1897E 030.2389E 03

.3007E 030.3786E 030.4766E 030.6000E 030.7554E 030.9509E 030.1197E 040.1507E 04

.1897E 040.2389E 040.3007E 040.3786E 040.4766E 040.6000E 040.7554E 040.9509E 04

.1197E 050.1507E 050.1897E 050.2389E 050.3007E 050.3786E 050.4766E 050.6000E 05

.7554E 050.9509E 05

F

.9174E-010.9273E-010.9389E-010.9526E-010.9684E-010.9865E-010.1007E 000.1030E 00

.1056E 000.1083E 000.1114E 000.1147E 000.1183E 000.1223E 000.1268E 000.1319E 00

.1377E 000.1442E 000.1514E 000.1592E 000.1675E 000.1760E 000.1848E 000.1932E 00

.2007E 000.2063E 000.2091E 000.2086E 000.2049E 000.1986E 000.1910E 000.1829E 00

.1755E 000.1693E 00

```
.IM =            9
 XLAMDA =   0.10E-06
 QZERO =   0.10E 01
 FP =   0.30E-01

 Z

.4766E 020.6000E 020.7554E 020.9509E 020.1197E 030.1507E 030.1897E 030.2389E 03

.3007E 030.3786E 030.4766E 030.6000E 030.7554E 030.9509E 030.1197E 040.1507E 04

.1897E 040.2389E 040.3007E 040.3786E 040.4766E 040.6000E 040.7554E 040.9509E 04

.1197E 050.1507E 050.1897E 050.2389E 050.3007E 050.3786E 050.4766E 050.6000E 05

.7554E 050.9509E 05

 F

.3811E-010.3852E-010.3900E-010.3956E-010.4021E-010.4096E-010.4180E-010.4274E-01

.4378E-010.4492E-010.4615E-010.4748E-010.4894E-010.5056E-010.5238E-010.5442E-01

.5674E-010.5934E-010.6222E-010.6536E-010.6875E-010.7238E-010.7624E-010.8029E-01

.8440E-010.8840E-010.9206E-010.9531E-010.9820E-010.1009E 000.1034E 000.1059E 00

.1081E 000.1101E 00
```

```
     IM =          10
     XLAMDA =   0.10E-06
     QZERO =   0.10E 01
     FP =   0.70E-02

     Z

.4766E 020.6000E 020.7554E 020.9509E 020.1197E 030.1507E 030.1897E 030.2389E 03

.3007E 030.3786E 030.4766E 030.6000E 030.7554E 030.9509E 030.1197E 040.1507E 04

.1897E 040.2389E 040.3007E 040.3786E 040.4766E 040.6000E 040.7554E 040.9509E 04

.1197E 050.1507E 050.1897E 050.2389E 050.3007E 050.3786E 050.4766E 050.6000E 05

.7554E 050.9509E 05

     F

.7788E-010.7822E-010.7856E-010.7890E-010.7918E-010.7937E-010.7938E-010.7912E-01

.7846E-010.7727E-010.7539E-010.7271E-010.6913E-010.6461E-010.5921E-010.5309E-01

.4657E-010.4009E-010.3423E-010.2953E-010.2640E-010.2494E-010.2491E-010.2582E-01

.2721E-010.2876E-010.3030E-010.3177E-010.3317E-010.3453E-010.3584E-010.3702E-01

.3793E-010.3843E-01

IHC002I STOP  00000
```

TABLE 12

THE PRINTED OUTPUT OF PROGRAM "FEED"

INDI = IM = Time (Sec)	10^4 Fraction of FP Vaporized	INDI = Time	4 Multiplier
0.0	0.0	0.0	0.0
0.1000D 02	0.0	0.1000D 02	0.1000D 01
0.1259D 02	0.1118D-09	0.1259D 02	0.9936D 00
0.1585D 02	0.5706D-09	0.1585D 02	0.9684D 00
0.1995D 02	0.1652D-08	0.1995D 02	0.9154D 00
0.2512D 02	0.3812D-08	0.2512D 02	0.8313D 00
0.3162D 02	0.7798D-08	0.3162D 02	0.7301D 00
0.3981D 02	0.1482D-07	0.3981D 02	0.6448D 00
0.5012D 02	0.2684D-07	0.5012D 02	0.6000D 00
0.6310D 02	0.4680D-07	0.6310D 02	0.5843D 00
0.7943D 02	0.7236D-07	0.7943D 02	0.5789D 00
0.1000D 03	0.1024D-06	0.1000D 03	0.5781D 00
0.1259D 03	0.1383D-06	0.1259D 03	0.5805D 00
0.1585D 03	0.1813D-06	0.1585D 03	0.5852D 00
0.1995D 03	0.2330D-06	0.1995D 03	0.5915D 00
0.2512D 03	0.2951D-06	0.2512D 03	0.5984D 00
0.3162D 03	0.3694D-06	0.3162D 03	0.6054D 00
0.3981D 03	0.4578D-06	0.3981D 03	0.6119D 00
0.5012D 03	0.5627D-06	0.5012D 03	0.6179D 00
0.6310D 03	0.6866D-06	0.6310D 03	0.6228D 00
0.7943D 03	0.8328D-06	0.7943D 03	0.6270D 00
0.1000D 04	0.1005D-05	0.1000D 04	0.6302D 00
0.1259D 04	0.1207D-05	0.1259D 04	0.6327D 00
0.1585D 04	0.1444D-05	0.1585D 04	0.6343D 00
0.1995D 04	0.1723D-05	0.1995D 04	0.6353D 00
0.2512D 04	0.2049D-05	0.2512D 04	0.6358D 00
0.3162D 04	0.2432D-05	0.3162D 04	0.6357D 00
0.3981D 04	0.2883D-05	0.3981D 04	0.6356D 00
0.5012D 04	0.3415D-05	0.5012D 04	0.6358D 00
0.6310D 04	0.4045D-05	0.6310D 04	0.6366D 00
0.7943D 04	0.4795D-05	0.7943D 04	0.6384D 00
0.1000D 05	0.5687D-05	0.1000D 05	0.6408D 00
0.1259D 05	0.6741D-05	0.1259D 05	0.6433D 00
0.1585D 05	0.7977D-05	0.1585D 05	0.6450D 00
0.1995D 05	0.9414D-05	0.1995D 05	0.6451D 00
0.2512D 05	0.1108D-04	0.2512D 05	0.6441D 00
0.3162D 05	0.1303D-04	0.3162D 05	0.6422D 00
0.3981D 05	0.1532D-04	0.3981D 05	0.6403D 00
0.5012D 05	0.1803D-04	0.5012D 05	0.6394D 00
0.6310D 05	0.2125D-04	0.6310D 05	0.6394D 00
0.7943D 05	0.2508D-04	0.7943D 05	0.6405D 00
0.1000D 06	0.2962D-04	0.1000D 06	0.6423D 00
(a)		(b)	

