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**¹³¹I Release from an HTGR
During the LOFC Accident**

by

John E. Foley

MASTER

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87544

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¹³¹I RELEASE FROM AN HTGR

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ABSTRACT

The time-dependent release of ¹³¹I from both the core and the containment building of a high temperature gas-cooled (HTGR) reactor during the loss of forced coolant (LOFC) accident is studied. A simplified core release model is combined with a containment building release model so that the total amount of the isotope released to the environment can be calculated. The time-dependent release of ¹³¹I from the core during the LOFC accident is primarily a function of the time-dependent core temperatures and the failed fuel release constants. The most important factor in calculating the amount of the isotope released to the environment is the total amount released into the containment building.

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I. INTRODUCTION

The release of volatile fission products from an HTGR core during the loss of forced coolant (LOFC) accident was studied. The release from both the core and the containment building was investigated so that the total amount released to the environment during the accident could be determined.

The time-dependent release of fission products from the HTGR core is calculated by General Atomic Company (GAC) with a computer program called SORS.¹ The basic techniques used in the SORS program to calculate the release are simple; however, the book-keeping required to keep track of all the isotopes, temperatures, release rates, etc., is complicated. In the SORS model, the core is divided into many small regions and the total fission product release is obtained by summing the release from each region. The temperature of each region is calculated with a computer program called CORCON.²

The LASL AYER³ heat conduction computer code was modified to duplicate the CORCON temperature calculations and the SORS fission product release calculations for the noble gases and iodines. Good agreement has been obtained between the results of

calculations made with the AYER and SORS models. References will be made to the results of calculations from both the AYER and the SORS models in this report, but neither model will be discussed in detail. A simplified, uniform core temperature release model will be discussed. This model forms the basis for both the AYER and SORS models.

II. FISSION PRODUCT RELEASE FROM CORE

A. Simplified Core Release Model

A simplified model was developed so that fission product release from the core during the LOFC accident could be studied easily with hand calculations. The following assumptions were made:

1. The entire core is at a uniform temperature.
2. All the coated particles fail at the same time.
3. Fission products are released only from failed particles (no release from intact particles).
4. The release rate of an isotope from the failed particles is given by the release constant from the SORS report (Ref. 1, Fig. 5-3).
5. There is no buildup of the isotope from precursor decay.

These assumptions will be justified in this report.

The rate of change of the amount (in units of curies, grams, atoms, etc.) of the isotope in the core $N(t)$ is given by

$$\frac{dN(t)}{dt} = -[r(t) + \lambda] N(t), \quad (1)$$

where

$r(t)$ is the release constant of the isotopes from the fuel particles, and

λ is the radioactive decay constant of the isotopes.

It has been assumed (Assumption 5) that there is no production of the isotope from precursor decay. This assumption does limit the applicability of Eq. (1) to certain isotopes, such as ^{131}I , ^{133}I , ^{85}Kr , etc., but the limitation is not important for this discussion. Precursor decay could have been included, but only at the expense of increased complexity.

The release rate R of the isotope from the core at any time t is given by

$$\frac{dR}{dt} = r(t) N(t), \quad (2)$$

and the total release is given by the integral of Eq. (2) over the time period of interest. Integration of Eq. (2) is difficult to do analytically because the release constant $r(t)$ is a function of the time. The simplest way to perform the integral is to divide the time period of interest into many short intervals and consider $r(t)$ to be a constant during each interval. The value of $r(t)$ to be used is the average value that occurs during the interval.

The amount of the isotope in the fuel at any time t within the first time interval of width Δt is then obtained by integrating Eq. (1) with $r(t) = r_1$ (constant):

$$N(t) = N_0 e^{-(r_1 + \lambda)t} \quad (3)$$

for $0 \leq t \leq \Delta t$, and

N_0 is the initial amount of the isotope in the core, and

r_1 is the average release constant of the isotope during the first time interval.

The amount of the isotope released from the core (R_1) during the first time interval is then obtained by integrating Eq. (2) over the width of the time interval:

$$R_1 = \int_0^{\Delta t} r_1 N(t) dt \quad (4)$$

$$= N_0 r_1 \int_0^{\Delta t} e^{-(r_1 + \lambda)t} dt \quad (5)$$

$$= N_0 \left(\frac{r_1}{r_1 + \lambda} \right) [1 - e^{-(r_1 + \lambda) \Delta t}]. \quad (6)$$

The amount of the isotope remaining in the core at the end of this first time interval is

$$N_1 = N_0 e^{-(r_1 + \lambda) \Delta t}. \quad (7)$$

N_1 is also the amount of the isotope in the core at the beginning of the second time interval.

