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FISSION PRODUCT CONTROL AND FUEL ELEMENT RELEASE AT THE PEACH BOTTOM HTGR NUCLEAR POWER STATION

(Results of Postconstruction Research and Development Procedures
DM-1, GM-1, GM-2, JM-1, and JM-8)

Work done by:

C. L. Allen
E. E. Anderson
R. D. Burnette
D. D. Busch
D. R. Lofing
B. D. Snow*
W. Knapp**
C. Orlando**

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Report written by:

D. R. Lofing
E. E. Anderson
W. E. Bell

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*Present address: General Dynamics Corporation, Convair Division.

**Philadelphia Electric Company, Peach Bottom Nuclear Power Station.

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GULF GENERAL ATOMIC COMPANY
P.O. BOX 81608, SAN DIEGO, CALIFORNIA 92138

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ABSTRACT

During startup and operation of Core 1 in the Peach Bottom HTGR Nuclear Power Station, various tests were performed to study (1) the release of noble gas and iodine fission products into the helium coolant system and (2) the performance of the coolant gas purification system. This report presents the results of these tests.

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ERRATUM

GAMD-7904, FISSION PRODUCT CONTROL AND FUEL ELEMENT RELEASE AT THE
PEACH BOTTOM HTGR NUCLEAR POWER STATION

by

D. R. Lofing, E. E. Anderson, and W. E. Bell

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The following erratum should be noted in Gulf General Atomic Report
GAMD-7904:

Page 40, Fig. 15 --

Change the ordinate to read ACTIVITY IN MAIN LOOP (mCi)

1. INTRODUCTION AND SUMMARY

During startup and operation of Core 1 in the Peach Bottom high-temperature gas-cooled reactor, various tests were performed to study (1) the release of noble gas and iodine fission products into the helium coolant system and (2) the performance of the coolant gas purification system. This report presents the test data. The lifetime of Core 1 was 452 effective full power days.

Fission gas release (R/B) values were determined for the release of krypton, xenon, and iodine nuclides into the fuel element purge stream. The R/B values increased by a factor of about 10 during the period from startup to about 3×10^5 MW(t)-hr of accumulated reactor thermal energy. From that point, the R/B values remained relatively constant for a period and then decreased somewhat. The beginning-of-life R/B value for Kr-85m was 3×10^{-4} and the end-of-life value was about 3×10^{-3} . The R/B values showed an approximate square root of half-life dependence, and the release of the xenon nuclides was lower than that of the krypton nuclides having similar half-lives. The R/B data indicate that 50% to 100% of the fuel particles had failed coatings at the end of life.

The purge and fission product trapping systems performed better than anticipated. Measured delay times for krypton and xenon isotopes in the delay beds were higher than expected. Gaseous activity in the main coolant was maintained far below the design value of 4225 Ci, even though at the end of Core 1 life almost 10% of the fuel elements had cracked sleeves and were therefore improperly purged. It was found that appreciable reduction of purge flow could be tolerated without increasing main loop activity to unsatisfactory levels.

2. REACTOR DESCRIPTION

2.1. PEACH BOTTOM REACTOR SYSTEM

The core of the Peach Bottom HTGR is composed of 804 individual fuel elements vertically oriented in a close-packed array. The core array is cylindrical, with an effective diameter of 9 ft and an active height of 7.5 ft. Helium coolant gas (at an operating pressure of 350 psia) passes upward at a rate of 463,000 lb/hr through the tricuspid-shaped passages formed by the elements.

The primary coolant system consists of the reactor, two steam generators, and two helium compressors arranged to form two parallel loops for circulating the helium coolant.

The Peach Bottom fuel element has an overall length of 12 ft and an outside diameter of 3.5 in. and consists of an upper reflector section, a fuel-bearing middle section, a bottom reflector section, and an internal fission product trap containing activated carbon. A low permeability sleeve extending from the upper reflector to the bottom reflector contains the fuel compacts and the internal fission product trap. The fuel compacts consist of fuel particles in a graphite matrix. The fuel particles are between 200 and 600 μ in diameter and consist of uranium-thorium carbide particles coated with pyrolytic carbon.⁽¹⁾

Helium purge gas enters each fuel element through a porous plug in the upper-reflector piece and then flows downward and around the fuel compacts, sweeping volatile fission products out of the grooved space between the fuel compacts and the graphite sleeve. The purge gas then flows through the internal trap, where some of the fission products are adsorbed by the activated carbon. Volatile fission products leaving each internal trap enter a purge line leading to the external fission product trapping system.

The external trapping system consists of a series of cooled activated-carbon beds which, because of the dynamic character of adsorption, delay the noble gas fission products long enough to allow decay of the shorter-lived isotopes with subsequent deposition of the daughter products in the carbon traps. A small amount (50 to 100 lb/hr) of the exit gas from this delay system is diverted through a liquid-nitrogen-cooled activated-carbon bed, where the long-lived Kr-85 (10.76 yr) is removed for future disposal. Figure 1 is a schematic flow diagram of the system.

2.2. FISSION PRODUCT TRAPPING SYSTEM

The fission product trapping system comprises four separate sections:

1. The fission product condensibles trap (A-301) is the first stage of the fission product trapping system external to the reactor core. This trap contains 150 lb of activated carbon and is used to remove iodine and other non-noble gas fission products which penetrate the internal trap. There is very little delay of noble gases through this trap. The trap was designed to operate at 80° to 100°F. The actual operating temperature was around 52° to 101°F.⁽²⁾
2. The second stage of the fission product trapping system comprises water-cooled delay beds (A-302 and A-303), each containing 600 lb of activated carbon. These beds (WCDBs) delay the transport of the krypton and xenon isotopes long enough to allow the shorter-lived isotopes to decay in situ and thus remove both parent and daughter activity from the coolant gas. A-302 and A-303 were designed to operate at 60° to 108°F and 62° to 71°F, respectively, by cooling the incoming gas with a water chiller system. The actual operating temperatures achieved were somewhat cooler than design with A-302 operating at 45° to 47°F and A-303 at about 40°F.