```
**FTN,L,E,M,G.
      PROGRAM RELEASE
      IMPLICIT REAL * 8(A-H,O-Z)
      DIMENSION TIME(4550),                                   FI(4550),Q(4550)
     1,P(4550),C(4550),B(4550),R(4550),FB(4550),CSAV(4550),BSAV(4550),FB
     2SAV(4550),RSAV(4550),W(4550),FU(4550),TITLE(10),RR(4550),RRSAV(455
     30),T(4550),TSAV(4550),AY(6)
     4,Z(42),F(42),WORK(42),ARG(5),VAL(5)
C CONSTANTS
C TIME AT FIRST CALCULATED VALUES, SEC
      TSTART=10.
C NUMBER OF VALUES CALCULATED PER DECADE OF TIME
C FROM T2 TO 1.E2 SEC
      XN2=1000.
C FROM 1.E2 TO 1.E3 SEC
      XN3=1500.
C FROM 1.E3 TO 1.E4 SEC
      XN4=1500.
C FROM 1.E4 TO 1.E5 SEC
      XN5=500.
C FROM 1.E5 TO 1.E6 SEC
      XN6=20.
C TIME AT LAST CALCULATED CONCENTRATION, SEC
      TSTOP=.999E5
C ACCELERATION DUE TO GRAVITY, CM/SEC**2
      GEE = 980.
C MEAN FREE PATH OF MOLECULES OF THE MEDIUM, CM
      ELL = 6.69E-6
C VISCOSITY OF THE MEDIUM, G/CM-SEC
      ETA = 1.82E-4
C CUNNINGHAM CORRECTION CONSTANTS
      AA = 0.864
```

```
C DELTA TIME PARAMETER
      U=2.
C TOTAL MASS OF UO2 CORE, G
      EMU = 1.48 E8
C REACTOR POWER, WATTS
      PWR=3.44E9
C FRACTIONAL REMOVAL EFFICIENCY OF IODINE ADSORBER ON CONTAINMENT
      EFFI=0.95
C FRACTIONAL REMOVAL EFFICIENCY OF PARTICLE FILTER ON CONTAINMENT
      EFF=.95
C  IPLOT=1  USE PLOT SUBROUTINE
      READ 81, IPLOT
   81 FORMAT (I10)
C ICOL,IROW,NDIM,EPS,Z,F ARE DESCRIBED IN SUBROUTINE DATSG WHICH IS USED
C TO INTERPOLATE THE CORRECTION FACTOR OF THE DECAY HEAT
      READ 7,ICOL,IROW,NDIM,EPS
    7 FORMAT(3I10,E10.2)
      READ 8,Z,F
    8 FORMAT(8D10.4)
C READ CLASS OF FISSION PRODUCT
C READ DECAY CONSTANT, 1/SEC
C READ INVENTORY IN FUEL AT TIME ZERO, CURIES
C READ FRACTION OF CLASS 3 FP WHICH REMAINS GASEOUS
C READ RATIO OF FISSION PRODUCT VAPOR PRESSURE TO UO2 VAPOR PRESSURE
C READ THE ATOMIC NUMBER OF THE FISSION PRODUCT
C LOOP FOR DIFFERENT FISSION PRODUCTS
  200 READ(50,58,END=17) IM,XLAMDA,QZERO,G,FP,ATNO
   58 FORMAT (I10,5E10.2)
C LOOP FOR DIFFERENT CASES
      DO 600 II=1,20
      IF(II.EQ. 1) GO TO 31
      IF(II.EQ. 2) GO TO 32
      IF(II.EQ. 3) GO TO 33
      IF(II.EQ. 4) GO TO 34
      IF(II.EQ. 5) GO TO 35
```

```
      IF(II.EQ. 6) GO TO 36
      IF(II.EQ. 7) GO TO 37
      IF(II.EQ. 8) GO TO 38
      IF(II.EQ. 9) GO TO 39
      IF(II.EQ.10) GO TO 40
      IF(II.EQ.11) GO TO 41
      IF(II.EQ.12) GO TO 42
      IF(II.EQ.13) GO TO 43
      IF(II.EQ.14) GO TO 44
      IF(II.EQ.15) GO TO 45
      IF(II.EQ.16) GO TO 46
      IF(II.EQ.17) GO TO 47
      IF(II.EQ.18) GO TO 48
      IF(II.EQ.19) GO TO 49
      IF(II.EQ.20) GO TO 50
      GO TO 600
   31 CONTINUE
C CASE  4
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III=  4
C TIME AFTER SHUTDOWN AT WHICH VAPORIZATION OF CORE BEGINS, SEC
      T1=60.
C TIME AFTER SHUTDOWN AT WHICH HEAT GENERATION FUNCTION CHANGES, SEC
      T2=10.
C NUMBER OF CONTAINMENTS,INCLUDING PRESSURE VESSEL
      IC=4
C FRACTION OF DECAY HEAT WHICH VAPORIZES UO2
      H=1.E-3
C VOLUME OF PRESSURE VESSEL, CM**3
      VP=5.E8
C VOLUME OF SECOND CONTAINMENT, CM**3
      VC=5.E9
C VOLUME OF THIRD CONTAINMENT, CM**3
      VB=5.E10
```

```
C VOLUME OF LAST CONTAINMENT, CM**3
      VT=5.E10
C FALL DISTANCE FOR PARTICLES IN PRESSURE VESSEL, CM
      HP=1.E2
C FALL DISTANCE FOR PARTICLES IN SECOND CONTAINMENT, CM
      HC=2.E2
C FALL DISTANCE FOR PARTICLES IN THIRD CONTAINMENT, CM
      HB=1.E3
C FALL DISTANCE FOR PARTICLES IN LAST CONTAINMENT, CM
      HT=6.E2
C FLOW RATES THROUGH IODINE ADSORBERS, CM**3/SEC
      FLTIC=0.
      FLTIB=0.
      FLTIT=0.
C FLOW RATES THROUGH PARTICULATE FILTERS, CM**3/SEC
      FLTRC=0.