The amount released during the second time interval (with the same length as the first) is obtained by replacing N_0 with N_1 (the new initial amount) and r_1 with r_2 (the new release constant):

$$R_2 = N_1 \left(\frac{r_2}{r_2 + \lambda} \right) [1 - e^{-(r_2 + \lambda) \Delta t}]. \quad (8)$$

The amount of the isotope remaining in the core at the end of the second time interval is simply

$$N_2 = N_1 e^{-(r_2 + \lambda) \Delta t}. \quad (9)$$

For i^{th} time interval:

$$R_i = N_{i-1} \left(\frac{r_i}{r_i + \lambda} \right) [1 - e^{-(r_i + \lambda) \Delta t}] \quad (10)$$

and

$$N_i = N_{i-1} e^{-(r_i + \lambda) \Delta t}. \quad (11)$$

These equations are used to calculate the release of the isotopes from the core for all time intervals, including the first ($i=1$) and the second ($i=2$).

The only variables in these equations are 1) the initial amount of the isotope N_0 , and 2) the release constants r_i . The initial amount is determined from the operating history of the reactor. The release constants are functions of the fuel particle coating integrity and the core temperature. The temperature-dependent release constants used by GAC for both intact and failed particles are given in Fig. 5-3 of Ref. 1.

Examination of Fig. 5-3 of Ref. 1 reveals that the release constants are much greater for failed than for intact particles; for example, the release rate of iodine from intact particles at 1773 K is $1.0 \times 10^{-5} \text{ h}^{-1}$, whereas from failed particles it is $3.0 \times 10^{-2} \text{ h}^{-1}$. Similar differences are found for other isotopes. Thus, the assumption is made that release occurs only from the failed particles (Assumption 3); i.e., there is no release from intact particles.

B. Calculated Core Release of ^{131}I for LOFC Accident

The simplified core release model was used to estimate the time-dependent release of ^{131}I from the HTGR core during the LOFC accident. This isotope was selected because it is the most important one in accident situations (also, there is no significant buildup of ^{131}I from precursor decay after the reactor trip).

Instead of considering the core to be at a uniform temperature, we could have subdivided it into many small regions, such as is done in the AYER and SORS models, and used the average temperature of each region to obtain the release constants. The release from each region would be calculated using Eq. (10), and the total release during a time interval would be obtained by summing the release from each small region. A single region - the entire core - was chosen for analysis in this report in order to keep the calculations simple. It should be remembered, however, that the model developed here can be extended easily to include more regions.

The average core temperature and the corresponding release constant of ^{131}I for failed fuel particles during one-hour time intervals are given in Table I. The temperatures and the release constants were read directly from Fig. 6-2 and Fig. 5-3 (both from Ref. 1), respectively. No attempts will be made in this report to justify the values of the

TABLE I
AVERAGE CORE TEMPERATURES AND
RELEASE CONSTANTS FOR ^{131}I
ADAPTED FROM FIG. 6-2, FIG. 5-3, REF. (1)

Time After Onset of Accident (h)	Average Core Temperature (K)	Average Release Constant (h^{-1})
0-1	1227	1.0×10^{-4}
1-2	1505	3.2×10^{-3}
2-3	1683	1.6×10^{-2}
3-4	1855	5.3×10^{-2}
4-5	2000	1.3×10^{-1}
5-6	2116	2.2×10^{-1}
6-7	2222	3.6×10^{-1}
7-8	2311	5.5×10^{-1}
8-9	2389	7.5×10^{-1}
9-10	2450	9.5×10^{-1}
10-11	2511	1.2
11-12	2583	1.5
12-13	2639	2.0

release constants. It is clear from a preliminary survey of some of the data from which the constants were derived that there is considerable uncertainty in the values of the release constants. It is seen from Fig. 5-1 and Fig. 5-2 of Ref. 1 for 2.5-year-old fuel (the average core life) that both TRISO and BISO fuel particles fail between $\sim 1400 \text{ K}$ (1150°C) and $\sim 1700 \text{ K}$ (1450°C). It is also seen from Table I that the core average temperature passes through this temperature range during the time interval 2-3 h after the onset of the accident. Thus, most of the fuel particles fail within this 1-h time interval. It will be assumed, again to simplify the calculations, that all the fuel particles fail 2 h after the onset of the accident (Assumption 2). It will be seen later in this report that the time-dependent release of ^{131}I (and other fission products) is nearly independent of the time at which the fuel particles fail. The fuel particles fail at a time (or temperature) when the release constants r_i for failed particles are still small. Thus, the release is insensitive to the time and temperature of failure.