3. The third stage, or low temperature delay bed (LTDB) section, contains five activated-carbon delay beds (A-304 through A-308). The first three beds each contain 1000 lb of carbon, while the last two are much larger, each containing 6000 lb of carbon. These beds get progressively cooler from precooling of the inlet gas with a Freon refrigeration system. A-304 was designed to operate at -48° to -96°F and A-308 at around -112°F . The actual operating temperature of these beds ranged from -91° to -112°F . All the krypton and xenon isotopes except Kr-85 (10.76 yr) are delayed long enough to decay to their daughter products, which are held in these chilled beds. The Kr-85 does not decay significantly in these beds, and breakthrough occurs as soon as sorption saturation is reached; the majority of the Kr-85 returns to the main coolant.
4. The fourth stage of the fission product trapping system is a liquid-nitrogen-cooled activated-carbon bed containing about 300 lb of activated carbon and operating at -320°F . About 10% of the fission product trapping system helium flow at the exit of the LTDB section is diverted through this trap. The remainder of the flow goes to the purified helium handling system and returns to the main coolant. This trap, operated as a classic adsorption bed at near-liquid-nitrogen temperature, adsorbs the Kr-85 from the purge stream and holds it for future disposal. Depending on the amount of other impurities present in the purge gas (e.g., N_2 and CO), this trap will adsorb krypton for up to a year before regeneration is required.

The expected delay times for krypton and xenon under design conditions in the previously described delay beds are shown in Table 1. These values were determined by extrapolation of laboratory measurements using Kr-85 and Xe-133 tracer⁽³⁾ activities. The values take into account the significant amount of heat generation anticipated for the design release.

Fig. 1. Diagram of Peach Bottom purification system (process parameters and times shown are design values)

TABLE 1
 EXPECTED DELAY TIMES FOR KRYPTON AND XENON IN THE
 HTGR EXTERNAL TRAPPING SYSTEM

Trap No.	Temp (°F)	Activated Carbon (lb)	Kr Delay (hr)	Xe Delay (hr)
A302	80	600	0.10	1.34
A303	67	600	0.16	2.72
A304	-96	1000	3.0	249
A305	-103	1000	6.9	900
A306	-108	1000	12	2000
A307	-111	6000	82	15600
A308	-112	6000	85	16500

3. METHODS OF MEASUREMENT

The purpose of this section is to describe methods for the determination of (1) the release of krypton, xenon, and iodine nuclides from Peach Bottom fuel compacts into the purge stream, (2) the effective permeability of noble gas fission products in the graphite fuel element sleeve, and (3) the noble gas delay through the fission product trapping system delay beds.

3.1. DETERMINATION OF R/B FOR NOBLE GASES

A useful term for expressing fission product retentivity of the fuel is the R/B value, or release factor, where R is the quantity of an isotope of krypton, xenon, or iodine residing external to the core under steady state (or equilibrium) conditions* and B is the total quantity of an isotope of krypton, xenon, or iodine at steady state. Expressed in another manner, R/B is the ratio of release rate to birth rate measured under steady state (or equilibrium) conditions.

Evaluation of R for the fuel element purge stream is accomplished by measuring the activity of an isotope in the purge stream, in which essentially 100% of all the activity released by the fuel compacts leaves the core. More specifically, the determination of R is made by measuring the specific activity ($\mu\text{Ci}/\text{cm}^3(\text{ntp})$)** of an isotope in the purge stream gas by means of gamma ray spectrometry. This specific activity value and the purge flow rate are used to calculate R. The details of sample taking and analysis are given in Section 4 of this report.

*Radioactive equilibrium is defined as $dC_i/dt = 0$. That is, where the rate of change in concentration of an i^{th} isotope does not change with respect to time.

**Microcuries/ cm^3 of helium at 1 atm and room temperature.

The following relationships are used for the evaluation of R/B values for the krypton and xenon isotopes. The value of R is determined using the following equation:

$$R = \frac{S_i k_i F}{\lambda_i} \text{ (Ci)},$$

where S_i = specific activity of i^{th} isotope in the purge stream gas sample ($\mu\text{Ci}/\text{cm}^3(\text{ntp})$),

k_i = conversion constant, 10^{-6} (Ci/ μCi),

F = purge flow rate ($\text{cm}^3(\text{ntp})/\text{sec}$),

λ_i = decay constant for i^{th} isotope.

The value of B is calculated from a knowledge of the steady state thermal power of the reactor. Thus,

$$B = P k_2 Y \text{ (atoms/sec)},$$

where P = reactor power (MW),

k_2 = conversion constant (3.2×10^{16} fissions/MW-sec),

Y = chain fission yield of i^{th} isotope.

This equation gives the birth rate of an isotope in atoms/sec at equilibrium, and this is equal to the decay rate in disintegrations/sec. The value B must have the same dimension as R. Thus,

$$B = \frac{P k_2 Y}{k_3} \text{ (Ci)},$$

where k_3 = conversion constant (3.7×10^{10} dps/Ci).

Finally,

$$\frac{R}{B} = \frac{S k_1 k_3 F}{P k_2 Y \lambda_i},$$

and, for simplicity, the constants can be combined to give the useful equation

$$\frac{R}{B} = \frac{S_i k_F}{PY\lambda_i} , \quad (1)$$

where $k = k_1 k_3 / k_2 = 1.09 \times 10^{-12}$.

3.2. DETERMINATION OF R/B FOR IODINE

Iodine release measurements cannot be made in the same straightforward manner as the noble gas measurements because of sorption in graphite and the internal trap and plateout on reactor components and sample lines. The method for iodine analysis is to determine the xenon daughter activity following a reactor shutdown. Once the core has cooled to an ambient temperature and fission processes have ceased, the release of krypton and xenon emanating from the fuel will drop to zero. The xenon isotopes present in the gas stream after core cooldown are there as a result of decay of iodine isotopes outside the fuel. This has been shown by taking purge stream grab samples at various times after cool-down and noting that the specific activity of a xenon isotope decreases with the half life of the iodine precursor.

Only two isotopes of iodine (I-135 and I-133) can be determined by this method, since only these two yield detectable radioactive xenon daughters:

The disintegration rate of the iodine isotope thus becomes the production rate (atoms/sec) of the xenon daughters. The newly born xenon atoms are then immediately released into the purge stream. (The elevated temperature of the internal traps aids in the release of xenon.)

It can be shown that

$$\text{dps}(I_i) = \text{aps}(Xe_i) = \frac{\text{dps}(Xe_i)/\text{cm}^3 \times F}{\lambda(Xe_i)},$$

where $\text{dps}(I_i)$ = total activity for the i^{th} isotope of iodine (disintegrations/sec),

$\text{aps}(Xe_i)$ = total production rate of xenon daughter (atoms/sec),

$\text{dps}(Xe_i)/\text{cm}^3$ = specific activity of xenon daughter ($\text{dps}/\text{cm}^3(\text{ntp})$),

F = purge flow rate ($\text{cm}^3(\text{ntp})/\text{sec}$),

$\lambda(Xe_i)$ = decay constant for Xe_i .