      FLTRB=0.
      FLTRT=0.
C LEAK RATE FROM PRESSURE VESSEL, CM**3/SEC
      ELP=1.E-4*VP
C LEAK RATE FROM SECOND CONTAINMENT, CM**3/SEC
      ELC=1.E-4*VC
C LEAK RATE FROM THIRD CONTAINMENT, CM**3/SEC
      ELB=1.E-4  *VB
C LEAK RATE FROM LAST CONTAINMENT, CM**3/SEC
      ELT=1.E-4  *VT
C PARTICLE SIZE DISTRIBUTION PARAMETERS
      RHO=11.
      RMIN=9.E-6
      RMAX=1.E-3
      X=4.
      GO TO 75
   32 CONTINUE
C CASE  7
C READ TITLE
```

```
      READ 16,(TITLE(K),K=1,10)
      III=  7
      ELT=6.E-8*VT
      GO TO 75
   33 CONTINUE
C CASE  9
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III=  9
      ELB=1.E-5 *VB
      ELC=6.E-8*VC
      GO TO 75
   34 CONTINUE
C CASE  8
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III=  8
      ELT=1.E-4   *VT
      GO TO 75
   35 CONTINUE
C CASE  5
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III=  5
      ELC=1.E-4*VC
      IC=2
      VC=6.E10
      HC=1.E3
      GO TO 75
   36 CONTINUE
C CASE  14
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III= 14
```

```
      ELC=6.E-8   *VC
      GO TO 75
   37 CONTINUE
C CASE  6
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III=  6
      FLTIC=1.E-2*VC
      FLTRC=1.E-2*VC
      GO TO 75
   38 CONTINUE
C CASE  13
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III= 13
      ELC=1.E-4*VC
      GO TO 75
   39 CONTINUE
C CASE X
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
   16 FORMAT(10A8)
      III=10
      T2=10.
      T1 = 60.
      IC=3
      H=1.E-3
      VP=5.E8
      VC=6.E10
      VB=5.E10
      VT=1.E10
      HP=1.E2
      HC=1.E3
```

```
      HB=6.E2
      HT=6.E2
      FLTIC=1.E-2*VC
      FLTIB=0.
      FLTIT=0.
      FLTRC=1.E-2*VC
      FLTRB=0.
      FLTRT=0.
      ELP=1.E-4*VP
      ELC=6.E-8*VC
      ELB=6.E-8*VB
      ELT=1.E-4*VT
      RHO = 11.
  176 RMAX=1.E-3
      RMIN=9.E-6
      X = 4.
      GO TC 75
   40 CONTINUE
C CASE XV
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III=15
      IC=3
      H=1.E-4
      VP=5.E8
      VC=5.E9
      VB=5.E10
      HP=1.E2
      HC=2.E2
      HB=1.E3
      FLTIC=0.
      FLTIB=0.
      FLTRC=0.
      FLTRB=0.
      ELP=1.E-4*VP
      ELC=1.E-4*VC
```

```
      ELB=1.E-4*VB
      GO TC 75
   41 CONTINUE
C CASE I
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III= 1
      H=1.E-2
      GO TC 75
   42 CONTINUE
C CASE XII
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III=12
      H=1.E-3
      ELC=6.E-8*VC
      GO TC 75
   43 CONTINUE
C CASE III
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III= 3
      ELB=1.E-5*VB
      GO TC 75
   44 CONTINUE
C CASE XI
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III=11
      ELC=1.E-4*VC
      GO TC 75
   45 CONTINUE
C CASE II
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III= 2
```

```
      ELB=1.E-4*VB
      H=1.E-3
      GO TO 75
   46 CONTINUE
C CASE XVI
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III=16
      H=1.E-3
      HP=1.E3
      HC=2.E3
      HB=1.E4
      GO TO 75
   47 CONTINUE
C CASE XVII
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III=17
      HP=1.E2
      HC=2.E2
      HB=1.E3
      RMIN=9.E-5
      GO TO 75
   48 CONTINUE
C CASE XVIII
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III=18
      RMIN=9.E-6
      RHO=5.
      GO TO 75
   49 CONTINUE
C READ TITLE
C CASE XIX
      READ 16,(TITLE(K),K=1,10)
      III=19
```

```
      RHO=11.
      T2=600.
      T1=650.
      GO TO 75
   50 CONTINUE
C CASE XX
C READ TITLE
      READ 16,(TITLE(K),K=1,10)
      III=20
      T2=3600.
      T1=3650.
   75 CONTINUE
C SET INITIAL VALUES
      DO 110 I=1,4550
C TIME AFTER SHUTDOWN, SEC
      TIME(I) = 0.
C FRACTION OF FISSION PRODUCT VAPORIZED
      FI(I)=0.
C FRACTION OF CORE VAPORIZED
      FU(I)=0.
C INVENTORY OF ONE FISSION PRODUCT IN THE FUEL, CURIES
      Q(I)=0.
C TOTAL INVENTORY OF ONE FISSION PRODUCT AIRBORNE IN THE PRESSURE VESSEL
C ,CURIES
      P(I) = 0.
C TOTAL INVENTORY OF ONE FISSION PRODUCT AIRBORNE IN THE CONTAINMENT,
C CURIES
      C(I) = 0.
C TOTAL INVENTORY OF ONE FISSION PRODUCT AIRBORNE IN THE REACTOR
C BUILDING,CURIES
      B(I) = 0.
C TOTAL INVENTORY OF ONE FISSION PRODUCT AIRBORNE IN THE ACCESS TUNNEL,
C CURIES
      T(I)=0.
C TOTAL INVENTORY OF ONE FISSION PRODUCT AIRBORNE IN THE ENVIRONMENT,
C CURIES
      R(I) = 0.
```

```
C RELEASE RATE OF FISSION PRODUCT INTO THE ENVIRONMET, CURIES/SEC
      RR(I)=0.
C FRACTION OF FISSION PRODUCT RELEASED
      FB(I)=0.
C IN CALCULATING HALOGEN FISSION PRODUCTS  CSAV,BSAV,TSAV,RSAV,RRSAV,
C FBSAV ARE USED TO STORE THE RESULT OF THE FIRST LOOP
      CSAV(I) = 0.
      BSAV(I) = 0.
      TSAV(I)=0.
      RSAV(I) = 0.
      RRSAV(I)=0.
      FBSAV(I)=0.
C W VALUE IS USED TO CHECK THE CALCULATION , IT SHOULD BE EQUAL TO ONE.
