BMI-1604

FISSION-PRODUCT-RELEASE MEASUREMENT FROM CLAD FUEL SPECIMENS

BATTELLE MEMORIAL INSTITUTE

Printed in USA
Price 50 cents

Available from the
Office of Technical Services
U. S. Department of Commerce
Washington 25, D. C.

Report No. BMI-1604

UC-25 Metals, Ceramics,
and Materials
(TID-4500, 18th Ed.)

Contract No. W-7405-eng-92

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November 28, 1962

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FISSION-PRODUCT-RELEASE MEASUREMENT FROM CLAD FUEL SPECIMENS

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Xenon-133 and -135, krypton-85m and -87, and iodine-131, -133, and -135 release from UO_2 fuel specimens with four types of metallic claddings was determined during irradiation in 2200 to 3200 F flowing helium and oxygen. Fission-gas samples cold trapped from the furnace sweep gas were identified in a gamma analyzer. Information on iodine release was obtained by monitoring xenon produced by iodine decay after irradiation and by washing and scrubbing the loop after irradiation to recover iodine plated out in the system. Uranium contamination of portions of the loop made it impossible to detect releases below a certain level from the specimens. Specimens clad with niobium or niobium-29.6 w/o aluminum-33.7 w/o titanium exhibited release fractions in the range of 10^{-6} at 2200 F and 10^{-5} at 3000 and 3200 F. Release values for iron-30 w/o chromium-1 w/o yttrium-clad material at 2200 F were around 2×10^{-2}. Material clad with iron-25 w/o chromium-1 w/o yttrium-4.67 w/o aluminum exhibited a release fraction of 1.6×10^{-3} during irradiation in 2200 F oxygen and oxygen saturated with water vapor.

INTRODUCTION

An important property of fuel-element cladding materials is their ability to retain fission products within the fuel element and minimize radioactive contamination of the coolant. This ability becomes increasingly difficult to secure with higher fuel operating temperatures. Consequently, the rate of fission-product migration through the cladding must be considered in selecting cladding materials for elevated-temperature operation.

Such considerations led to the program described in this report. Information was required on the fission-product retention capabilities of a variety of cladding materials developed by GE-ANPD for operation at temperatures of 2200 F and above. For this purpose a program was undertaken to investigate the level of release of iodine and fission-gas isotopes during irradiation of fueled specimens clad with the materials of interest.

EXPERIMENTAL PROCEDURES

The experiments were conducted in a loop contained in a beam tube of the Battelle Research Reactor. Fission gases were collected in a fission-gas trapping system from the sweep gas which flowed over the specimen. Iodine was collected for analysis by washing and scrubbing the various components in the loop after completion of the irradiation experiment.

Description of Equipment

The specimens were irradiated in a loop contained in an 8-in.-diameter beam tube of the BRR. The specimen itself was contained in a furnace attached to the end of an easily removable 2-1/2-in.-diameter beam-hole plug. The furnace and removable plug are shown in Figure 1. An outer containment can was placed over the furnace to provide a vacuum seal. Vycor was used as the outer can for the initial experiments with a vacuum seal being provided by O-rings. A stainless steel can, silver soldered to the plug, was used in later experiments because of difficulties in maintaining the O-ring seals.

The furnaces were made from high-purity Norton alumina tubes with platinum-40 w/o rhodium resistance windings using standard laboratory construction procedures. The furnace components are shown in Figure 2 and consist of an inner tube which is grooved to hold the wire and an outer tube which is placed over the windings for thermal insulation. Prior to placement of the outer tube, the wire is first covered with high-purity Alundum cement. The position of baffles in the furnace is also shown. The specimen is placed between the baffles in the inner tube. Two platinum-platinum 10 w/o rhodium thermocouples are placed directly at the rear of the specimen and exit through the protection tubes upon which the rear baffles are built.

The platinum-40 w/o rhodium winding was satisfactory for all experiments at 2200 F. However, at 2500 F the windings exhibited extremely short lives, 10 to 20 hr, in-pile. Previously, a similar furnace had been built and operated out-of-pile under identical experimental conditions in the absence of a neutron flux. This furnace operated for 260 hr at 2500 F and for an additional 60 hr at temperatures up to about 3200 F. The in-pile furnace burned out only after over 10 hr at the latter temperature. Analyses showed appreciable amounts of silicon in the failed windings, and it was suspected that this element, formed by transmutation of aluminum, might be responsible for the failure. However, the amount of silicon formed in the refractory Al_2O_3 by neutron capture and decay is negligible compared with the silicon already present as an impurity. It appears more probable that pickup by the platinum-40 w/o rhodium of silicon already present in the refractory is enhanced somehow by the irradiation.

As a result of this problem, only one reasonably long-time experiment was conducted at 2500 F and above. This was accomplished with a furnace in which tantalum was substituted for the platinum-40 w/o rhodium windings.

Helium and oxygen were used as carrier gases at flow rates of 25 to 60 cm^3 per min. The helium was high-purity AEC-type which was passed through a Deoxo unit, which combines oxygen and hydrogen to form water, and through a molecular sieve to remove the water vapor. The gas entered the specimen plug, flowed over the outside of the furnace, where it was preheated, and then flowed down through the furnace tube over the specimen. A zirconium getter was placed just before the specimen to remove any additional oxygen contained in the gas. The gas flowed from over the specimen into the gas-trapping system. Flow was maintained by a vacuum pump at the end of the trapping system. Exhaust gas was released through a stack system.