Dividing both sides of the equation by the conversion constant $3.7 \times 10^{10} \text{ dps/Ci}$, converting the right side to μCi , and correcting for decay, one obtains

$$A_{I_i} = \frac{S_{Xe_i} \times F \times k_1 \times e^{\lambda_{I_i} t}}{\lambda(Xe_i)},$$

where A_{I_i} = activity level of I_i at time of reactor shutdown (Ci),

S_{Xe_i} = specific activity of Xe_i in the purge stream ($\mu\text{Ci}/\text{cm}^3(\text{ntp})$),

$k_1 = \text{Ci}/\mu\text{Ci} (10^{-6})$,

λ_{I_i} = decay constant for i^{th} isotope of iodine precursor,

t = time from reactor shutdown to measurement of daughter activity.

The value A determined for I_i is equal to the value R in previously described equations for krypton and xenon. Iodine fractional release values are then calculated as for krypton or xenon:

$$R/B(I_i) = \frac{S_{Xe_i} \times F \times k_1 \times e^{\lambda_{I_i} t} \times k_3}{P \times k_2 \times Y \times \lambda(Xe_i)}, \quad (2)$$

where k_2 = conversion constant (3.2×10^{16} f/MW-sec),
 P = reactor power (MW),
 Y = chain fission yield for I_i ,
 k_3 = conversion constant (3.7×10^{10} dps/Ci).

3.3. DETERMINATION OF IODINE PLATEOUT IN MAIN LOOP

A knowledge of iodine plateout in the main circuit is important from the standpoint of maintenance of (or remedial action on) main circuit components.

The method requires the measurement of the specific activity of the decay daughter activities Xe-135 and Xe-133 from the main loop helium following a reactor shutdown. The measurement requires that the fuel element purge and steam generator purge flow rate be maintained at normal condition following a reactor shutdown for a period of 6 hr. This allows time for the fuel to cool to ambient temperature and a sufficient clean-up time for the Xe-135 and Xe-133 in the main loop that originated from diffusion through the fuel element sleeves. The quantities of Xe-135 and Xe-133 that remain after about 3 hr of cleanup are those originating from I-135 and I-133 plateout decay.

The radioactive equilibrium that exists under these conditions can be represented as follows:

$$N_2 = \frac{\lambda_1}{[(r + \lambda_2) - \lambda_1]} N_1^0 (e^{-\lambda_1 t}),$$

where N_2 = number of atoms of the daughter activity,

N_1^0 = number of original atoms of parent activity,

λ_1 = decay constant for parent,

λ_2 = decay constant for daughter,

t = time from reactor shutdown to measurement of the daughter activities,

$r = \text{cleanup rate of main loop} = \text{total cleanup rate (lb/hr/helium inventory} \times 3600 \text{ or sec}^{-1}\text{)}.$ *

In order for this equation to be valid, the value of r must be much greater than λ_2 . Otherwise, a case of no equilibrium is approached, resulting in a more complicated solution.

The normal value for r in the Peach Bottom reactor is

$$\frac{1000 \text{ lb/hr}}{900 \text{ lb He}} \times \frac{1}{3600} = 3.09 \times 10^{-4} \text{ sec}^{-1},$$

whereas the values of λ_2 are $2.11 \times 10^{-5} \text{ sec}^{-1}$ for Xe-135 and $1.52 \times 10^{-6} \text{ sec}^{-1}$ for Xe-133.

The value for r in this case is sufficiently greater than λ_2 for either isotope of xenon to fulfill the above requirements and is the controlling factor determining steady state concentration of xenon isotopes in the main loop.

The previously given equation for N_2 can be reduced to a more usable form by multiplying by λ_2 :

$$\lambda_2 N_2 = \frac{\lambda_2 (\lambda_1 N_1^0) (e^{-\lambda_1 t})}{r + \lambda_2 - \lambda_1}.$$

Rearranging yields

$$\lambda_1 N_1^0 = \frac{(\lambda_2 N_2) (r + \lambda_2 - \lambda_1)}{\lambda_2 (e^{-\lambda_1 t})},$$

*The cleanup rate is the sum of the fuel element purge and steam generator purge.

where $\lambda_1 N_1^0$ = disintegration rate of I_i at time of shutdown,
 $\lambda_2 N_2$ = disintegration rate of Xe_i at time after shutdown.

Dividing both sides of the equation by 3.7×10^{10} dps/Ci and changing the xenon value to a volumetric basis gives

$$I = X \times V_{He} \times \frac{(r + \lambda_2 - \lambda_1)}{\lambda_2} e^{-\lambda_1 t}, \quad (3)$$

where I = steady state level of the specific iodine isotope at reactor shutdown (Ci),
 X = specific activity in the main loop for a specific xenon isotope at time t after reactor shutdown (Ci/cm³(ntp)),
 V_{He} = helium inventory (cm³(ntp)).

3.4. DETERMINATION OF FISSION PRODUCT TRAPPING SYSTEM DELAY TIMES

A means of evaluating the performance of the fission product trapping system is to measure the delay times for the noble gases through the delay beds. This can be accomplished by measuring the inlet and outlet specific activities of individual isotopes and using these data in the following equation:

$$C = C_o e^{-\lambda_i \tau}, \quad (4)$$

where C_o = inlet concentration of isotope i ,
 C = outlet concentration of isotope i ,
 λ_i = decay constant of isotope i ,
 τ = delay time.

The delay times can also be calculated using flow and temperature data during the test along with the mass of activated carbon in the bed and laboratory-determined dynamic adsorption coefficients.⁽³⁾ The following equation is used for this calculation:

$$\tau = \frac{KM}{F}, \quad (5)$$

where K = dynamic adsorption coefficient (cm^3/g),
 M = mass of activated carbon (g),
 F = volumetric flow rate (cm^3/sec).

3.5. DETERMINATION OF EFFECTIVE SLEEVE PERMEABILITY (k_{eff})

A parameter for relating the main coolant specific activity to the purge stream specific activity or fuel body fission product release is the effective sleeve permeability (k_{eff}). The relationship is:

$$k_{\text{eff}} = \left(\frac{S_L}{S_p} \right)_i \frac{2(\lambda_i + r)v}{(a/l)}, \quad (6)$$

where k_{eff} = effective permeability coefficient of noble gas (cm^2/sec),
 $(S_L/S_p)_i$ = ratio of specific activity of an i^{th} isotope in the primary coolant to the specific activity in the purge stream,
 λ_i = decay constant (sec^{-1}),
 r = purification system cycling rate constant = total of both purification and stream generator purge flow rate divided by helium inventory (sec^{-1}),
 v = void volume of loop (cm^3),
 a = mean area of fuel element sleeves (cm^2),
 l = thickness of sleeves (cm).

Equation (6) applies as long as other means of introduction of activity to the main loop (e.g., by cracked sleeves) are unimportant. The equation does not apply to Kr-85 since the purification system returns it.