C A LOOP TO CALCULATE W(I)
  110 W(I)=1.
C CALCULATION OF TIME INDEPENDENT PARAMETERS
      A = 3./((1./(RMIN**3))-(1./(RMAX**3)))
      S = 1./DLOG(RMAX/RMIN)
      E = 1./RMIN-1./RMAX
C RATE OF VAPORIZATION OF UC2 CORE AT TIME T1, G/SEC
      ELUT1=6.511E-5*PWR*DEXP(-.291*DLOG(T1))*H*0.7
  201 ELUT1=ELUT1*EXPF(-25.*ELUT1/EMU)
C FRACTION OF CORE VAPORIZED AT TIME T1
      FUT1=ELUT1*(T1-T2)/(2.*EMU)
C COAGULATION RATE CONSTANT
      D = 3.E-10 *RHO*A/S*4.*3.1416/3.*6.023E23/ATNO*XLAMDA/3.7E10
      CPRIME = 1.+(AA*ELL/(E*(X-2.)))*((1./RMIN**2)-(1./RMAX**2))
      VFALL = (2.*RHO*GEE*A*E*CPRIME)/(9.*ETA)
      DNP=VFALL/HP
      DNC=VFALL/HC
      DNB=VFALL/HB
      DNT=VFALL/HT
C CALCULATION OF CORRECTION TERMS, W(I)
    2 IMSAV=IM
      IM=1
      IMM=1
      GO TO 151
```

```
C T LOOP TO CALCULATE FISSICN PRODUCT INVENTORIES AND RELEAE RATES
  152 IMM=2
      IM=IMSAV
  151 IM3=0
      Q(1)=QZERO
      IF((XLAMDA*T2).GT.70.) EX2=0.
      IF((XLAMDA*T2).GT.70.) GO TO 115
      IF((XLAMDA*T2).LT.1.E-6) EX2=1.-XLAMDA*T2
      IF((XLAMDA*T2).LT.1.E-6) GO TO 115
      EX2=DEXP(-XLAMDA*T2)
  115 QT2=QZERO*EX2
      X1=-FP*DLOG(1.-FUT1)+XLAMDA*(T1-T2)
      IF(X1.GT.70.) EX1=0.
      IF(X1.GT.70.) GO TO 116
      IF(X1.LT.1.E-6) EX1=1.-X1
      IF(X1.LT.1.E-6) GO TO 116
      EX1=DEXP(-X1)
  116 QT1=QT2*EX1
 3000 I = 1
    3 I = I + 1
      XI=I-2
      IF(TIME(I-1).LT..999E2) TIME(I)=TSTART*(10.**(XI/XN2))
      IF(TIME(I-1).GE..999E2) TIME(I)=TIME(I-1)*(10.**(1./XN3))
      IF(TIME(I-1).GE..999E3) TIME(I)=TIME(I-1)*(10.**(1./XN4))
      IF(TIME(I-1).GE..999E4) TIME(I)=TIME(I-1)*(10.**(1./XN5))
      IF(TIME(I-1).GE..999E5) TIME(I)=TIME(I-1)*(10.**(1./XN6))
      TP=TIME(I)
      DT=TIME(I)-TIME(I-1)
      IF(TP.LT.T2) FU(I)=0.
      IF(TP.LT.T2) GO TO 117
      IF(TP.LE.T1) FU(I)=FUT1*((TP-T2)/(T1-T2))**2
C INTERPOLATE THE CORRECTION FACTOR OF DECAY HEAT
      CALL DATSG
     1          (TIME(I),Z,F,WORK,IROW,ICOL,ARG,VAL,NDIM)
      CALL DALI(TIME(I),ARG,VAL,Y,NDIM,EPS,IER)
      RWR=PWR*Y
      IF(TP.GT.T1)FU(I)=FUT1+             ( 9.183E-5*RWR*H/EMU)*(DEXP(.
```

```
    1709*DLOG(TP))-DEXP(.709*DLOG(T1)))
1117 IF((XLAMDA*TP).GT.70.) EXL=0.
     IF((XLAMDA*TP).GT.70.) GO TO 117
     IF((XLAMDA*TP).LT.1.E-6) EXL=1.-XLAMDA*TP
     IF((XLAMDA*TP).LT.1.E-6) GO TO 117
     EXL=DEXP(-XLAMDA*TP)
 117 IF(TP.LE.T2) Q(I)=QZERO*EXL
     IF(TP.LE.T2) GO TO 80
     X4=-FP*DLOG(1.-FU(I))+XLAMDA*TP
     IF(X4.GT.70.) EX4=0.
     IF(X4.GT.70.) GO TO 119
     IF(X4.LE.1.E-6) EX4=1.-K4
     IF(X4.LE.1.E-6) GO TO 119
     EX4=DEXP(-X4)
 119 IF(TP.GT.T2) Q(I)=QZERO*EX4
  80 IF(Q(I).GT.QZERO*EXL) Q(I)=QZERO*EXL
     IF(EXL.EQ.0.)FI(I)=1.
     IF(EXL.NE.0.)FI(I)=(QZERO*EXL-Q(I))/(QZERO*EXL)
     YP = ELP/VP
     ZP=ELP/VC
     IF(IM.EQ.4)AXP=YP+XLAMDA+DNP
     IF(IM.NE.4)AXP=YP+XLAMDA
     FMU=(1-FU(I))*EMU
     IF(TP.LE.T1) YQ=ELUT1*FP*(TP-T2-DT/2.)/(FMU*(T1-T2))
     IF(TP.LE.T2) YQ=0.
     IF(YQ.LE.0.) YQ=0.
     ELU=6.511E-5*RWR*H*(1.-(FU(I)+FU(I-1))/2.)*DEXP(-.291*DLOG(TP-DT/2
    1.))
     IF(TP.GT.T1) YQ=ELU*FP/FMU
     QR=Q(I)-(Q(I)-Q(I-1))/U
     IF(QR.LT.1.E-30) QR=0.
     IF(I.EQ.2) CR=C(I-1)
     IF(I.NE.2) CR=C(I-1)+(C(I-1)-C(I-2))/U
     IF(CR.LT.1.E-30) CR=0.
     XP=DSQRT(4*D*(YQ*QR+ZP*CR)+AXP**2)
     IF((XP*DT).GT.70.) EXP=0.