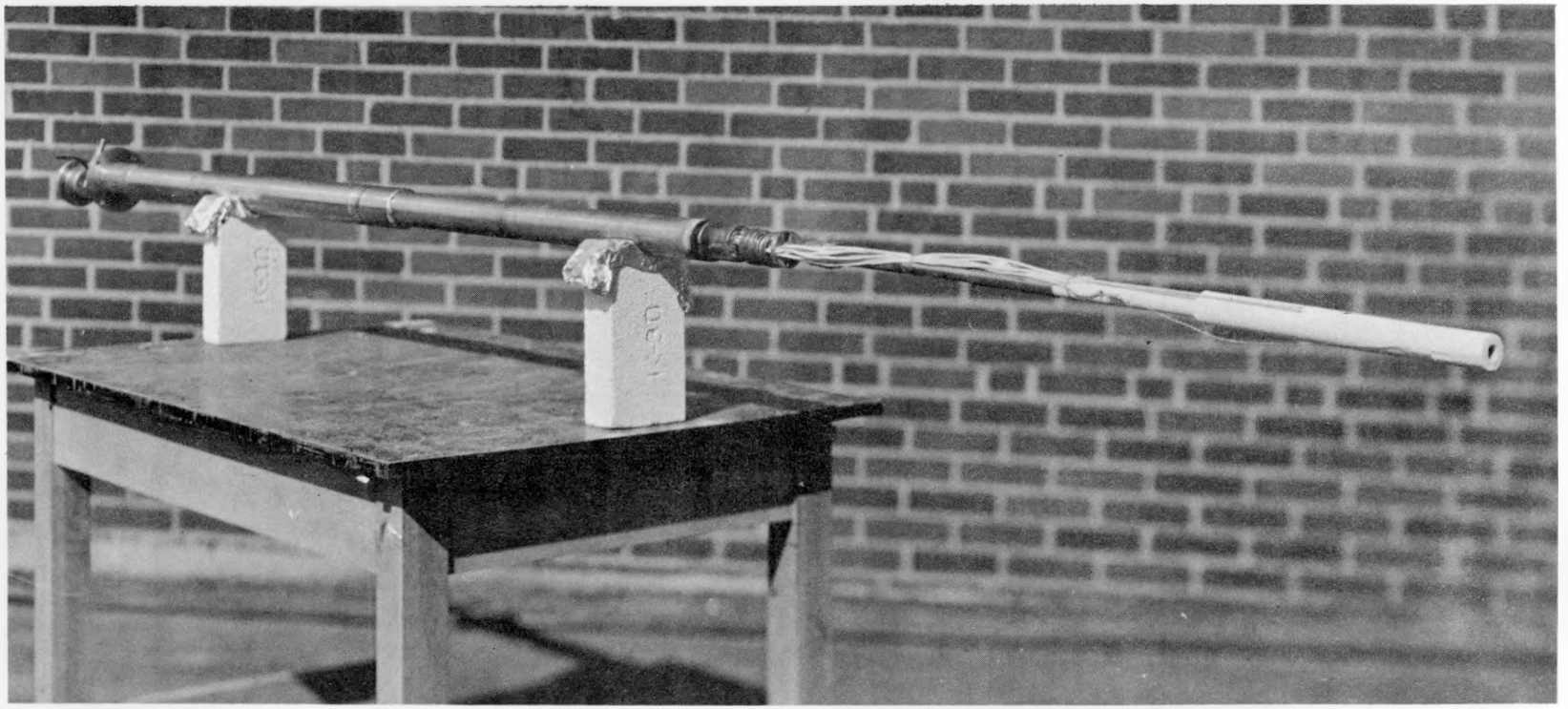

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FIGURE 1. SPECIMEN PLUG WITH FURNACE IN PLACE WITHOUT OUTER CONTAINMENT CAN

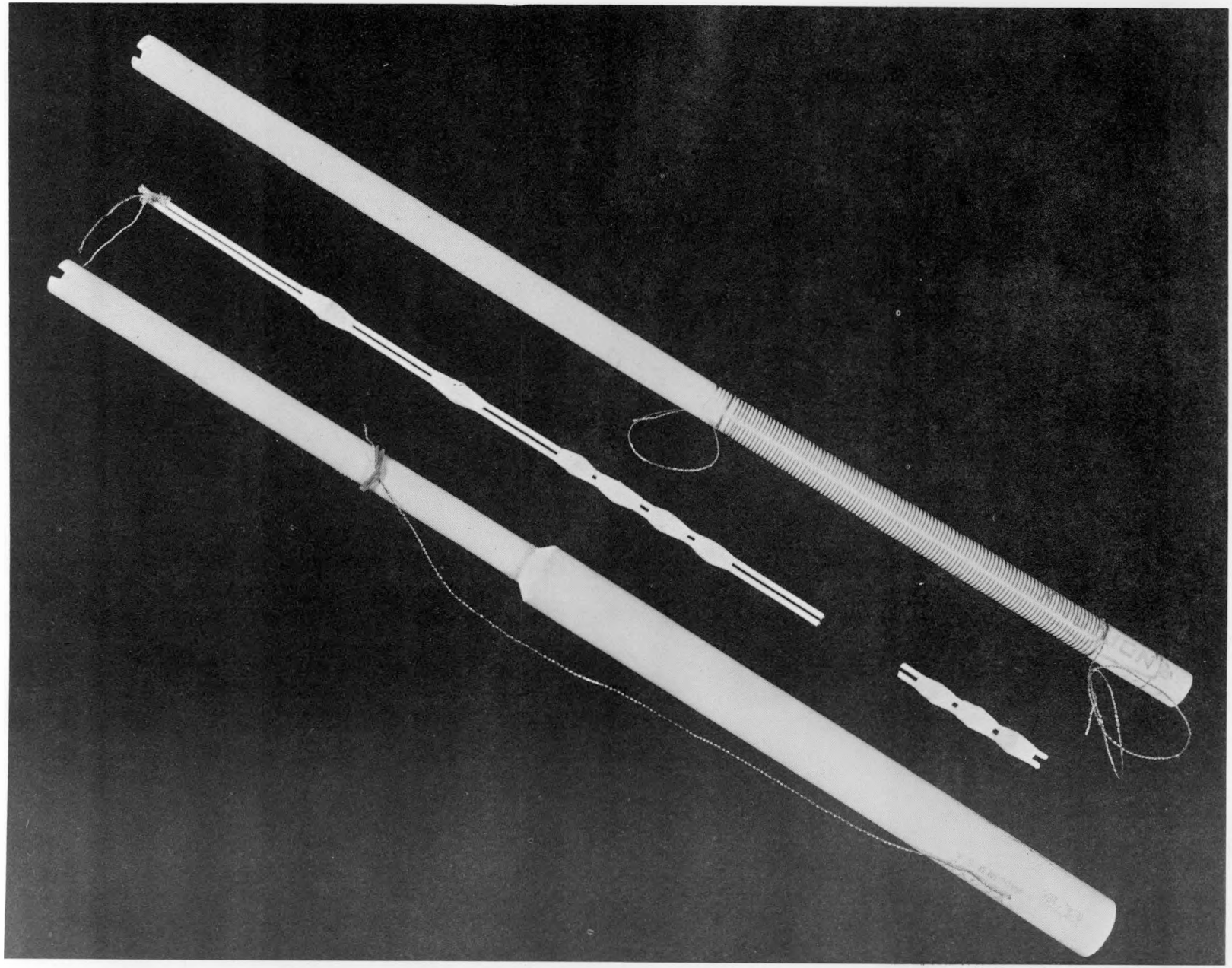

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FIGURE 2. FURNACE COMPONENTS