4. SAMPLING AND TEST EQUIPMENT

Associated with the reactor is a gas sampling system⁽⁴⁾ which consists of an array of various valves, flowmeters, pressure gauges, switches, and interconnecting piping. Sample piping from the purge stream, main coolant gas stream, and various points throughout the purification system are brought together to a common manifold at the gas sampling station designated as XSM-310. Gas samples can be taken at will from any one of these selected sample points by proper manipulation of the various valves. The sampling system reduces the reactor gas pressure to near atmospheric pressure, and gas samples are taken for analysis of the radioactive krypton and xenon isotopes. Gas sample volumes are either 2.7 or 125 cm³ (ntp).

Gas samples collected in the sample vials are analyzed on a 400-channel⁽⁵⁾ pulse height analyzer using a 3 in. x 3 in. sodium iodide (thallium-activated) scintillation detector. Gamma rays emitted by the isotopes are used to identify the specific isotopes of interest. Isotopes normally of interest are listed in Table 2 with their half lives and gamma rays of importance.

A Cary flow-through ionization chamber with a vibrating reed type electrometer is also associated with the main coolant gas by way of a bypass purge line from the steam generator inlet moisture sample line. Helium pressure from the main coolant loop is reduced to about 15 psig and continually purged through the chamber. Readout from the instrument is recorded on a strip chart recorder for continuous monitoring of the noncondensable gaseous activity during reactor operation. The electrometer is capable of measuring total loop helium noncondensable gaseous activity from a few millicuries through any probable activity.

TABLE 2
NOBLE GAS ISOTOPEs OF INTEREST

Isotope	Half-Life, $t_{1/2}$	γ -Ray Energy (MeV) (a)
Kr-85	10.76 yr	0.517
Kr-85m	4.4 hr	0.150
Kr-87	76 min	0.403
Kr-88	2.8 hr	0.191
Kr-89 (Rb-89)	3.2 min (15 min)	(1.05)
Xe-133	5.27 day	0.081
Xe-135	9.2 hr	0.250
Xe-138 (Cs-138)	17 min (32.2 min)	(1.43)

(a) γ -ray energies used in the analyses.

The system was calibrated using the expression

$$A = \frac{mV}{Q\rho} \quad , \quad (7)$$

where A = activity level of gaseous fission products in primary coolant (Ci),

m = molar ratio of helium in primary loop to that in ion chamber,

Q = calibration factor for Xe-133 (amp/Ci),

V = voltage read from recorder (volts),

ρ = resistance of range-change resistor used on vibrating-reed electrometer (ohms).

For a constant coolant inventory of 900 lb of helium in the main loop and a pressure of 15 psig in the ion chamber, the value of m is calculated to be 5.7×10^6 .

By injecting a known amount of Xe-133 into the ion chamber and measuring the resulting current, the value of Q was found to be 2.36×10^{-6} amp/Ci. If the 10^{12} -ohm resistor is in use, the following relationship between the primary loop gaseous activity in terms of Xe-133 equivalent and the recorder voltage is obtained:

$$A = 2.42 V \quad .$$

5. EXPERIMENTAL DATA AND ANALYSES

5.1. GASEOUS ACTIVITY DETERMINATION AT 30% POWER (TEST DM-1)⁽⁶⁾

On January 24, 1967, the Peach Bottom HTGR was operated at 1 to 2 MW(t); this level was slowly increased to 35 MW(t), which was attained on January 30, 1967. The first major noble gas fission product behavior test (DM-1) was performed on March 10, 1967. Objectives of the test were to:

1. Determine R/B at 30% power.
2. Determine krypton and xenon delay times through water-cooled delay beds and the first of the low temperature delay beds.
3. Determine the krypton and xenon activity in the main loop.

Reactor conditions during this initial test were:

Reactor power (thermal)	30.60 MW
Purge flow rate	665 lb/hr
Steam generator purge flow rate	153 lb/hr
Total purge flow rate	818 lb/hr
Main loop inventory	761 lb
Main loop pressure	330 psia
Purge stream pressure between A-302 and A-303	315 psia
Purge stream pressure at A-304	295 psia
Temperature of purge gas sample point at inlet A-301	80°F
Temperature of bed A-301	Average 65°F
Temperature of beds A-302 and A-303	Average 47°F
Temperature of bed A-304	-91°F
Temperature of beds A-305, A-306, A-307, A-308	-112°F
Time reactor at steady state	>48 hr
Main loop ion chamber indication	25 mCi

The measurements during this initial test yielded (1) R/B data for the fuel elements (measured for the main purge stream at various locations), (2) delay times through water-cooled delay beds, and (3) main loop activity. Test equipment and methods of measurement described in Sections 3 and 4 were utilized.

5.1.1. Fission Product Release from Fuel Compacts into Purge Stream

Radioactive gas samples were analyzed, and the results are shown in Table 3. The log R/B data are plotted versus log half life ($t_{1/2}$) in Fig. 2. The R/B data were derived from the specific activity data given in Table 3 for the inlet to bed A-301.

Figure 2 shows that the R/B values obtained during test DM-1 are almost a direct function of the square root of half life. This indicates that release was predominately diffusion-controlled and that recoil release was relatively unimportant.

5.1.2. Determination of Delay Times Through Delay Beds A-301, A-302, A-303, and A-304

Measured delay times for krypton and xenon isotopes in delay beds A-301 through A-304 were obtained using observed data and Eq. (4).

Delay times for the delay beds were calculated using flow and temperature conditions during test DM-1 and Eq. (5). Values of K, the dynamic adsorption coefficient, were taken from Ref. 3.

Table 4 summarizes the results of both evaluations for comparison purposes. Delay beds A-301, A-302, and A-303 were evaluated as one bed because the sample points are at the inlet of A-301 and the outlet of A-303.

TABLE 3
SPECIFIC ACTIVITIES OF NOBLE GAS ISOTOPES IN THE PURGE STREAM AT VARIOUS
LOCATIONS AS MEASURED ON 3/10/67 AT 30% POWER (TEST DM-1)

Source	Activity ($\mu\text{Ci}/\text{cm}^3$ (ntp))						
	Kr-85m	Kr-87	Kr-88	Kr-89	Xe-133 ^(a)	Xe-135	Xe-138
A-301 inlet	8.1×10^{-3}	2.1×10^{-2}	1.4×10^{-2}	2.8×10^{-1}	3.3×10^{-3}	1.4×10^{-2}	6.5×10^{-2}
A-303 outlet	6.5×10^{-3}	1.3×10^{-2}	1.3×10^{-2}	N.D.	2.2×10^{-3}	4.5×10^{-3}	N.D.
A-304 outlet	5.8×10^{-4}	N.D. ^(b)	3.8×10^{-4}	N.D.	N.D.	N.D.	N.D.
LTDB outlet	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Main loop	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

(a) Not at equilibrium.