```

```
      IF((XP*DT).GT.70.) GO TO 120
      IF((XP*DT).LE.1.E-8) EXP=1.-XP*DT
      IF((XP*DT).LE.1.E-6) GO TO 120
      EXP=DEXP(-XP*DT)
  120 PE=XP/(2*D)
      PD=-AXP/(2*D)
      PX=P(I-1)-PC
      PP=PX+PE
      PM=PX-PE
  125 IF(P(I-1).LE.1.E-30) P(I-1)=0.
      P(I)=PD+PE*(PP+PM*EXP)/(PP-PM*EXP)
      IF (IM.EQ.4) GO TO 106
      IF ((AXP*DT).GT.70.) EXP=0.
      IF ((AXP*DT).GT.70.) EXPP=1.
      IF ((AXP*DT).GT.70.) EXPPP=1./AXP
      IF ((AXP*DT).GT.70.)GO TO 1104
      IF ((AXP*DT).LE.1.E-8) EXP=1.-AXP*DT
      IF ((AXP*DT).LE.1.E-8) EXPP=AXP*DT
      IF ((AXP*DT).LE.1.E-8) EXPPP=DT
      IF ((AXP*DT).LE.1.E-8) GO TO 1104
      EXP=DEXP(-AXP*DT)
      EXPP=1.-EXP
      EXPPP=EXPP/AXP
 1104 PD=((YQ*QR)+(ZP*CR))*EXPPP
      P(I)=PD+P(I-1)*EXP
  106 IF (IC.GT.2) GO TO 90
      FLTIT=FLTIC
      FLTRT=FLTRC
      VT=VC
      ELT=ELC
      ELB=ELP
      YB=ELP/VP
      ZB=ZP
      B(I)=P(I)
      GO TO 92
   90 YC=ELC/VC
      ZC=ELC/VB
```

```
      IF(IM.NE.1)AXC=YC+XLAMDA+DNC +ZP+FLTRC*EFF/VC
      IF(IM.EQ.1)AXC=YC+XLAMDA+ZP
      IF(IM.NE.3) GO TO 95
      IF(IM3.EQ.0)AXC=YC+XLAMDA+FLTIC*EFFI/VC+ZP
   95 PR=P(I)-(P(I)-P(I-1))/U
      IF(PR.LT.1.E-30) PR=0.
      IF(I.EQ.2) BR=0.
      IF(I.EQ.2) GO TO 129
      IF(IC.NE.3) BR=B(I-1)+(B(I-1)-B(I-2))/U
      IF(IC.EQ.3) BR=T(I-1)+(T(I-1)-T(I-2))/U
  129 IF(BR.LT.1.E-30) BR=0.
      XC=DSQRT(4*D*(YP*PR+ZC*BR)+AXC**2)
      IF((XC*DT).GT.70.) EXC=0.
      IF((XC*DT).GT.70.) GO TO 121
      IF((XC*DT).LE.1.E-6) EXC=1.-XC*DT
      IF((XC*DT).LE.1.E-6) GO TO 121
      EXC=DEXP(-XC*DT)
  121 CE=XC/(2*D)
      CD=-AXC/(2*D)
      CX=C(I-1)-CD
      CP=CX+CE
      CM=CX-CE
  126 IF(C(I-1).LE.1.E-30) C(I-1)=0.
      C(I)=CD+CE*(CP+CM*EXC)/(CP-CM*EXC)
      IF (IM.EQ.2) GO TO 1002
      IF (IM.EQ.4) GO TO 1002
      IF (IM.EQ.1) GO TO 1011
      IF (IM3.NE.0) GO TO 1002
 1011 IF((AXC*DT).GT.70.)EXC=0.
      IF((AXC*DT).GT.70.) GO TO 1001
      IF((AXC*DT).LE.1.E-6)EXC=1.-AXC*DT
      IF((AXC*DT).LE.1.E-6) GO TO 1001
      EXC=DEXP(-AXC*DT)
 1001 CD= (((YP*PR)+ZC*BR) /AXC)*(1.-EXC)
      C(I)=CD+C(I-1)*EXC
 1002 IF(IC.GT.3) GO TO 93
```

```
      B(I)=C(I)
      FLTIT=FLTIB
      FLTRT=FLTRB
      VT=VB
      ELT=ELB
      YB=ELC/VC
      ZB=ZC
      GO TO 92
   93 YB=ELB/VB
      ZB=ELB/VT
      IF(IM.NE.1)AXB=YB+XLAMDA+DNB +ZC+FLTRB*EFF/VB
      IF(IM.EQ.1)AXB=YB+XLAMDA+ZC
      IF(IM.NE.3) GO TO 96
      IF(IM3.EQ.0)AXB=YB+XLAMDA+FLTIB*EFFI/VB+ZC
   96 CR=C(I)-(C(I)-C(I-1))/U
      IF(CR.LT.1.E-30) CR=0.
      IF(I.EQ.2) TR=T(I-1)
      IF(I.NE.2) TR=T(I-1)+(T(I-1)-T(I-2))/U
      IF(TR.LT.1.E-30) TR=0.
      XB=DSQRT(4*D*(YC*CR+ZB*TR)+AXB**2)
      IF((XB*DT).GT.70.) EXB=0.
      IF((XB*DT).GT.70.) GO TO 122
      IF((XB*DT).LE.1.E-6) EXB=1.-XB*DT
      IF((XB*DT).LE.1.E-6) GO TO 122
      EXB=DEXP(-XB*DT)
  122 BE=XB/(2*D)
      BD=-AXB/(2*D)
      BX=B(I-1)-BD
      BP=BX+BE
      BM=BX-BE
  127 IF(B(I-1).LE.1.E-30) B(I-1)=0.
      B(I)=BD+BE*(BP+BM*EXB)/(BP-BM*EXB)
      IF (IM.EQ.2) GO TO 92
      IF (IM.EQ.4) GO TO 92
      IF (IM.EQ.1) GO TO 1013
      IF (IM3.NE.0) GO TO92
 1013 IF((AXB*DT).GT.70.)EXB=0.
      IF((AXB*DT).GT.70.) GO TO 1003
```

```
      IF((AXB*DT).LE.1.E-6)EXB=1.-AXB*DT
      IF((AXB*DT).LE.1.E-6) GO TO 1003
      EXB=DEXP(-AXB*DT)
 1003 BD=(((YC*CR)+(ZB*TR))/AXB)*(1.-EXB)
      B(I)=BD+B(I-1)*EXB
   92 YT=ELT/VT
      IF(IM.NE.1)AXT=YT+XLAMDA+DNT +ZB+FLTRT*EFF/VT
      IF(IM.EQ.1)AXT=YT+XLAMDA+ZB
      IF(IM.NE.3) GO TO 101
      IF(IM3.EQ.0)AXT=YT+XLAMDA+FLTIT*EFFI/VT+ZB
  101 BR=B(I)-(B(I)-B(I-1))/U
      IF(BR.LT.1.E-30) BR=0.