Collection and Interpretation of Data

Traps for fission gases were removed for analysis every 4 hr except at the start of an experiment when they were removed more often. The traps contained activated charcoal maintained at liquid-nitrogen temperatures. A sketch illustrating the basic trapping system is shown in Figure 3. The gas flows through a bypass line when the trap is removed. Trapping times were varied to obtain gas samples of a convenient activity to analyze and ranged from 1 to 30 min. To test the efficiency of the activated-carbon traps a second trap was placed behind the first trap. Analysis of the second trap showed that some leakage through the first trap did take place. This amounted to about 10 per cent for trapping times of 15 min. For trapping times of 5 min, no noticeable leakage was detected.

When the released activities became high a different trapping technique was used. In such cases, a gas sample of known volume was obtained in a small vial and analyzed.

All traps were counted in a 100-channel gamma analyzer with a sodium iodide crystal. Counting times were varied from 1 to 5 min, depending on activity of the trap. Analyses were made for xenon-133 and xenon-135 and for krypton-85m and krypton-87. Krypton-88 and xenon-135m were detected, but quantitative analysis of these isotopes was not attempted because of overlap in the gamma-energy spectrum.

Results of the gas analyses were calculated as R/B values, where R is the number of atoms release per second, and B is the number of atoms produced per second by fission and precursor decay at equilibrium. Thus, R/B is the fractional release of a particular isotope. The B, or production, values are calculated from the fission rate based on uranium-235 content and neutron flux. The R values are obtained by gamma counting the gas traps.

In order to determine the neutron flux and fission rate, a burnup analysis was performed on the first specimen after the experimental run. For this purpose cesium-137 analysis was considered unreliable because of the high temperatures involved, while a niobium-95 analysis could not be run because the specimen was clad with niobium. Consequently, a cerium-144 determination was performed for the burnup. The burnup results indicated an effective neutron flux of 0.5×10^{12} nv, with the reactor running at 75 per cent power during the experiment. However, the reactor ran at various power levels during subsequent experiments. The fluxes, consequently, were adjusted from this value on the basis of the reactor power during a particular experiment.

Titanium-0.58 w/o cobalt dosimeter wires were also included with the specimen in some of the runs. The fluxes indicated by these wires were in general agreement with those based on the burnup analysis corrected for reactor power level.

Data were also sought on iodine release, in particular iodine-131, iodine-133, and iodine-135. The latter two isotopes are precursors to xenon-133 and xenon-135, for which gas-trap analyses were obtained during irradiation.

For this purpose gas trapping was continued after shutdown of the furnace and retraction of the specimen plug out of the neutron flux in the beam hole. In this manner, only the xenon-133 and xenon-135 which formed by decay of iodine-133 and iodine-135