The amount of ^{131}I in the core of a 3000 MWt HTGR at the onset of the LOFC accident is $\sim 7.78 \times 10^7 \text{ Ci}$ (Appendix A). The decay constant for this isotope, which has an 8.05-day half-life, is 0.00358 h^{-1} .

Since it is assumed that there is no release during the first 2 h following the onset of the accident, the release constants for the first two 1-h time intervals are set to zero; Table II (adapted from Table I) gives the values used for the calculations.

TABLE II

PARAMETER VALUES FOR ^{131}I RELEASE CALCULATIONS

Time Interval	Time After Onset of Accident (h)	r_i (h^{-1})	$(r_i + \lambda)$ (h^{-1})
1	0-1	0	3.58×10^{-3}
2	1-2	0	3.53×10^{-3}
3	2-3	1.6×10^{-2}	1.96×10^{-2}
4	3-4	5.3×10^{-2}	5.66×10^{-2}
5	4-5	1.3×10^{-1}	1.34×10^{-1}
6	5-6	2.2×10^{-1}	2.24×10^{-1}
7	6-7	3.6×10^{-1}	3.64×10^{-1}
8	7-8	5.5×10^{-1}	5.54×10^{-1}
9	8-9	7.5×10^{-1}	7.54×10^{-1}
10	9-10	9.5×10^{-1}	9.54×10^{-1}
11	10-11	1.2	1.2
12	11-12	1.5	1.5
13	12-13	2.0	2.0

1. First Time Interval (0-1 h). There is no release of the isotope during this time interval because the fuel particles have not failed yet. There is, however, a decrease in the amount of the isotope in the core because of the radioactive decay. The amount of the isotope remaining at the end of the interval is determined from Eq. (11):

$$N_1 = 7.78 \times 10^7 e^{-0.00358} \\ = 7.75 \times 10^7 \text{ Ci .}$$

2. Second Time Interval (1-2 h). Again, there is no release of the isotope. The amount remaining in the core at the end of the second time interval is

$$N_2 = 7.75 \times 10^7 e^{-0.00358} \\ = 7.72 \times 10^7 \text{ Ci .}$$

3. Third Time Interval (2-3 h). ^{131}I release begins during this time interval. The amount of

release is determined from Eq. (10):

$$R_3 = (7.72 \times 10^7) \times \left(\frac{1.6 \times 10^{-2}}{1.96 \times 10^{-2}} \right) \times (1 - e^{-0.0196}) \\ = 1.22 \times 10^6 \text{ Ci .}$$

The amount of the isotope remaining in the core at the end of this time interval is

$$N_3 = 7.72 \times 10^7 e^{-0.0196} \\ = 7.57 \times 10^7 \text{ Ci .}$$

4. Remaining Time Intervals. This process is continued until only a small fraction of the original amount of the isotope remains in the core. The results of these calculations are shown in Table III. Less than 0.05% of the original amount of ^{131}I remains in the core 13 h after the onset of the accident.

The total amount (A_i) of the isotope in the coolant at the end of the i^{th} time interval is given by

$$A_i = A_{i-1} e^{-\lambda \Delta t} + R_i \quad (12)$$

where A_{i-1} is the amount in the coolant at the end of the $(i-1)^{\text{st}}$ time interval.