(b) None detected.

Fig. 2. Half-life dependence of R/B data measured at inlet to bed A-301 during test DM-1 performed on 3/10/67 at 30% power

TABLE 4
BED DELAY TIMES MEASURED AND CALCULATED IN TEST DM-1

Bed No.	Delay Times (min)	
	Measured Average	Calculated for Existing Conditions
A-301 - A-303	Kr, 53 ^(a)	Kr, 37
	Xe, 900 ^(b)	Xe, 697
A-304	Kr, 817 ^(c)	Kr, 733

(a) Average of values for Kr-85m, Kr-87, and Kr-88.

(b) Value for Xe-135.

(c) Average of values for Kr-85m and Kr-88.

As indicated by the data in Table 4, the delay times through beds A-301 through A-303 are somewhat longer than calculated from conditions prevalent at the time of test DM-1. Nevertheless, the observed and calculated data are in reasonable agreement considering inaccuracies in determining isotopic concentration values. Also, bed scale-up and temperature and flow rate measurements contribute some uncertainty.

The measured delay time of krypton through A-304, the first low temperature delay bed, is quite close to the calculated delay time. Xenon, of course, could not be measured as the delay time in bed A-304 is too long.

The delay times in Table 4 cannot be compared directly with those in Table 1 because of differences in temperature and flow conditions.

5.1.3. Main Coolant Activity at 30% Power

With the reactor at 30% power (during test DM-1), grab samples from the main coolant showed no detectable activity. This was due to the sensitivity limits of this type of analysis. The pressure in the manifold of XSM-310 for the main coolant sample position is only 10 psig. This relatively low

pressure results in a relatively small sample size. The only other means of monitoring the main coolant activity was the Cary flow-through ion chamber.

Accordingly, since individual isotopic activities were not detectable in the main coolant gas, the effective sleeve permeability (k_{eff}) had to be derived from the ion chamber reading. Using $k_{\text{eff}} = 10^{-5}$ cm²/sec on the basis of GAIL III-B performance,* one calculates from Eq. (6) that the total gaseous activity in the Peach Bottom main coolant should be approximately 90 mCi. At 30% power (during test DM-1) the Cary ion chamber showed only 25 mCi of noncondensable activity. This level indicates a k_{eff} of about 3×10^{-6} cm²/sec.

This value for k_{eff} is three to four times better (lower) than that found for the GAIL III-B test element. The better purge performance is probably due in part to cooler fuel elements as compared with GAIL III-B and in part to inaccuracies in the measurements.

5.2. INITIAL MEASUREMENT OF NOBLE GAS RELEASE VALUES AT 100% POWER (TEST GM-1) (8)

The reactor was first taken to full power on May 26, 1967, and commenced commercial operation on June 1. In July, the first major full power fission product noble gas analyses (test GM-1) were performed.

5.2.1. Main Coolant Activity

The level of fission gas release into the main coolant (with all fuel elements properly purged) was found to be satisfactorily low, indeed much lower than expected. A comparison of expected, design, and observed activity levels in the main coolant at 5000 MWd is given in Table 5.

*GAIL III-B was a General Atomic in-pile loop where a full diameter prototype of a Peach Bottom fuel element was irradiated for 2 yr. (7)

TABLE 5
 REACTOR MAIN COOLANT ACTIVITY AT 100% POWER
 (With All Fuel Elements Properly Purged)

<u>Case</u>	<u>Activity Inventory (Ci)</u>
Expected at beginning of life	108
Design	4225
Observed at 5000 MWd	0.2

5.2.2. Fission Product Release from Fuel Compacts into Purge Stream

Analyses for individual xenon and krypton radioactive species were made by counting gaseous samples taken from the fuel element purge stream at 100% power. The R/B values obtained are shown in Fig. 3. The R/B data appear to vary with the square root of the half life as anticipated. The values are slightly higher than those observed in test DM-1, which was performed at 30% reactor power.

5.3. LONG-TERM MEASUREMENT OF FISSION PRODUCT RELEASE FROM FUEL COMPACTS AT 100% POWER (TEST JM-1)⁽⁹⁾

Test JM-1 was essentially a continuation of test GM-1, since both were performed at full power operation. However, test JM-1 was performed periodically throughout the life of the reactor core in order to (1) correlate R/B values with fuel burnup, (2) observe any long-term changes in the effectiveness of the fission product trapping system, and (3) study the change in main coolant activity as a function of long-term operation.

In Figs. 4 through 10, purge stream R/B values for Kr-85m, Kr-87, Kr-88, Kr-89, Xe-133, Xe-135, and Xe-138 are shown for the life of Core 1 as a function of accumulated reactor thermal energy. These data show that the R/B values increased by a factor of about 10 during the period from startup to about 3×10^5 MW(t)-hr of accumulated reactor thermal energy. From that point, the R/B values remained relatively constant for a period and then decreased somewhat. The decrease is particularly noticeable for the isotopes

Fig. 3. Noble gas release into purge stream at full power (at 5000 MWd)

Fig. 4. R/B values for release of Kr^{85m} into the purge stream

Fig. 5. R/B values for release of Kr^{87} into the purge stream

Fig. 6. R/B values for release of Kr^{88} into the purge stream

Fig. 7. R/B values for release of Kr^{89} into the purge stream

Fig. 8. R/B values for release of Xe-133 into the purge stream

Fig. 9. R/B values for release of Xe-135 into the purge stream

Fig. 10. R/B values for release of Xe-138 into the purge stream

with the shortest half lives, 17-min Xe-138 and 3.2-min Kr-89. The decrease at the very end of each plot may be attributed to the measurements having been taken at reduced power levels. However, general decreases in R/B values may be explained by the expansion of the fuel compacts, which gradually closed the gap between the compacts and the fuel element sleeves. This resulted in improved heat transfer and lower fuel temperatures, and hence lower release rates.

The Core 1 release behavior, except for the decrease, correlates with the release behavior observed during the GAIL III-B experiment, where a full-diameter section of a Peach Bottom fuel element was irradiated for 2 yr in the General Atomic in-pile loop.⁽⁷⁾

In Fig. 11 end-of-life R/B data for Core 1 are plotted against the half life of the fission products. The R/B values show an approximate square root of half-life dependence, and the release of the xenon nuclides is lower than that of the krypton isotopes. This behavior is the same as was observed in earlier measurements (see Figs. 2 and 3) and in the GAIL III-B experiment.