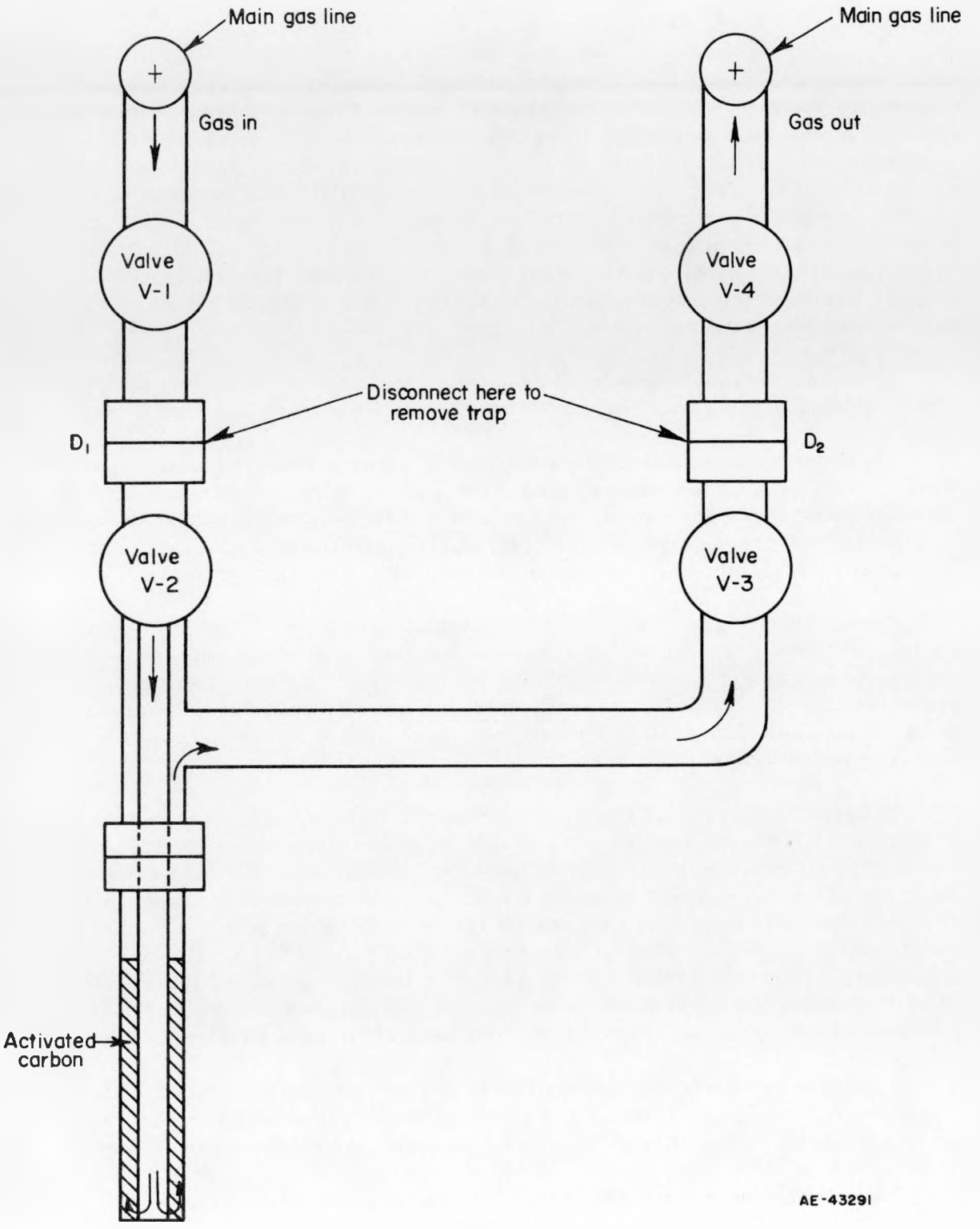

FIGURE 3. SIMPLIFIED SKETCH OF ANALYTIC FISSION-GAS TRAP ILLUSTRATING DISCONNECT POINTS

were collected, permitting a calculation of the amounts of iodine which had plated out in the tubing of the loop. Subsequently, individual parts of the furnace and specimen plug were washed out separately, including all tubing leading to the gas-trapping system. The stainless steel tubing and alumina furnace parts were washed in 1N HCl, while copper tubing in the system was washed in 1N NH_4OH. Two washings were made of each part. The resulting solutions were then analyzed by gamma counting and radiochemical techniques for iodine-131, iodine-133, and iodine-135.

Description of Specimens

For these experiments, eight different UO_2 fuel specimens were supplied by GE-ANPD. The specimens were clad with four different materials and are described in Table 1.

TABLE 1. DESCRIPTION OF EXPERIMENTAL SPECIMENS

Cladding Composition, w/o	Specimen	Run	Total UO_2, g	Total Uranium-245, g	Cladding Thickness, mils	Specimen Dimensions, in	
						Diameter	Length
100 Nb	A	1	4.87	0.32(a)	10(b)	0.210	1.69
	B	6	5.17	0.33(a)	10(b)	0.210	1.69
	C	8	4.83	0.31(a)	13	0.216	1.69
	D	9	4.90	0.31(a)	13	0.216	1.69
Nb-29.6 Al-33.7 Ti	E	2,5	4.7	0.41(a)	13	0.216	1.69
Fe-30 Cr-1 Y	F	3,10	0.51	0.42	7-10	0.035	19
	G	4	0.52	0.43	7-10	0.035	21
Fe-25 Cr-1 Y-4.67 Al	H	7	0.63	0.51	7-10	0.035	--

(a) Fuel consisted of fully enriched UO_2 dispersed in depleted UO_2; all other specimens contained enriched UO_2 only.

(b) 6 mils was machined off the as-received specimen diameters.

The niobium- and niobium-aluminum-titanium-clad specimens were cylinders with approximately 1/4-in.-thick end caps. These specimens were fueled with a dispersion of fully enriched UO_2 in depleted UO_2. The remaining specimens, clad with iron-chromium-base alloys were in wire form, the wire being wrapped around a tube made of the same alloy as the cladding. The fueled core in these wires was enriched UO_2.

Two of the as-received niobium-clad specimens were machined to obtain surface samples for analysis of uranium content. The uranium in the niobium was less than the 0.01 w/o detection limit.

The test conditions for each experiment are shown in Table 2. A majority of the specimens were exposed at 2200 F with helium as the sweep gas. However, tests were also run at 2500 F, and one specimen was irradiated briefly at 3200 F. Also, oxygen and oxygen saturated with water vapor at room temperature were employed as the sweep gas in two experiments involving specimens clad with iron-chromium-base alloys. The neutron flux varied in direct proportion to the power level, being 0.5×10^{12} at 75 per cent power.

TABLE 2. EXPERIMENTAL CONDITIONS

Run	Specimen	Cladding Composition, w/o	Temperature, F	Sweep Gas	Reactor Power Level, per cent of full power	Time of Run, hr
1	A	100 Nb	2200	He	75.0	168
2	E	Nb-29.6 Al-33.7 Ti	2200 and 2500	He	77.5	220
3	F	Fe-30 Cr-1 Y	2200	He	82.5	109
4	G	Fe-30 Cr-1 Y	2200	He	82.5	4
5	E	Nb-29.6 Al-33.7 Ti	2500	He	97.5	10
6	B	100 Nb	2200 and 2500	He	97.5	26
7	H	Fe-25 Cr-1 Y-4.67 Al	2200	O_2 and H_2O-saturated O_2	97.5	245
8	C	100Nb	2200 and 2500	He	100	66
9	D	100 Nb	2500, 3000, and 3200	He	96.5	110
10	F	Fe-30 Cr-1 Y	2200	He and O_2	98.0	85

The times of test depended upon a number of factors. Tests were generally run long enough to make certain that equilibrium releases were being observed and then were stopped. A few tests were discontinued when it was believed that a specimen was defective or had failed during the test. In some cases, tests were terminated by a furnace failure.

EXPERIMENTAL RESULTS

The results of fission-gas trapping are given in the following paragraphs in terms of release fractions or R/B values. The results are presented in graphical form. In the majority of the experiments, the release fractions for all four isotopes for which analyses were made fell within fairly well defined limits, and within the limits of accuracy of analysis no differences in release fractions were apparent among the four isotopes. Consequently, the range within which the release fractions fell are generally shown. In those cases where excessive scatter or deviations from this general behavior were observed actual data points or identifications of isotopes showing unique behavior are given.

Data are also presented for three iodine isotopes. From these data inferences concerning release fractions for iodine are drawn.

Before proceeding to the exceptional results with clad specimens, a supplementary experiment should be described, since the results have a significant bearing on the release fraction which can be detected. This experiment was run after completion of all specimen tests. The experiment was conducted because the insignificant difference in release fractions for a number of niobium-clad and niobium-aluminum-titanium specimens suggested that the primary source of release might be contaminant uranium in various parts of the furnace and specimen plug rather than from the specimen. A blank run was made without a specimen at 2200 F under conditions identical to those employed in testing specimens. Fission-gas analyses showed that the amount of gas generated within the loop was sufficient to account for the release fractions obtained for a number

of the specimens. Consequently, for these experiments it can only be concluded that the release fraction is less than the number obtained.