TABLE III

REMAINING TIME INTERVAL CALCULATIONS

Time Interval	Time After Onset of Accident (h)	Amount Released (Ci)	Amount Remaining (Ci)	Amount in Coolant Ci	Fraction of Initial Amount
1	0-1	0	7.75×10^7	0	0
2	1-2	0	7.72×10^7	0	0
3	2-3	1.22×10^6	7.57×10^7	1.22×10^6	0.0157
4	3-4	3.90×10^6	7.15×10^7	5.12×10^6	0.0658
5	4-5	8.70×10^6	6.26×10^7	1.38×10^7	0.1774
6	5-6	1.23×10^7	5.00×10^7	2.61×10^7	0.3355
7	6-7	1.51×10^7	3.48×10^7	4.11×10^7	0.5280
8	7-8	1.47×10^7	2.00×10^7	5.56×10^7	0.7147
9	8-9	1.05×10^7	9.41×10^6	6.59×10^7	0.8470
10	9-10	5.76×10^6	3.62×10^6	7.14×10^7	0.9177
11	10-11	2.53×10^6	1.09×10^6	7.37×10^7	0.9473
12	11-12	8.47×10^5	2.44×10^5	7.43×10^7	0.9550
13	12-13	2.11×10^5	3.30×10^4	7.42×10^7	0.9537

Radioactive decay is the only removal mechanism considered here; leakage from the containment building and removal by a clean-up system will be included later in this report. The amount of ^{131}I in the coolant normalized to the initial core inventory is shown in Fig. 1. Results from both the GAC SORS model (Ref. 1, Table 6-1) and the LASL AYER model are also shown. The agreement between the simple, uniform temperature model developed here and the more sophisticated models is good. It will be seen later in this report that these differences in the time-dependence of the release are not important; the important factor is the total amount released, not the time-dependency of release.

From Fig. 1 (using any of the release models) it is seen that there is little release of ^{131}I to the coolant during the first 4 h after the onset of the accident. Most of the release to the coolant occurs during the 4- to 12-h time period; the release is essentially complete 12 h after the onset of the accident.

C. Effects of the Time of Fuel Failure

The effects of the time at which the fuel particles fail on the time-dependent release to the coolant was investigated by varying the time of failure from 0 h, 2 h, 4 h, and 6 h after the onset of the accident; these failure times correspond to failure temperatures of 1088 K (815°C), 1588 K (1315°C), 1940 K (1667°C), and 2172 K (1900°C), respectively. These temperatures span the failure regions for both BISO and TRISO fuel particles (see Fig. 5-1 and 5-2, Ref. 1). The results of these calculations made with the uniform temperature model

Fig. 1. Calculated ^{131}I release from HTGR core during the LOFC accident.

are shown in Fig. 2; the amount of ^{131}I in the coolant is nearly independent of the time of particle failure. For example, 50% of the core inventory is released by 7 h after the accident if the particles fail at the onset of the accident (1088 K); 50% is released by ~7.75 h if the particles fail 6 h after the onset (2172 K). Thus a 6-h delay in failure produces less than 1 h delay in the release of one-half of the core inventory. These results were checked with the more sophisticated AYER model; Fig. 3 illustrates the amount released for fuel failure temperature of 1573 K (~2 h after the onset of the accident) and 2073 K (~5 h after the onset). The 3-h delay in fuel failure results in only ~1/2-h delay in the release of 50% of the iodine core inventory.

Fig. 2. Calculated ^{131}I release from HTGR during the LOFC accident for various times of fuel failure.

Fig. 3. Calculated ^{131}I release from HTGR core during the LOFC accident for two fuel failure temperatures.

Thus, the time-dependent release of ^{131}I to the coolant is nearly independent of the fuel failure model. The reason for this, as stated earlier, is that the fuel particles fail when the release constants (r_i) for failed particles are small. The release is governed by the release constants, not by the integrity of the fuel particles. Assumption 2 is thus completely justified and, for simplicity, it can be assumed that the particles fail at the onset of the accident. There is no need for further study of the fuel failure model.

The important variables for calculating the release of the volatile fission products during the LOFC accident are the time-dependent core temperatures and the release constants. For the release of the metallic fission products, the adsorption and diffusion parameters are also important. The fuel failure model is not important.

III. FISSION PRODUCT RELEASE FROM CONTAINMENT BUILDING

A. Containment Building Model

The release of the volatile fission products from the containment building involves two steps: 1) leakage of the isotope from the PCRV (into the containment building), and 2) release of the isotope from the containment building. The analysis of the leakage of a volatile fission product from the containment building is done in a manner similar to that just described for the release from the core.

Fission products released from the PCRV become the time-dependent source of the isotope in the containment building. To simplify the analysis, it is assumed that this source is constant over a short time interval; the source strength is the average value in the time interval. The rate of change of the number of atoms of the isotope $N'(t)$ in the containment building during the i^{th} time interval (ignoring buildup from precursor decay) is given by

$$\frac{dN'_i(t)}{dt} = S_i - (\lambda + V_i + L_i) N'_i(t) \quad (13)$$

where

λ is the radioactive decay constant of the isotope.