The R/B values, after they became relatively constant (i.e., after about 6×10^5 MW-hr), are close to values obtained in experiments at 1000°C on 200- μ m-diameter (Th,U)C₂ particles held in graphite matrix material.⁽¹⁰⁾ This indicates that a large fraction (in the range of 50% to 100%) of the Core 1 fuel particles had cracked coatings.

5.4. EVALUATION OF FISSION PRODUCT DELAY BED PERFORMANCE

Attempts were made to determine delay times for krypton and xenon in the water-cooled delay beds during full power reactor operation. However, due to other operations, it was difficult to hold the fuel element purge stream flow rate constant for a period sufficiently long (24 hr) to establish an equilibrium concentration of krypton and xenon in these beds and in the first low temperature delay bed, A-304. This resulted in continuous fluctuation of inlet and outlet activity concentrations.

Fig. 11. End-of-life R/B values versus half life for Core 1

The best value for the water-cooled delay beds was determined for Xe-135 (9.1 hr). On October 10, 1967, the A-301 inlet concentration was $0.23 \mu\text{Ci}/\text{cm}^3$ and the A-303 outlet was $0.046 \mu\text{Ci}/\text{cm}^3$, giving a Xe-135 delay time of 21 hr. This value is considerably higher than expected, indicating satisfactory performance.

Krypton-89 (3.2 min) and Xe-138 (17 min) have never been observed at the outlet of the water-cooled delay beds, indicating that the delay time is more than sufficient to accomplish the purpose for which the beds were intended.

5.5. MAIN COOLANT NOBLE GAS ACTIVITY DURING REACTOR OPERATION

The main coolant gaseous activity, as measured by the Cary electrometer, remained essentially constant during the initial period of operation (June 1967 to January 1968). The total activity for all noncondensable gaseous species in the main loop helium was generally less than 0.4 Ci. Considering that the expected activity at the beginning of life was 108 Ci and the design activity was 4225 Ci, this value is satisfactorily low.

It was observed that even though the purge stream activity increased by about a factor of 10, the main coolant activity only doubled during the initial period of operation. Based on the following measured values, the release fraction through the fuel element sleeves, as determined in October 1967, was about 6×10^{-5} , which corresponds to an effective sleeve permeability (k_{eff}) of $7 \times 10^{-7} \text{ cm}^2/\text{sec}$:

<u>Stream</u>	<u>Xe-135 Concentration ($\mu\text{Ci}/\text{cm}^3$)</u>
Fuel element purge	9.0×10^{-2}
Main coolant loop	5.1×10^{-6}

This release fraction is about two orders of magnitude lower than that for GAIL III-B and about three times lower than the design xenon release fraction of 2×10^{-4} . The reasons for this excellent performance are very complicated. Possible explanations are: (1) unlike the Peach Bottom elements, the GAIL III-B elements did not have a purge stream inlet porous plug to develop a significant pressure drop along the entire sleeve; (2) the pore size distribution may be more favorable in the Peach Bottom sleeves than in the GAIL III-B sleeve; and (3) the Peach Bottom fuel element temperatures are generally lower than the GAIL III-B fuel element temperature and the effective permeability is temperature-dependent.

The main coolant activity, as indicated by the Cary instrument, is presented in Figs. 12, 13, and 14 for 1967, 1968, and 1969, respectively. As shown in Fig. 12, during reactor full power operation for the year 1967, the total main coolant activity inventory remained between 150 and 400 mCi and increased only very slightly with time. There was one unexpected increase (argon contamination), which will be discussed later.

In 1968 the main coolant activity increased as a result of the cracking of fuel element sleeves and consequent loss of purge flow for the particular elements. This subject is discussed in the following sections.

5.5.1. Main Coolant Activity Increase due to Improperly Purged Fuel Elements

At approximately 2300 hr on January 9, 1968, a rapid increase was noted on the Cary ionization chamber recorder. Figure 15 is a plot of the activity as a function of time, as taken from the recorder.

At 2300 hr on January 10, 1968, a 125-cm^3 main loop gas sample was taken, principally to determine whether the increase in fission gas release observed with the Cary instrument was due to short-lived krypton and xenon nuclides. Krypton-89 (3.2 min) and Xe-138 (14 min) were observed for the first time in the main loop. These isotopes had not been previously observed, even when concentrated gas samples were taken. The presence of these two isotopes indicated a source of relatively fresh fission products, such as normally found in the fuel element purge stream.

Fig. 12. Main coolant activity during June to December, 1967

Fig. 13. Main coolant activity during January to October, 1968 (Nos. represent the estimated number of improperly purged fuel elements)

Fig. 14. Main coolant activity during March to October 1969 (Nos. represent estimated number of improperly purged elements)

Fig. 15. Peach Bottom main loop activity during rapid increase on January 9, 1968

Table 6 shows the specific activities in the main loop and purge stream before the activity increase, and Table 7 shows comparable data after the increase. A comparison of the release fractions from the fuel to the purge stream is given in Table 8. These data indicate that the increase in main coolant activity level was due to fuel element or standoff failure and not increased fuel particle failure.

It was concluded from the data that at least one fuel element was not being purged properly. Therefore, the reactor was shut down, and the faulty fuel element was located and removed for examination. The element (C05-05) proved to have a cracked sleeve about midway axially. Because of pressure drop in the core, the upper half of the element was purged directly into the main coolant. It was determined that sudden increases in main coolant activity levels could be used as an indication of fuel element failure. Furthermore, as estimated from the first two activity increases, each improperly purged element contributed about 3 Ci of activity to the main loop. During 1968 the main loop activity increased to 36.2 Ci as shown in Fig. 13; and during a shutdown in October of that year, eleven additional improperly purged fuel elements were located and removed.

During 1969 operation, additional improperly purged elements were indicated by the Cary instrument, as shown in Fig. 14. The maximum amount of activity observed to be present was 270 Ci. Based on 3.3 Ci of activity per improperly purged element (as estimated from eleven elements previously found), 82 additional elements were estimated to have failed. At this point the reactor was shut down for the 450 EFPD (effective full power day) core examination. An additional 78 improperly purged elements were located, showing that the Cary reading is a good indication of the number of failed elements.

5.5.2. Rapid Activity Increase due to Argon Contamination

On December 6, 1967, a portion of the gases trapped in the liquid-nitrogen-cooled trapping system was inadvertently allowed to escape into the main loop helium. This gas contained some stable argon that had been removed from the main helium inventory during the normal operation of the

TABLE 6
MAIN COOLANT AND PURGE STREAM SPECIFIC ACTIVITY BEFORE
RAPID INCREASE
($\mu\text{Ci}/\text{cm}^3$, ntp)

Date	Sample	Kr-85m	Kr-87	Kr-88	Kr-89	Xe-135
11/16/67	Main loop	1.1×10^{-5}	1.5×10^{-5}	1.6×10^{-5}	(a)	5.4×10^{-6}
11/16/67	Purge stream	0.24	0.55	0.65	10.0	0.18

(a) Not detected.