Niobium-Clad Specimens

Four specimens, clad with niobium, were exposed to irradiation for fission-gas release studies. Release for three of these specimens is shown in Figure 4. The fourth specimen was apparently defective. It was exposed at 2500 and then 2200 F, exhibiting release fractions on the order of 10^{-2}. Data are not shown for this specimen.

The first specimen was exposed at 2200 F for a total of 168 hr (Run 1, Specimen A). During the first 11 hr of the experiment, an air leak developed in the loop system and the specimen was removed and examined visually and macroscopically in the BMI Hot-Cell Facility. No evidence of damage to the cladding was noted so the specimen was reinserted and the test continued. Release fractions are shown in Figure 4a. After 101 hr, another air leak developed, and the release of fission gases increased rapidly and then leveled off. The high background associated with argon activity, the argon being introduced with the air, made it impossible to analyze for any isotope other than xenon-135 during this final 67-hr period.

After removal from the loop, the specimen was examined in the hot cells and it was found that it had split into two pieces. The specimen diameter had increased from 0.210 in. to 0.213 in. and the cladding appeared oxidized. It was uncertain whether the specimen broke during irradiation or during removal from the loop. However, it appears certain that the increased release fraction during the last period of operation was a result of oxidation of the specimen.

The release fractions recorded for the first 101 hr of operation are of the order of magnitude that can be accounted for on the basis of fission-product production in and release from the furnace parts rather than from the specimen. Consequently, it must be concluded that the release fraction shown in Figure 4a represents maximum values, with the release fraction from the specimen itself probably being significantly lower.

A second specimen was exposed at 2200 F for 42 hr and then at 2500 F for 24 hr (Run 8, Specimen C). Results are shown in Figure 4b. No increase in release accompanied the increase in temperature from 2200 to 2500 F. As with the previous specimen, the release fractions observed can be accounted for on the basis of fission-gas generation by contaminant uranium in the system rather than release from the specimen.

A final niobium-clad specimen was exposed at 2200 F for 11 hr then at 2500 F for 65 hr, at 3000 F for 30 hr, and at 3200 F for roughly 4 hr (Run 9, Specimen D). Release fractions for the xenon and krypton isotopes as can be seen in Figure 4c increased slightly with increasing temperature but as with the previous specimens the source of the fission gases is believed to be principally uranium impurity in the furnace parts. However, xenon-133 release appeared to be higher than could be attributed to this source particularly at 3000 and 3200 F. This higher level of xenon-133 release is consistent with the advent of detectable diffusion release.

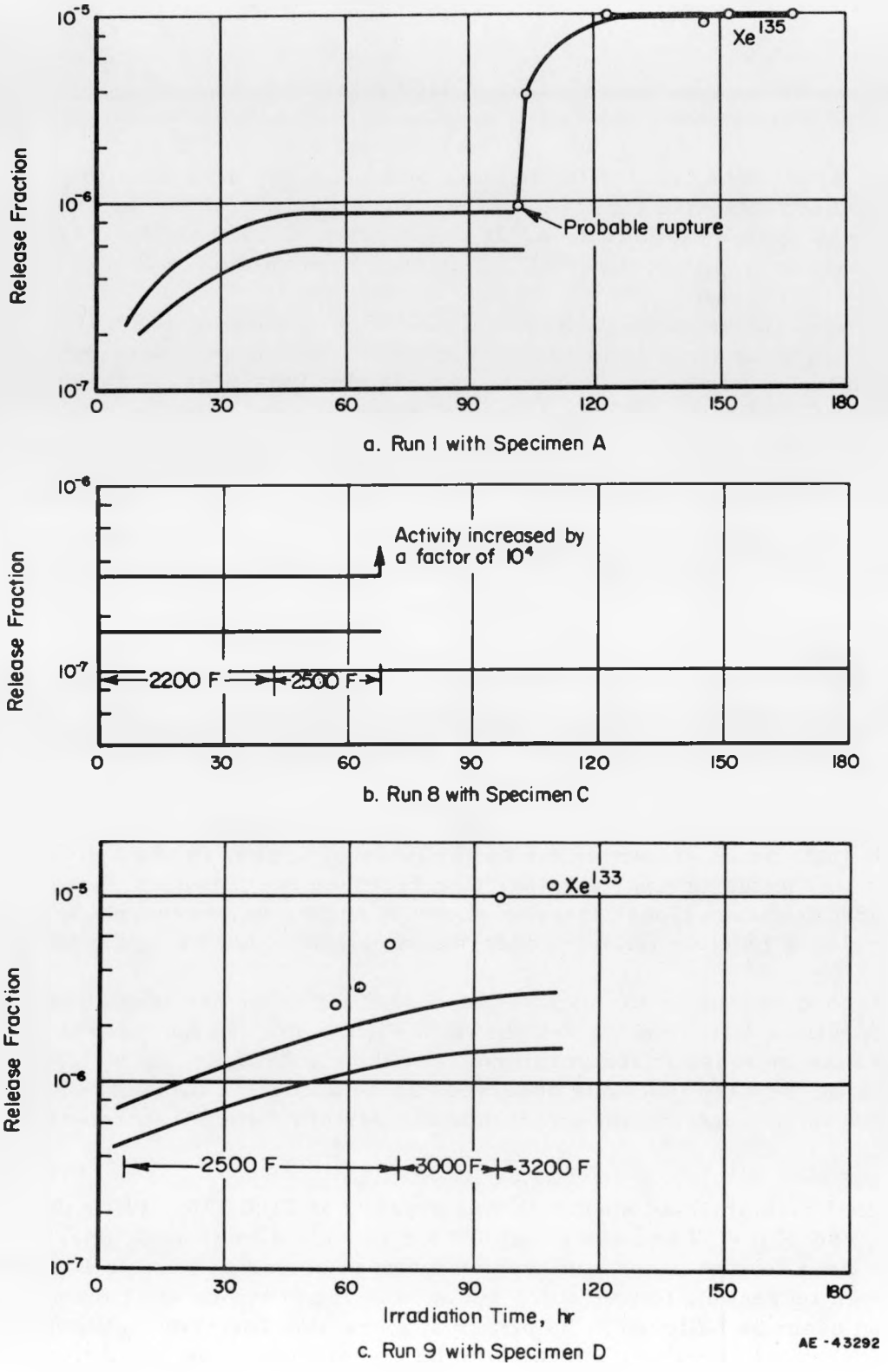

FIGURE 4. FISSION-GAS-RELEASE FRACTIONS FROM NIOBIUM-CLAD SPECIMENS

Xenon-133 releases were also fairly high at the beginning of this particular experiment, although these high values are not shown. It is believed that the specimen plug, which was reused directly after an experiment in which high release rates were obtained, was contaminated with iodine-133. The rate of decrease in xenon-133 release was consistent with this assumption, since the decrease showed an iodine-133 half-life dependency.