V_i is the containment cleanup system removal rate during the i^{th} time interval.

L_i is the containment building leak rate during the i^{th} time interval.

S_i is the constant source strength during the i^{th} time interval.

If the same time intervals that are used for calculating the release from the containment building are used for calculating the release from the core, then, during any time interval, the source strength S_i is equal to the core release R_i (given by Eq. 10).

The assumption is made that all of the iodine released to the coolant during any time interval gets into the containment building; that is, there is no time delay in the transfer of the isotope from the coolant to the containment building and there is no deposition of the isotope along the flow path. Regulatory Guides 1.3 and 1.4 (Ref. 4 and 5) for light-water cooled reactors (LWR) suggest that only 25% of the iodine in the core is released during a core meltdown, and the remaining 75% adheres firmly to surfaces. GAC applies this same reduction factor to the iodine released in the HTGR LOFC accident; however, it is not obvious that this reduction should be used for the HTGR. No reduction will be used for the calculations presented in this report. The reduction could be included by simply multiplying the source term S_i by 0.25.

The amount of the isotope inside the containment building at any time t during the time interval ($t_{i-1} \leq t \leq t_i$) is given by the solution of Eq. (13):

$$N'_i(t) = (N'_{i-1} - \frac{S_i}{\lambda_i}) e^{-\lambda_i(t-t_{i-1})} + \frac{S_i}{\lambda_i} \quad (14)$$

where

N'_{i-1} is the number of atoms of the isotope present in the containment building at the end of the $(i-1)^{\text{st}}$ time interval (at time t_{i-1}).

$\lambda_i = \lambda + V_i + L_i$ is the total "decay" constant for the i^{th} time interval.

The amount of the isotope released R'_i from the containment building during the i^{th} time interval

$\Delta t = (t_i - t_{i-1})$ is then:

$$R'_i = \int_{t_{i-1}}^{t_i} L_i N'_i(t) dt \quad (15)$$

$$= \frac{L_i}{\lambda_i^*} (N'_{i-1} - \frac{S_i}{\lambda_i^*}) (1 - e^{-\lambda_i^* \Delta t}) + L_i \frac{S_i}{\lambda_i^*} \Delta t. \quad (16)$$

The total release from the containment building during the entire duration of the accident is obtained by summing the individual releases during each time interval.

Equation (14), which gives the amount of the isotope in the containment building at the end of the i^{th} interval, and Eq. (16), which gives the amount of the isotope released from the building during the interval, are similar in form to Eq. (11) and Eq. (10), respectively, which describe the amount of the isotope present in the core and the amount released during the time interval. These four equations describe the release of the volatile fission products from the HTGR containment building during the LOFC accident. The only information needed to perform the calculations is:

1. the time-dependent core temperature,
  2. the radioactive decay constant, λ ,
  3. the release constants, r_i ,
  4. the containment cleanup constant, V_i , and
  5. the containment building leak rate, L_i .
- B. Calculated Containment Building Release for LOFC Accident

The release of ^{131}I from the containment building was calculated for the LOFC accident considered earlier in this report. The source term S_i of the isotope in the containment building was set equal to the 1-h time interval core releases R_i given in Table III. For example, the source term of ^{131}I in the containment building during the 6th time interval (5 to 6 h after the onset of the accident) is $1.23 \times 10^7 \text{ Ci/h}$. As stated earlier, it is assumed that the entire amount of the isotope released from the core during the time interval gets into the building.

The containment building leak rates used for the calculation were obtained from the Fulton Plant PSAR:⁶ 0.001/day for the first 24 h after the onset of the accident, and 0.0005/day thereafter. The actual leak rate of the HTGR containment building may be significantly greater than these values because of the high internal pressure (~15 psig) in

the containment building after a PCRV depressurization.⁷ These numbers will be used, however, for lack of better values.