TABLE 7
MAIN COOLANT AND PURGE STREAM SPECIFIC ACTIVITY AFTER RAPID INCREASE
($\mu\text{Ci}/\text{cm}^3$, ntp)

Date	Time	Sample	Kr-85m	Kr-87	Kr-88	Kr-89	Xe-133	Xe-135	Xe-138
1/10/68	2300	Main loop	2.2×10^{-4}	3.3×10^{-4}	3.9×10^{-4}	6.4×10^{-4}	1.6×10^{-5}	1.5×10^{-4}	2.1×10^{-4}
1/11/68	1400	Main loop	2.4×10^{-4}	2.6×10^{-4}	5.5×10^{-4}	5.9×10^{-4}	---	1.5×10^{-4}	2.0×10^{-4}
1/11/68	1500	Purge stream	0.32	0.86	0.70	7.1	0.11	0.24	2.1

TABLE 8
RELEASE FRACTIONS (R/B) FROM FUEL TO PURGE STREAM

Date	Kr-85m	Kr-87	Kr-88	Kr-89	Xe-133	Xe-135	Xe-138
Before rapid increase:							
12/7/67	3.0×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	3.7×10^{-4}	5.7×10^{-3}	9.6×10^{-4}	3.9×10^{-4}
After rapid increase:							
1/11/68	3.2×10^{-3}	1.5×10^{-3}	1.8×10^{-3}	2.8×10^{-4}	7.3×10^{-3}	1.2×10^{-3}	3.7×10^{-4}

liquid nitrogen system. The stable argon gas became activated in the reactor core to form Ar-41, which was detected by the Cary ionization chamber. As the Ar-41 began to build up, the cleanup system began to remove it with a 1-hr time constant. The result was a rather symmetrical peak, which is shown in Fig. 16.

The stable argon and the radioactive Ar-41 were held up in the low temperature delay beds long enough for the Ar-41 to decay (1.83-hr half life). However, the stable argon eventually passed through the low temperature delay beds and returned to the reactor to become activated again, resulting in a second peak. On each pass through the low temperature delay beds, the pulse of stable argon began to spread out or disperse, resulting in slightly wider and shorter peaks (as observed on the Cary recorder). Concurrently, on each pass through the low temperature delay beds, the downstream liquid-nitrogen-cooled system permanently removed a portion of the stable argon. The end result was the gradual disappearance of the Ar-41 activity in about 100 hr. The time interval between activity peaks, which is a measure of the mean delay time through the low temperature delay beds for argon, was found to be 15.6 hr.

The effects on main loop activity produced during this period by the purge flow reductions for test GM-2 and the power changes for the xenon decay tests are also shown in Fig. 16. It is interesting that it was possible to observe these effects on the Cary ionization chamber and to explain the phenomena, even though all three conditions were in operation simultaneously.

5.6. REDUCED PURGE FLOW EXPERIMENT (TEST GM-2)⁽¹¹⁾

On December 7 and 8, 1967, a reduced purge flow experiment (test GM-2) was run for the first time. Table 9 shows the results for three flow rates corresponding to about 100%, 75%, and 50% of the available fuel element purge stream. The test was run at approximately 97% of full power at rated steam conditions.

Fig. 16. Ar-41 activity release to main loop as measured by Cary electrometer

TABLE 9
RESULTS OF REDUCED PURGE FLOW EXPERIMENT (TEST GM-2)

	Kr-85m	Kr-88	Kr-87	Kr-89	Xe-138	Xe-135
Purge Flow Rate = 777 lb/hr (corrected)						
R/B (purge)	2.3×10^{-3}	1.1×10^{-3}	9.5×10^{-4}	2.2×10^{-4}	3.1×10^{-4}	7.3×10^{-4}
Main coolant, $\mu\text{Ci}/\text{cm}^3$	6.8×10^{-6}	5.3×10^{-6}	9.3×10^{-6}	N.D. (a)	N.D.	3.4×10^{-6}
Purge stream, $\mu\text{Ci}/\text{cm}^3$	0.25	0.49	0.60	6.1	1.9	0.16
$k_{\text{eff}}, \text{cm}^2/\text{sec}$	8.7×10^{-7}	3.7×10^{-7}	6.5×10^{-7}	---	---	6.3×10^{-7}
Purge Flow Rate = 585 lb/hr (corrected)						
R/B (purge)	3.0×10^{-3}	1.9×10^{-3}	1.3×10^{-3}	3.7×10^{-4}	3.9×10^{-4}	9.6×10^{-4}
Main coolant, $\mu\text{Ci}/\text{cm}^3$	1.7×10^{-5}	2.9×10^{-5}	2.3×10^{-5}	N.D.	N.D.	1.3×10^{-5}
Purge stream, $\mu\text{Ci}/\text{cm}^3$	0.44	0.76	1.1	13.7	3.2	0.28
$k_{\text{eff}}, \text{cm}^2/\text{sec}$	1.0×10^{-6}	1.1×10^{-6}	7.5×10^{-7}	---	---	1.1×10^{-6}
Purge Flow Rate = 386 lb/hr (corrected)						
R/B (purge)	2.6×10^{-3}	1.4×10^{-3}	1.0×10^{-3}	2.7×10^{-4}	3.7×10^{-4}	7.3×10^{-4}
Main coolant, $\mu\text{Ci}/\text{cm}^3$	2.3×10^{-5}	3.4×10^{-5}	3.2×10^{-5}	N.D.	N.D.	1.7×10^{-5}
Purge stream, $\mu\text{Ci}/\text{cm}^3$	0.57	1.2	1.3	15.0	4.6	0.32
$k_{\text{eff}}, \text{cm}^2/\text{sec}$	8.3×10^{-7}	6.5×10^{-7}	7.4×10^{-7}	---	---	9.5×10^{-7}

(a) Not detected.

Release factors (R/B) and the fuel element sleeve effective permeability coefficient (k_{eff}) were computed for the three different purge flow rates from samples taken from the main loop and the fuel element purge stream. The k_{eff} value was calculated as described in Section 3.5.

The k_{eff} values shown in the Table 9 for a purge flow of 585 lb/hr are probably high because of contamination of the XSM-310 gas manifold. A purge stream sample was inadvertently taken before the main loop sample, resulting in a high value for the main loop specific activity. The overall results show the k_{eff} values to be significantly lower than design values and lower by a factor of about 10 than values for the GAIL III-B, indicating satisfactory performance.