Niobium-Aluminum-Titanium-Clad Specimens

A specimen clad with a niobium-29.6 w/o aluminum-33.7 w/o titanium alloy was exposed for 205 hr at 2200 F and then for 15 hr at 2500 F (Run 2, Specimen E). No increase in fission-gas release was noted when the temperature was increased. Results are shown in Figure 5a. A number of air leaks developed in the loop during this experiment but these had no effect on the release of fission gases.

The release of fission gases, as with the niobium specimens described previously, is below the background level of release due to impurity uranium in the system. Thus, the release fractions reported must be considered maximum values with actual release fractions less than those calculated.

This same specimen was re-exposed at 2500 F for 10 hr (Run 5, Specimen E). The release fraction increased steadily during this period as can be seen in Figure 5b, and it is suspected that the specimen developed a defect as a result of handling. Subsequent metallographic examination in the hot cells revealed evidence of cracking although it was not certain that these cracks formed during irradiation rather than during metallographic preparation.

Iron-Chromium-Yttrium-Clad Specimens

Two specimens clad with the iron-30 w/o chromium-1 w/o yttrium alloy were tested at 2200 F. Within 11 hr after insertion of the first specimen, release fractions of about 10^{-2} were obtained (Run 3, Specimen F). It was thought that the specimen might be defective, and the specimen plug was removed from the flux. However, it was decided to observe release during irradiation for longer periods with the results shown in Figure 6a. The specimen plug was reinserted into the flux and the specimen temperature reached 450 F. Power was then applied to the furnace and the temperature was increased in 300 F increments to 2200 F over a 50-hr period. The release fraction increased steadily and then leveled off at a maximum of 2×10^{-2}, as can be seen in Figure 6a, during operation at 2200 F. The test was discontinued after a total of 109 hr. One feature in the release behavior was the significantly lower fractional release of krypton-87 compared with xenon-133 and xenon-135 and krypton-85m. As can be seen in Figure 6a the release fraction for krypton-87 was lower by about one order of magnitude than for the remaining isotopes. This suggests a time-dependent release mechanism. Krypton-87 is the shortest lived of the isotopes, having a half-life of 78 min. Decay during release would lead to a lower release fraction for this isotope compared with the remaining longer lived isotopes.