      XT=DSQRT(4*D*YB*BR+AXT**2)
      IF((XT*DT).GT.70.) EXT=0.
      IF((XT*DT).GT.70.) GO TO 123
      IF((XT*DT).LE.1.E-6) EXT=1.-XT*DT
      IF((XT*DT).LE.1.E-6) GO TO 123
      EXT=DEXP(-XT*DT)
  123 TE=XT/(2*D)
      TD=-AXT/(2*D)
      TX=T(I-1)-TD
      TP=TX+TE
      TM=TX-TE
  128 IF(T(I-1).LE.1.E-30) T(I-1)=0.
      T(I)=TD+TE*(TP+TM*EXT)/(TP-TM*EXT)
      IF (IM.EQ.2) GO TO 1006
      IF (IM.EQ.4) GO TO 1006
      IF (IM.EQ.1) GO TO 1015
      IF (IM3.NE.0) GO TO 1006
 1015 IF((AXT*DT).GT.70.)EXT=0.
      IF((AXT*DT).GT.70.) GO TO 1005
      IF((AXT*DT).LE.1.E-6)EXT=1.-AXT*DT
      IF((AXT*DT).LE.1.E-6) GO TO 1005
      EXT=DEXP(-AXT*DT)
 1005 TB=(YB*BR/AXT)*(1.-EXT)
      T(I)=TB+T(I-1)*EXT
```

```
1006 IF((XLAMDA*DT).GT.70.) EXR=0.
     IF((XLAMDA*DT).GT.70.) GO TO 124
     IF((XLAMDA*DT).LT.1.E-6) EXR=1.-XLAMDA*DT
     IF((XLAMDA*DT).LT.1.E-6) GO TO 124
     EXR=DEXP(-XLAMDA*DT)
 124 TR=T(I)-(T(I)-T(I-1))/U
     IF(TR.LT.1.E-30) TR=0.
     IF(XLAMDA.LE.1.E-6) R(I)=YT*TR*DT+R(I-1)*EXR
     IF(XLAMDA.GT.1.E-6) R(I)=(YT*TR/XLAMDA)*(1.-EXR)+R(I-1)*EXR
     IF(R(I).LE.1.E-30)R(I)=0.
     RR(I)=YT*TR
     IF(IC.EQ.2) SUM=P(I)+T(I)+R(I)
     IF(IC.EQ.3) SUM=P(I)+C(I)+T(I)+R(I)
     IF(SUM.LT.1.E-30)  SUM=0.
     IF(IC.EQ.4) SUM=P(I)+C(I)+B(I)+T(I)+R(I)
     IF(EXL.EQ.0.) GO TO 4
     IF(SUM.EQ.0.) GO TO 4
     IF(IMM.EQ.1) W(I)=(SUM+Q(I))/(QZERO*EXL)
   4 IF(R(I).LT.1.E-30) FB(I)=0.
     IF(R(I).GE.1.E-30) FB(I)=R(I)/QZERO
     IF(TIME(I)/TSTOP.GE.1.)6,3
   6 IF(IM.NE.3) GO TO 5
     IF(IM3.EQ.1) GO TO 305
     DO 54 J=1,I
     CSAV(J) = G * C(J)
     BSAV(J) = G * B(J)
     TSAV(J)=G*T(J)
     RSAV(J) = G * R(J)
     RRSAV(J)=G*RR(J)
  54 FBSAV(J)=G*FB(J)
     IM3=1
     GO TO 3000
 305 DO 55 J=1,I
     C(J) =(1.-G) * C(J)
     B(J) = (1.-G) * B(J)
```

```
      T(J)=(1.-G)*T(J)
      R(J) = (1.-G) * R(J)
      FB(J)=(1.-G)*FB(J)
      RR(J)=(1.-G)*RR(J)
      C(J) = C(J) + CSAV(J)
      B(J) = B(J) + BSAV(J)
      T(J)=T(J)+TSAV(J)
      R(J) = R(J) + RSAV(J)
      RR(J)=RR(J)+RRSAV(J)
   55 FB(J)=FB(J)+FBSAV(J)
    5 IF(IMM.EQ.1) GO TO 152
      IF(IC.NE.3) GO TO 102
      DO 103 K=1,I
  103 B(K)=0.
  102 IF(IC.NE.2) GO TO 105
      DO 104 K=1,I
      B(K)=0.
  104 C(K)=0.
  105 TIME(I+1)=TIME(1)
      FU(I+1)=FU(1)
      FI(I+1)=FI(1)
      FB(I+1)=FB(1)
      Q(I+1)=Q(1)
      P(I+1)=P(1)
      C(I+1)=C(1)
      B(I+1)=B(1)
      T(I+1)=T(1)
      W(I+1)=W(1)
      R(I+1)=R(1)
      RR(I+1)=R(1)
      N2=XN2/10.
      N3=XN3/10.
      N4=XN4/10.
      N5=XN5/10.
      N6=XN6/10.