Because of the unforeseen Ar-41 activity in the main loop, it was not possible to determine accurately the level of activity reached on each purge flow reduction. A fair estimate can be made, however, from a graphic subtraction of the Ar-41 contribution shown in Fig. 16. After subtracting Ar-41 contribution at 777 lb/hr, there were 315 mCi in the main loop, at 585 lb/hr there were 470 mCi in the main loop, and at 386 lb/hr there were 830 mCi in the main loop. Thus, a reduction in purge flow from 77.7% to 38.6% of the normal (1000 lb/hr is considered normal) resulted in less than a factor of three increase in main coolant activity. These results indicate that much lower purge flows could be tolerated.

5.7. IODINE RELEASE (R/B) AND PLATEOUT IN THE MAIN LOOP (TEST JM-8)⁽¹²⁾

Equilibrium quantities of iodine nuclides in the purge system and in the main loop were determined, and from these data R/B values were determined. These results are described in the following sections.

5.7.1. Main Loop and Purge Stream Inventory

Several iodine release measurements were performed during Core 1 operation. Equilibrium quantities of iodine nuclides in the purge system and in the main

loop were determined. The data presented in Table 10 compare activity levels during normal core conditions and with improperly purged fuel elements present in the core. The amounts shown for normal core conditions on 11/16/67 are estimated using Xe-135 main coolant specific activity and purge stream R/B values during normal reactor operation. The values for 1/11/68 and 10/23/68 were actually determined following core shutdown. It can be seen (1) that the quantities of iodine nuclides in the main loop, even though relatively low, were higher than normal as a result of cracked fuel element sleeves and (2) that the quantities were proportional to the number of cracked sleeves.

TABLE 10
I-133 AND I-135 INVENTORY IN MAIN LOOP AND PURGE STREAM

Date	Core Condition	Total Activity (Ci)			
		Main Loop		Purge Stream	
		I-133	I-135	I-133	I-135
11/16/67	Normal	---	<0.1 ^(a)	9,700 ^(a)	2,400 ^(a)
1/11/68	1 cracked sleeve	8.0	3.2	11,300	2,990
10/23/68	11 cracked sleeves	110	29	12,000	3,300

(a) Estimated from Xe-135 specific activity and R/B values.

5.7.2. Fuel Release Fractions for Iodine

Iodine release fraction (R/B) values calculated on the basis of release into the purge stream are shown in Table 11 for various times throughout the life of Core 1. Comparison of these values indicates only a slight increase in R/B values over the specified time period. No further determinations were made between 10/23/68 and the time of Core 1 removal.

TABLE 11
IODINE RELEASE FRACTIONS
(R/B for I-135 and I-133)

Date	I-135	I-133	Burnup (MW-hr)
7/12/67	2.3×10^{-4}	1.3×10^{-3}	125,000
8/1/67	3.4×10^{-4}	1.0×10^{-3}	168,000
8/31/67	3.8×10^{-4}	1.5×10^{-3}	243,000
1/12/68	4.3×10^{-4}	1.8×10^{-3}	466,000
10/23/68	6.0×10^{-4}	1.9×10^{-3}	828,000

REFERENCES

1. Turner, R. F., and R. B. Duffield, "HTGR Fuel Element Performance in the Peach Bottom Reactor," USAEC Report CONF-670713-7, General Dynamics Corporation, General Atomic Division, 1967.
2. Westlake, W. J., and H. E. Stelling, "Peach Bottom Helium Purification System Performance," USAEC Informal Report GAMD-7902, Gulf General Atomic Incorporated, 1968.
3. Burnette, R. D., W. W. Graham, III, and D. C. Morse, "The Removal of Radioactive Krypton and Xenon from a Flowing Helium Stream by Fixed Bed Adsorption," USAEC Report TID-7622, General Dynamics, General Atomic Division, pp. 218-235.
4. General Dynamics Corporation, General Atomic Division, "Operation Manual for the Radiochemical Sampling System (System XSM-310) for the Peach Bottom Reactor," unpublished data.
5. Lofing, D. R., E. E. Anderson, and L. R. Zumwalt, "The Use of Gamma-Ray Spectroscopy in the Study of Fission-Product Release from Nuclear Fuels," General Dynamics Corporation, General Atomic Division Report GA-4615, 1963.
6. Gulf General Atomic Incorporated, "Peach Bottom Materials Test Procedure - DM-1," unpublished data.
7. Turner, R. F., et al., "Irradiation Test of the Gail III-B Fuel Element in the General Atomic In-pile Loop," USAEC Report GA-5314, General Dynamics Corporation, General Atomic Division, 1964.
8. Gulf General Atomic Incorporated, "Peach Bottom Materials Test Procedure - GM-1," unpublished data.
9. Gulf General Atomic Incorporated, "Peach Bottom Materials Test Procedure - JM-1," unpublished data.
10. Zumwalt, L. R., E. E. Anderson, and P. E. Gethard, "Fission Product Release from (Th,U)C₂-Graphite Fuels," in Ceramic-Matrix Fuels Containing Coated Particles. Proceedings of the Meeting on Ceramic Coated Particle Nuclear Fuels, November 5-6, 1962, Battelle Memorial Institute (TID-7654).

11. Gulf General Atomic Incorporated, "Peach Bottom Materials Test Procedure - GM-2," unpublished data.
12. Gulf General Atomic Incorporated, "Peach Bottom Materials Test Procedure - JM-8," unpublished data.

BIBLIOGRAPHY

40-MW(e) Prototype High-Temperature Gas-Cooled Reactor Postconstruction Research and Development Program Progress Reports

GA-5700-Period Ending July 31, 1964
GA-5924-August, 1964, through October, 1964
GA-6134-November, 1964, through January, 1965
GA-6406-February, 1965, through April, 1965
GA-6647-May, 1965, through July, 1965
GA-6829-August, 1965, through October, 1965
GA-6995-November, 1965, through January, 1966
GA-7232-February, 1966, through April, 1966
GA-7426-May, 1966, through July, 1966
GA-7595-August, 1966, through October, 1966
GA-7830-November, 1966, through January, 1967
GA-7988-February, 1967, through April, 1967
GA-8153-May, 1967, through July, 1967
GA-8370-August, 1967, through October, 1967
GA-8500-November, 1967, through January, 1968
GA-8679-February, 1968, through April, 1968
GA-8816-May, 1968, through July, 1968
GA-9080-August, 1968, through October, 1968
GA-9237-November, 1968, through January, 1969
GA-9360-February, 1969, through April, 1969
GA-9494-May, 1969, through July, 1969
GA-9797-August, 1969, through October, 1969
GA-9898-November, 1969, through January 1970