The containment cleanup system removal rate for ^{131}I was chosen to be 0.9 h^{-1} ; this value is consistent with that given in the Fulton Plant PSAR for the removal of elemental iodine.⁶ The three chemical forms of ^{131}I - elemental, organic, particulate - are removed by the containment cleanup system at different rates because of the different collection efficiencies of these forms in the filters. Each chemical form should be treated separately in the containment building by applying the appropriate source terms and the proper containment cleanup rates. However, since ~91% of the iodine release is considered to be elemental,⁶ the cleanup constant for elemental iodine will be used here. This simplification introduces some error into the calculations, but not enough to be of concern here (we are in effect calculating the release of elemental ^{131}I from the containment building).

The release rate and the total amount released for ^{131}I from the containment building are given in Table IV. The release from the containment building during the 6th time interval (5-6 h after the onset of the accident), for example, is 383.3 Ci and the total cumulated release up to the end of this time period is 702.7 Ci. The total release of ^{131}I is calculated to be 3497 Ci. This amount is significantly higher than the value given in the Fulton Plant PSAR⁸ mainly because: 1) the total release of iodine was considered here, not just 25% release, and 2) no credit was given to the Supplementary Leak Collection System.⁶ When credit is given to these reductions, the total release of ^{131}I is calculated to be 498.9 Ci, a value nearly identical with that given in the PSAR as 499.6 Ci (see Appendix B).

Most of the release occurs during the 8-h interval from 4 to 12 h after the onset of the accident; very little release occurs before 4 h or after 12 h (Fig. 4). The release rate approaches zero after 12 h because the containment cleanup system has effectively removed all of the iodine from the atmosphere inside the containment building. These results would be significantly altered if the containment cleanup system failed during the LOFC accident.

TABLE IV

¹³¹I RELEASE FROM CONTAINMENT BUILDING
DURING THE LOFC ACCIDENT

Time After Onset of Accident (h)	Amount Released (Ci)	Cumulated Release (Ci)
0-1	0	0
1-2	0	0
2-3	19.2	19.2
3-4	83.5	102.8
4-5	216.6	319.4
5-6	383.3	702.7
6-7	537.1	1240
7-8	625.8	1866
8-9	590.9	2456
9-10	452.9	2909
10-11	290.7	3200
11-12	160.7	3361
12-13	78.3	3439
13-14	34.2	3473
14-16	19.5	3493
16-18	3.2	3496
18-20	0.5	3496

Fig. 4. Calculated ¹³¹I release from the containment building following the LOFC accident.

IV. FACTORS AFFECTING DOSE CALCULATIONS

A. Core Release Fractions

As mentioned earlier, GAC assumes that 25% of the iodine is available for release from the containment building. They further assume that 1% of the solids and 100% of the noble gases are available for release. No attempt has been made to justify these values; however, their use is suggested by Regulatory Guides 1.3 and 1.4 and by TID-14844.⁹ GAC has measured the total release fraction of fission products in small furnace annealing experiments,

but the values obtained are not used to justify the release fractions for either the Fulton or the Delmarva HTGR stations. The measurements made by GAC¹⁰ indicate that the fractions released into the containment building atmosphere are significantly less than the assumed values; for example, the measurements indicate that only ~5.5% of the iodine and ~0.023% of the Sr are released from the PCRV, whereas the assumed values are 25% and 1%, respectively.

B. Atmosphere Condition

Regulatory Guides 1.3 and 1.4 imply that the 8-h time period for the worst atmospheric transport of the fission products (the period of least dilution) should coincide with the period of the maximum release of fission products from the containment building. The period used in the Fulton Plant PSAR for the worst atmospheric conditions is 4 to 12 h after the onset of the accident.¹¹ Figure 4 confirms that this is the period of maximum release of ¹³¹I; it is probably also the period of maximum release of the other iodines and noble gases. The metallic fission products are released from the core at a much slower rate and the period of maximum release of Sr (calculated by GAC with SORS) does not occur until ~30 h after the onset of the accident (Ref. 1, Fig. 6.4). Because the release rates of the various fission products from the HTGR core are different, it is difficult to apply the procedures of Regulatory Guides 1.3 and 1.4 (which were developed for LWR's) to HTGR's in a satisfactory manner.

C. Dose Calculations

The atmospheric diffusion factors $\left(\frac{\bar{x}}{Q}\right)$ from the Fulton Plant PSAR¹¹ for the Low Population Zone (LPZ) boundary (2.4 km from the reactor) used for the different time intervals are shown in Table V. As mentioned earlier, the period of worst atmospheric

TABLE V

ATMOSPHERIC DIFFUSION FACTORS

Time	$\bar{x}/Q$ (s/m ³)
0-4 h	4.3×10^{-5}
4-8 h	3.3×10^{-4}
12-24 h	4.3×10^{-5}
1-4 days	2.2×10^{-5}
4-30 days	4.8×10^{-6}

condition was chosen for the 4- to 12-h time period following the onset of the accident.