```

```
      MM=I+2
      MMM=I+42
      DO 700 M=MM,MMM
      IF(M.LE.(I+12)) L=(M-I-2)*N2+2
      IF(M.GT.(I+12)) L=(M-I-2)*N3+2-500
      IF(M.GT.(I+22)) L=(M-I-2)*N4+2-500
      IF(M.GT.(I+32)) L=(M-I-2)*N5+2+2500
      TIME(M)=TIME(L)
      FU(M)=FU(L)
      FI(M)=FI(L)
      FB(M)=FB(L)
      Q(M)=Q(L)
      P(M)=P(L)
      C(M)=C(L)
      B(M)=B(L)
      T(M)=T(L)
      W(M)=W(L)
      RR(M)=RR(L)
  700 R(M)=R(L)
      PRINT 59,(TITLE(K),K=1,10),III
   59 FORMAT (1H1,5X,10A8/6X,5HCASE ,I2)
      PRINT 56,XLAMDA,QZERO,FP,G,IM
   56 FORMAT (1H0,5X,'DECAY CONSTANT, 1/SEC',29X,E12.3/6X,'CORE INVENTOR
     1Y AT ZERO TIME, CURIES',15X,E12.3/6X,'RATIO OF FP VAPOR PRESSURE T
     2O UO2 VAPOR PRESSURE',2X,E12.3/6X,'FRACTION OF FP WHICH IS GASEOUS
     3',19X,E12.3/6X,'CLASS OF FISSION PRODUCT',36X,I2)
      PRINT 24,(TIME(K),FU(K),FI(K),
     1                                 FB(K),Q(K),P(K),C(K),B(K),T(K),R(K),R
     2R(K),W(K),K=MM-1,MMM)
   24 FORMAT (1H0,6X,'TIME',6X,'FRACTION',2X,'FRACTION',2X,'FRACTION',2X
     1,'INVENTORIES (CURIES)',30X,'RELEASE'/17X,'OF CORE',3X,'OF FP',5X,
     2'OF FP'/7X,'(SEC)',5X,'VAPORIZED',1X,'VAPORIZED',1X,'RELEASED',2X,
     3'IN CORE',3X,'IN PV',5X,'IN (2)',4X,'IN (3)',4X,'IN (4)',4X,'(CURI
     4ES)',2X,'(CI/SEC)'/(5X,12E10.2))
      IF(IPLOT.EQ.0) GO TO 600
      CALL LOGLOG (15,9,5,4,2.667,1,AY)
```

```
      CALL LETTER (0,80,TITLE(1),AY)
      CALL LETTER (1,41,41HTIME AFTER CESSATION OF FISSIONING, (SEC),AY)
      CALL LETTER (2,33,33HINVENTORIES AND RELEASE, (CURIES),AY)
      DO 60 J=1,I
   60 CALL CURVE (J,TIME(J),Q(J),AY)
      DO 61 J=1,I
   61 CALL CURVE (J,TIME(J),P(J),AY)
      DO 62 J=1,I
   62 CALL CURVE (J,TIME(J),C(J),AY)
      DO 63 J=1,I
   63 CALL CURVE (J,TIME(J),B(J),AY)
      DO 65 J=1,I
   65 CALL CURVE(J,TIME(J),T(J), AY)
      DO 64 J=1,I
   64 CALL CURVE (J,TIME(J),R(J),AY)
      CALL ADVANCE(AY)
  600 CONTINUE
  500 CONTINUE
      GO TC 200
   17 END
```

```
C
      SUBROUTINE DATSG(X,Z,F,WORK,IROW,ICCL,ARG,VAL,NDIM)                DTS
C                                                                        DTS
C                                                                        DTS
      DIMENSION Z(1),F(1),WCRK(1),ARG(1),VAL(1)                          DTS
      DOUBLE PRECISION X,Z,F,WORK,ARG,VAL,B,DELTA                        DTS
      IF(IROW)11,11,1                                                    DTS
    1 N=NDIM                                                             DTS
C     IF N IS GREATER THAN IROW, N IS SET EQUAL TO IROW.                 DTS
      IF(N-IROW)3,3,2                                                    DTS
    2 N=IRCW                                                             DTS
C                                                                        DTS
C     GENERATION OF VECTOR WORK AND COMPUTATION OF ITS GREATEST ELEMENT.DTS
    3 B=0.D0                                                             DTS
      DO 5 I=1,IROW                                                      DTS
      DELTA=DABS(Z(I)-X)                                                 DTS
      IF(DELTA-B)5,5,4                                                   DTS
    4 B=DELTA                                                            DTS
    5 WORK(I)=DELTA                                                      DTS
C                                                                        DTS
C     GENERATION OF TABLE (ARG,VAL)                                      DTS
      B=B+1.D0                                                           DTS
      DO 10 J=1,N                                                        DTS
      DELTA=B                                                            DTS
      DO 7 I=1,IROW                                                      DTS
      IF(WCRK(I)-DELTA)6,7,7                                             DTS
    6 II=I                                                               DTS
      DELTA=WORK(I)                                                      DTS
    7 CONTINUE                                                           DTS
      ARG(J)=Z(II)                                                       DTS
      IF(ICOL-1)8,9,8                                                    DTS
    8 VAL(2*J-1)=F(II)                                                   DTS
      III=II+IROW                                                        DTS
      VAL(2*J)=F(III)                                                    DTS
      GOTO 10                                                            DTS
    9 VAL(J)=F(II)                                                       DTS
   10 WORK(II)=B                                                         DTS
   11 RETURN                                                             DTS
      END                                                                DTS
                                                                         DTS
```

```
C                                                                        DAL
      SUBROUTINE DALI(X,ARG,VAL,Y,NDIM,EPS,IER)                          DAL
C                                                                        DAL
C                                                                        DAL
      DIMENSION ARG(1),VAL(1)                                            DAL
      DOUBLE PRECISION ARG,VAL,X,Y,H                                     DAL
      IER=2                                                              DAL
      DELT2=0.                                                           DAL
      IF(NDIM-1)9,7,1                                                    DAL
C                                                                        DAL
C     START OF AITKEN-LOOP                                               DAL
    1 DO 6 J=2,NDIM                                                      DAL
      DELT1=DELT2                                                        DAL
      IEND=J-1                                                           DAL
      DO 2 I=1,IEND                                                      DAL
      H=ARG(I)-ARG(J)                                                    DAL
      IF(H)2,13,2                                                        DAL
    2 VAL(J)=(VAL(I)*(X-ARG(J))-VAL(J)*(X-ARG(I)))/H                     DAL
      DELT2=DABS(VAL(J)-VAL(IEND))                                       DAL
      IF(J-2)6,6,3                                                       DAL
    3 IF(DELT2-EPS)10,10,4                                               DAL
    4 IF(J-8)6,5,5                                                       DAL
    5 IF(DELT2-DELT1)6,11,11                                             DAL
    6 CONTINUE                                                           DAL
C     END OF AITKEN-LOOP                                                 DAL
```

```
C                                                                        DAL
    7 J=NDIM                                                             DAL
    8 Y=VAL(J)                                                           DAL
    9 RETURN                                                             DAL
C                                                                        DAL
C     THERE IS SUFFICIENT ACCURACY WITHIN NDIM-1 ITERATION STEPS         DAL
   10 IER=0                                                              DAL
      GOTO 8                                                             DAL
C                                                                        DAL
C     TEST VALUE DELT2 STARTS OSCILLATING                                DAL
   11 IER=1                                                              DAL
   12 J=IEND                                                             DAL
      GOTO 8                                                             DAL
C                                                                        DAL
C     THERE ARE TWO IDENTICAL ARGUMENT VALUES IN VECTOR ARG              DAL
   13 IER=3                                                              DAL
      GOTO 12                                                            DAL
      END                                                                DAL
```

```
**FTN,L,E,M,G.
      PROGRAM FEED
      IMPLICIT REAL * 8(A-H,O-Z)
      DIMENSION TIME(4550),FU(4550),FI(4550),Q(4550),Z(34),F(34),
     1WORK(34),ARG(5),VAL(5),DMULT(4550),RDMULT(4550)
      TSTART=10.