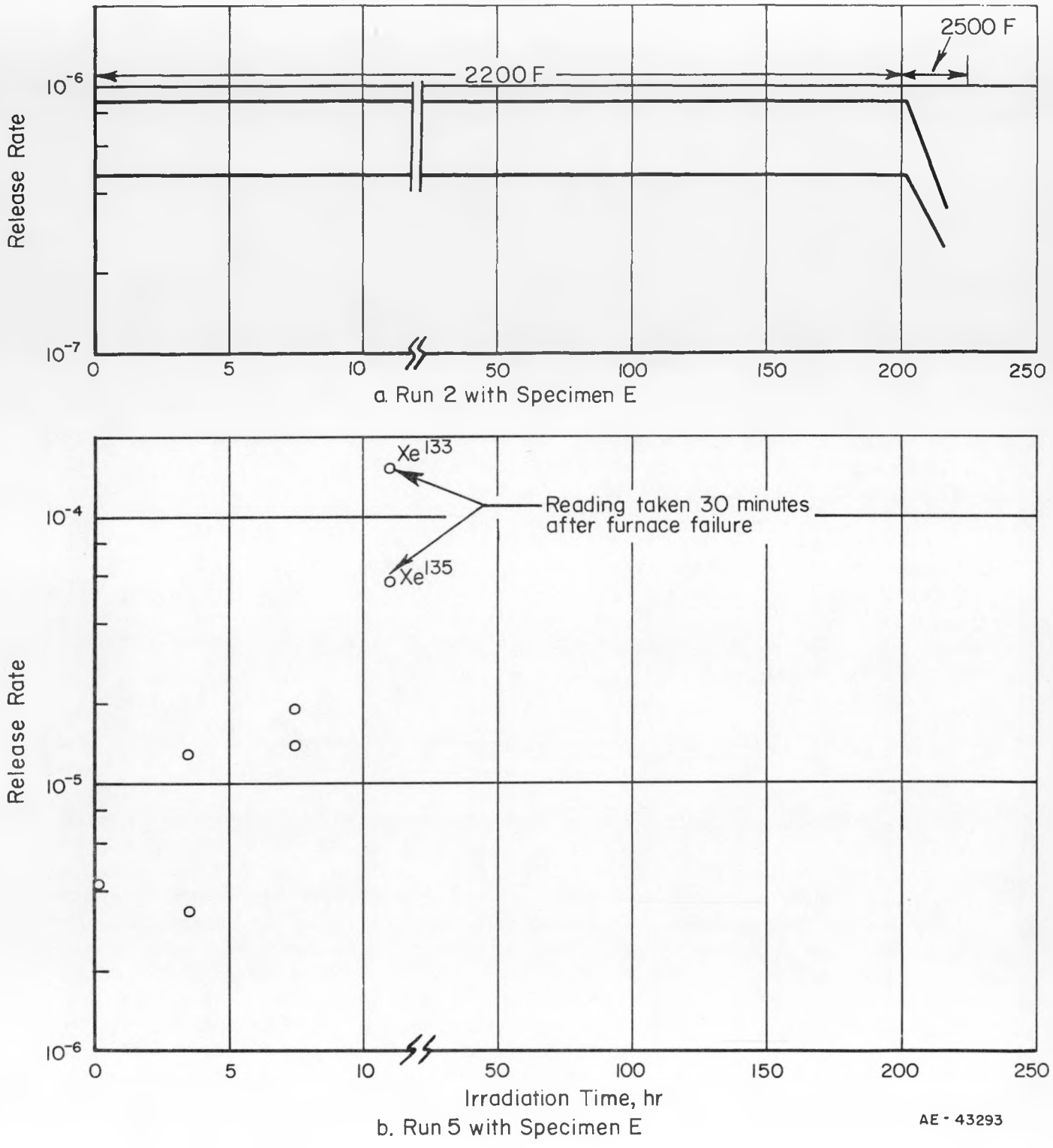

FIGURE 5. FISSION-GAS-RELEASE FRACTIONS FROM A SPECIMEN CLAD WITH NIOBIUM-29.6 w/o ALUMINUM-33.7 w/o TITANIUM

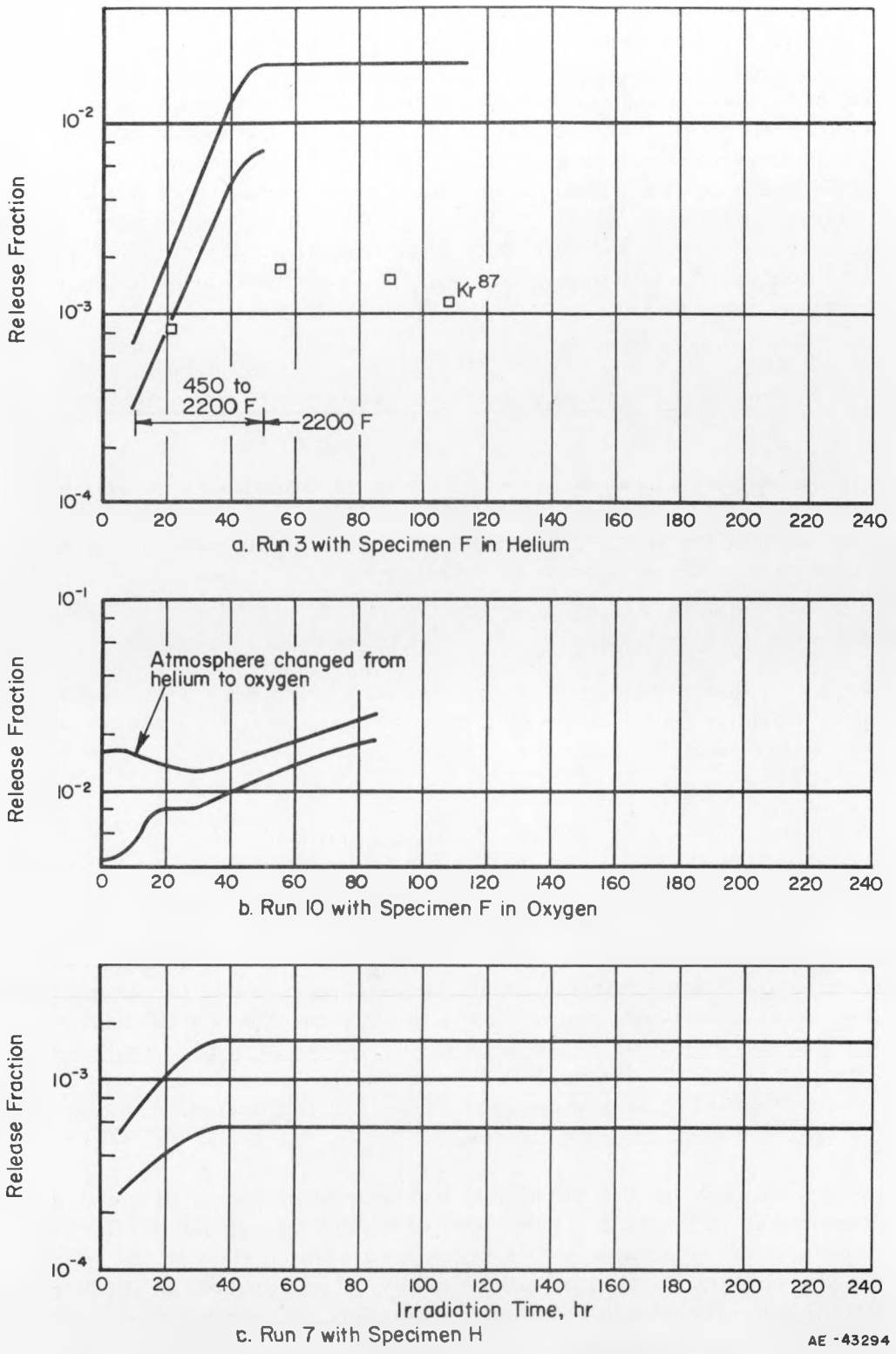

FIGURE 6. FISSION-GAS-RELEASE FRACTIONS FROM SPECIMENS CLAD WITH IRON-30 w/o CHROMIUM-1 w/o YTTRIUM AND WITH IRON-25 w/o CHROMIUM-1 w/o YTTRIUM-4.67 w/o ALUMINUM

Since leakage from the specimen was suspected, a second identical specimen was also irradiated at 2200 F. This specimen exhibited the same fractional-release behavior as the first specimen, and, consequently, the test was discontinued.

Both of these tests were run with helium as the sweep gas. A third test was run at 2200 F reusing the first specimen but with oxygen as the sweep gas to determine its effect on fractional release of the fission gases (Run 10, Specimen F). The results of this test appear in Figure 6b. Helium was used as the sweep gas for the first 8 hr and then oxygen was introduced. While the readings showed a wide spread initially and narrowing of the spread upon the introduction of oxygen, followed by a gradual increase in release with continued exposure, there was little significant difference in the results of the runs made in helium and in oxygen atmospheres.

Iron-Chromium-Yttrium-Aluminum-Clad Specimen

A single specimen clad with an iron-25 w/o chromium-1 w/o yttrium-4.67 w/o aluminum alloy was irradiated at 2200 F (Run 7, Specimen H). Oxygen was used as the carrier gas throughout the test, and in the latter part of the experiment the oxygen was saturated with water vapor at room temperature by bubbling the oxygen through water. The specimen was exposed in-pile for a total of 245 hr, the last 27 hr to the water vapor-oxygen gas stream.

The results of this experiment are shown in Figure 6c. The release fraction increased slightly initially and then leveled off. No change in release occurred with the introduction of water vapor.