The thyroid dose (D) from inhalation of the released ^{131}I to an individual located on the LPZ boundary is given by

$$D = C \int_{t_1}^{t_2} \left(\frac{\lambda}{Q} \right) B \dot{Q} dt \quad (17)$$

where

C is the dose conversion factor (rem/Ci inhaled).

B is the breathing rate (m^3/s).

$\dot{Q}$ is the release rate of ^{131}I from the containment building.

Because both the breathing rate (B) and the atmospheric diffusion factor $\left(\frac{\lambda}{Q} \right)$ are constants during the time periods of interest (Table V), they can be removed from under the integral sign in Eq. (17):

$$D = C \left(\frac{\lambda}{Q} \right) B \int_{t_1}^{t_2} \dot{Q} dt \quad (18)$$

The integral of the release rate $\dot{Q}$ over the time interval in Eq. (18) is equal to the total amount of the iodine released during the time interval. Thus, the dose received by an individual during the 4- to 12-h time interval (or any time interval) is proportional to the total amount of the isotope released during the time interval; it is not a function of the time-dependency of the release.

Figure 4 shows the time-dependent release of ^{131}I from the containment building calculated using the uniform core temperature model (as developed in this report) and the more sophisticated AYER core release model. The GAC SORS model predicts a release similar to that predicted by the AYER model. It is seen in Fig. 4 that the total amount of ^{131}I released during the 4- to 12-h time period is relatively independent of the core release model; for example, the cumulated amount released from the containment building 12 h after the onset of the accident (very little release occurs before 4 h) is calculated to be ~3500 Ci using the uniform temperature model and ~2800 Ci using the AYER release

model. Since the dose to the individual is proportional to the total amount released during the interval, the calculated dose is relatively insensitive to the core release model. The dose received during the 4- to 12-h interval calculated using the AYER model is ~80% of that calculated using the simplified model. The AYER model predicts that some additional dose will be received by the individual after 12 h from the iodine released following this time period. This additional dose will be small because: 1) most of the release occurred during the first 12 h, and 2) there is significantly more dispersion of the fission products in the atmosphere because of the better (assumed) weather conditions during the later time intervals. The uniform core temperature model predicts very little release after 12 h.

Figure 5 illustrates the time-dependent releases calculated using the uniform core temperature model for different total core release fractions. We have been assuming to this point that all of the iodine in the core is released, whereas GAC assumes that only 25% is released. Figure 5 illustrates the release for 100, 50, 25, and 10% (these curves can be obtained by scaling the 100% release case). It is of interest to compare these curves with those of Fig. 4. The amount released during the 4- to 12-h time period is directly proportional to the fractional core release (as expected), and it is relatively independent of the release model. Thus, the governing factor in the dose calculations is the total amount of the isotope released into the atmosphere of the containment building.

Fig. 5. Calculated ^{131}I release from containment building following the LOFC accident for total core release fractions.

V. CONCLUSIONS

The time-dependent release of ^{131}I from an HTGR core during the LOFC accident is dependent primarily on the time-dependent core temperatures and the failed fuel particle release constants; the release is nearly independent of the fuel failure model. A simple, uniform core temperature model adequately describes the release of ^{131}I during the LOFC accident. The model can also be used to describe the release of any volatile fission product that does not have long-lived precursors.

The thyroid dose calculation is relatively insensitive to the core release model because the most important factor in the calculations is the total amount of the isotope released following the accident, not the time-dependency of the release. Further work needs to be done to define better the total fraction of the core inventory of iodine that is available for release to the containment building. This release fraction is the single most important parameter in the dose calculations.