      XN2=1000.
      XN3=1500.
      XN4=1500.
      XN5=500.
      XN6=20.
      T2=10.
      T1=60.
      TSTOP=.999E5
      EMU = 1.48 E8
      PWR=3.44E9
      H=1.E-3
      INDI=1
      READ  2,ICOL,IROW,NDIM,EPS,ISET
    2 FORMAT(3I10,E10.2,I10)
      DO 100 I=1,4550
  100 RDMULT(I)=1.
  110 DO 120 I=1,4550
  120 DMULT(I)=0.
    5 READ(50,58,END=17) IM,XLAMDA,QZERO,FP
   58 FORMAT (I10,3E10.2)
      READ 4,Z
    4 FORMAT (8E10.4)
      READ 6,F
    6 FORMAT (8E10.4)
      DO 10 I=1,4550
      FI(I)=0.
   10 TIME(I)=0.
      ELUT1=6.511E-5*PWR*DEXP(-.291*DLOG(T1))*H*RDMULT(780)
  201 ELUT1=ELUT1*EXPF(-25.*ELUT1/EMU)
      FUT1=ELUT1*(T1-T2)/(2.*EMU)
```

```
3000 I = 1
   3 I = I + 1
     XI=I-2
     IF(TIME(I-1).LT..999E2) TIME(I)=TSTART*(10.**(XI/XN2))
     IF(TIME(I-1).GE..999E2) TIME(I)=TIME(I-1)*(10.**(1./XN3))
     IF(TIME(I-1).GE..999E3) TIME(I)=TIME(I-1)*(10.**(1./XN4))
     IF(TIME(I-1).GE..999E4) TIME(I)=TIME(I-1)*(10.**(1./XN5))
     IF(TIME(I-1).GE..999E5) TIME(I)=TIME(I-1)*(10.**(1./XN6))
     TP=TIME(I)
     DT=TIME(I)-TIME(I-1)
     RWR=PWR*RDMULT(I)
     IF(TP.LT.T2) FU(I)=0.
     IF(TP.LT.T2) GO TO 117
     IF(TP.LE.T1) FU(I)=FUT1*((TP-T2)/(T1-T2))**2
     IF(TP.GT.T1) FU(I)=1.-(1.-FUT1)*DEXP((-9.183E-5*RWR*H/EMU)*(DEXP(.
    1709*DLOG(TP))-DEXP(.709*DLOG(T1))))
1117 IF((XLAMDA*TP).GT.70.) EXL=0.
     IF((XLAMDA*TP).GT.70.) GO TO 117
     IF((XLAMDA*TP).LT.1.E-6) EXL=1.-XLAMDA*TP
     IF((XLAMDA*TP).LT.1.E-6) GO TO 117
     EXL=DEXP(-XLAMDA*TP)
 117 IF(TP.LE.T2) Q(I)=QZERO*EXL
     IF(TP.LE.T2) GO TO 80
     X4=-FP*DLOG(1.-FU(I))+XLAMDA*TP
     IF(X4.GT.70.) EX4=0.
     IF(X4.GT.70.) GO TO 119
     IF(X4.LE.1.E-6) EX4=1.-X4
     IF(X4.LE.1.E-6) GO TO 119
     EX4=DEXP(-X4)
 119 IF(TP.GT.T2) Q(I)=QZERO*EX4
  80 IF(Q(I).GT.QZERO*EXL) Q(I)=QZERO*EXL
     IF(EXL.EQ.0.)FI(I)=1.
     IF(EXL.NE.0.)FI(I)=(QZERO*EXL-Q(I))/(QZERO*EXL)
     CALL DATSG(TIME(I),Z,F,WORK,IROW,ICOL,ARG,VAL,NDIM)
     CALL DALI(TIME(I),ARG,VAL,Y,NDIM,EPS,IER)
```

```
      DMULT(I)=(1.-FI(I))*Y+DMULT(I)
      IF(TIME(I).LT.TSTOP) GO TO 3
      ISAV=I
      TIME(I+1)=TIME(1)
      FI(I+1)=FI(1)
      DMULT(I+1)=DMULT(1)
      N2=XN2/10.
      N3=XN3/10.
      N4=XN4/10.
      N5=XN5/10.
      N6=XN6/10.
      MM=I+2
      MMM=I+42
      DO 700 M=MM,MMM
      IF(M.LE.(I+12)) L=(M-I-2)*N2+2
      IF(M.GT.(I+12)) L=(M-I-2)*N3+2-500
      IF(M.GT.(I+22)) L=(M-I-2)*N4+2-500
      IF(M.GT.(I+32)) L=(M-I-2)*N5+2+2500
      TIME(M)=TIME(L)
  700 FI(M)=FI(L)
      PRINT 20,INDI,IM
   20 FORMAT(1H1,4X,'INDI = ',I10/5X,'IM = ',I10)
      PRINT 30,(TIME(K),FI(K),K=MM-1,MMM)
   30 FORMAT(1H0,9X,'TIME',6X,'FRACTION'/20X,'OF FP'/7X,'(SEC)',8X,
     1'VAPORIZED'/(5X, E10.4,8X,E10.4))
      IF(IM.LT.10)GO TO 5
      DO 15 I=1,4550
   15 RDMULT(I)=DMULT(I)
      I=ISAV
      DO 800 M=MM,MMM
      IF(M.LE.(I+12)) L=(M-I-2)*N2+2
      IF(M.GT.(I+12)) L=(M-I-2)*N3+2-500
      IF(M.GT.(I+22)) L=(M-I-2)*N4+2-500
      IF(M.GT.(I+32)) L=(M-I-2)*N5+2+2500
      TIME(M)=TIME(L)
```

```
800 RDMULT(M)=RDMULT(L)
    PRINT 40 ,INDI
 40 FORMAT(1H1,5X,'INDI = ',I10)
    PRINT 50,(TIME(K),RDMULT(K),K=MM-1,MMM)
 50 FORMAT(1H0,6X,'TIME',9X,'MULTIPLIER'/(5X, E10.4,8X,E10.4))
    IF(INDI.LT.ISET) INDI=INDI+1
    IF(INDI.LT.ISET) GO TO 110
 17 END
```

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