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REFERENCES

1. M. H. Schwartz, D. B. Sedgley, and M. M. Mendonca, "SORS: Computer Programs for Analyzing Fission Product Release from HTGR Cores during Transient Temperature Excursions," General Atomic Company report GA-A12462 (April 1974).
2. K. E. Schwartztrauber and F. A. Silady, "CORCON: A Computer Program for Analysis of HTGR Core Heatup during a Hypothetical Loss of Forced Circulation," General Atomic Company report GA-12868 (July 1974).
3. R. G. Lawton, "The AYER Heat Conduction Computer Program," Los Alamos Scientific Laboratory report LA-5613-MS (May 1974).
4. Regulatory Guide 1.3, Directorate of Regulatory Standards, U. S. Atomic Energy Commission (June 1974).
5. Regulatory Guide 1.4, Directorate of Regulatory Standards, U. S. Atomic Energy Commission (June 1973).
6. Fulton Generating Station PSAR, Philadelphia Electric Company, Appendix C, Change 8 (May 1974), p. C.6-1.
7. Fulton Generating Station PSAR, Change 3 (January 1974), Fig. 6.2.1-2.
8. Fulton Generating Station PSAR, Appendix C, Change 8 (May 1974), Table C.6-1.
9. J. J. Dinunno, F. D. Anderson, R. E. Baker, and R. L. Waterfield, "Calculation of Distance Factors for Power and Test Reactor Sites," USAEC report TID-14844, Division of Licensing and Regulation (1962).
10. Fort St. Vrain FSAR, Public Service of Colorado, Appendix D.
11. Fulton Generating Station PSAR, Appendix C, Change 8 (May 1974), p. C.6-3.
12. Y. A. Zysin, Fission Product Yields and Their Mass Distribution (Consultants Bureau, New York 1964), p. 110.
13. S. Glasstone and A. Sesonske, Nuclear Reactor Engineering (O. Van Nostrand, Princeton, 1963), p. 15.

APPENDIX A

INVENTORY OF ^{131}I

Since ^{131}I has a relatively short half-life (8 days), equilibrium will be reached after a few weeks of reactor operation. This isotope is generated directly from fission with a yield of 0.031 (Ref. 12). Since $1\text{ W} = 3.1 \times 10^{10}\text{ fissions/s}$ (Ref. 13), then the equilibrium activity of ^{131}I per watt of reactor power is

$$A = \frac{(0.031)(3.1 \times 10^{10})}{(3.7 \times 10^{10})} \text{ Ci/W} \\ = 2.59 \times 10^{-2} \text{ Ci/W}.$$

The core inventory (equilibrium activity) for a 3000 Mwt reactor is then

$$I = (3 \times 10^9)(2.59 \times 10^{-2}) \text{ Ci} \\ = 7.78 \times 10^7 \text{ Ci}.$$

APPENDIX B
DETAILED ^{131}I RELEASE

Detailed ^{131}I release from the containment building was calculated using the uniform core temperature model and the containment building model. The same assumptions that were used in the Fulton Plant PSAR¹¹ were used here:

1. The containment building leak rate is 0.1%/day for the first 24 h following the accident and 0.05%/day thereafter.
2. Fifty percent of the iodine leaking from the containment building is collected in the Supplementary Leak Collection System and exhausted through filters with efficiencies of 95% for elemental iodine, 95% for the methyl iodine, and 99% for particulates.
3. The ^{131}I released is in the form of 91% elemental, 5% particulate, and 4% organic (Regulatory Guide 1.4).
4. The containment cleanup system filter efficiencies are 90% for elemental iodine, 70% for methyl iodine, and 99% for particulate.
5. The cleanup rate is one containment volume per hour.

The results of the time-dependent release calculations of ^{131}I are shown in Table B-I. The second column gives the release to the environment calculated using the simple release model and the last column gives release values presented in the Fulton Plant PSAR.⁸ Results of the calculations made with the simplified model indicate a higher

TABLE B-I
 ^{131}I RELEASE FROM THE CONTAINMENT BUILDING
DURING THE LOFC ACCIDENT

Time Interval (h)	Uniform Core Temperature Model Release (Ci)	Fulton PSAR Release (Ci)
0-2	0	0.8
2-4	9.5	25.9
4-6	58.4	85.4
6-8	135.0	120.0
8-10	158.1	95.6
10-12	97.5	59.7
12-14	32.9	38.9
14-18	7.3	42.5
18-24	0.2	24.3
24-30	0	3.9
30-40	0	2.4
40-96	0	0.2
Total	498.9	499.6

release during the time interval 6-12 h than do the results shown in the PSAR; this higher release reflects the larger source strength predicted by the simplified model during this time interval (Fig. 1). The total release calculated using the uniform core temperature model agrees well with the total release presented in the PSAR.