Iodine Release

Figure 7 shows a typical plot illustrating the continued release of xenon-133 and xenon-135 after removal of the loop from the reactor. This continued release is a result of decay of iodine trapped or plated out in various parts of the loop, as can be seen by the dependence of xenon production on the precursor iodine half-life. Extrapolation of the continued xenon evolution rates back to the completion of irradiation in a series of experiments indicated that from 25 to 75 per cent of the xenon release detected during irradiation was a product of iodine decay. Thus, the indications are that iodine and xenon release fractions are roughly equivalent.

The results of washing and scrubbing various components of the loop after irradiation are summarized in Table 3. Recovery of iodine was generally incomplete as indicated by the number of iodine atoms recovered compared with the number required for the levels of xenon production by iodine decay after removal of the loop from the neutron environment. However, it seems reasonable to assume that the percentage recovery of each of the three iodine isotopes of interest is equivalent.

Table 3 gives the number of atoms present at the completion of in-pile irradiation. These values were obtained by counting the number of atoms in the wash solutions obtained and correcting these numbers for decay back to the time of retraction of the loop out of the reactor flux field. These values were converted to equilibrium release rates

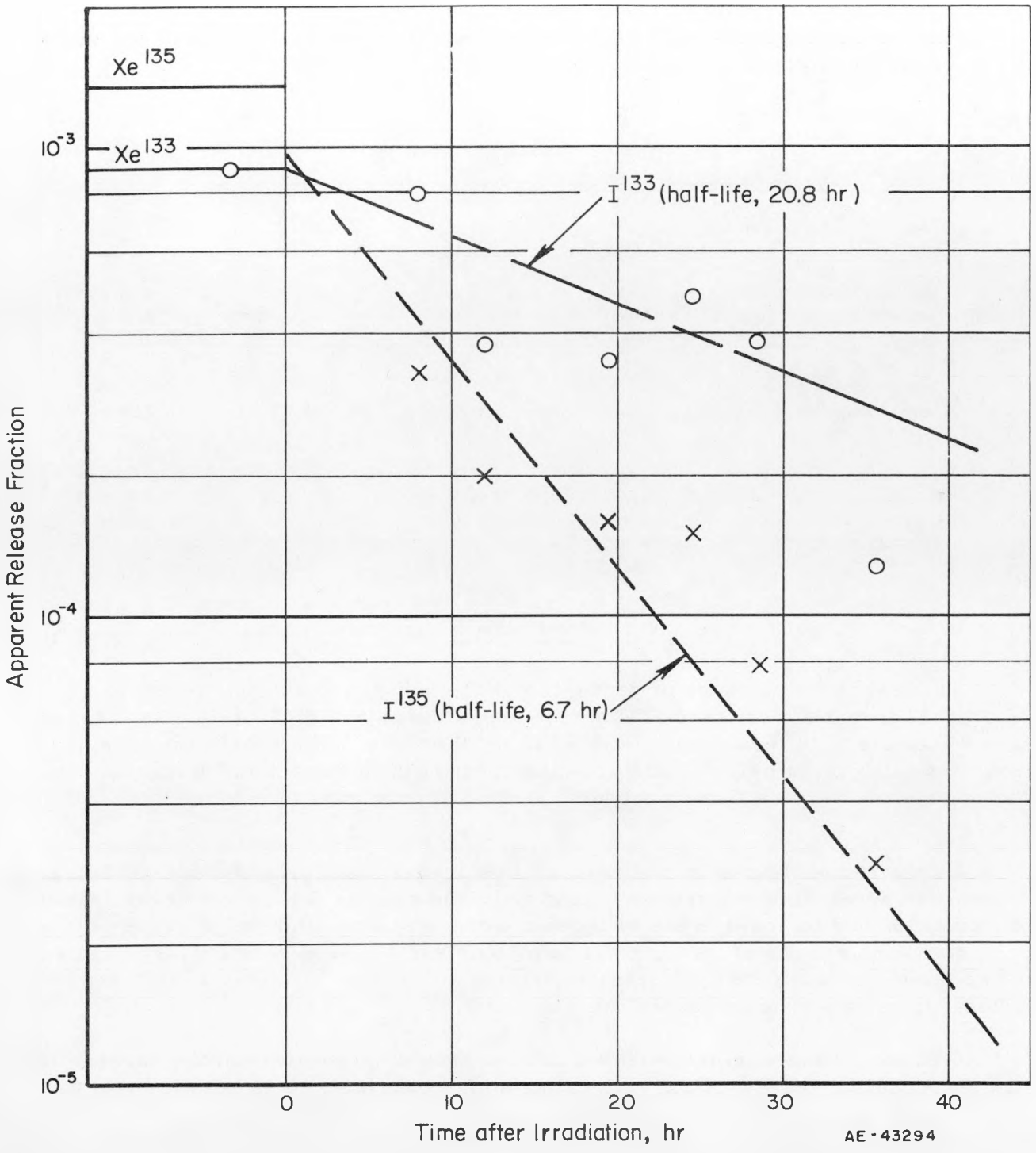

FIGURE 7. APPARENT XENON RELEASE FRACTIONS AFTER IRRADIATION DUE TO IODINE DECAY FOLLOWING RUN 7

by multiplying the number of atoms present by the decay constant. The values for release per fission were obtained by dividing the previous numbers by the fractional fission yield of the individual isotopes. The resulting values are comparable in terms of release fractions and indicate that within experimental accuracy the fractional releases of the three iodine isotopes are equivalent.

TABLE 3. IODINE-RECOVERY DATA

	Iodine Isotope	Run 6	Run 7	Run 8
Number of Iodine Atoms Present at End of Irradiation	131	1.11×10^{12}	1.26×10^{13}	4.45×10^{14}
	133	1.07×10^{12}	5.52×10^{12}	2.66×10^{14}
	135	1.21×10^{11}	--	--
Equilibrium Release Rate, atoms per sec	131	1.1×10^{5}	1.3×10^{7}	4.4×10^{8}
	133	9.9×10^{6}	5.1×10^{7}	2.36×10^{9}
	135	2.5×10^{6}	--	--
Comparable Release per Fission, atoms per sec	131	3.8×10^{7}	4.5×10^{8}	1.53×10^{8}
	133	1.5×10^{8}	7.8×10^{8}	3.63×10^{8}
	135	4.2×10^{7}	--	--

DISCUSSION

The fractional releases of xenon-133 and xenon-135 and krypton-85m and krypton-87 from the various clad samples are summarized in Table 4 except for those runs where the specimens were believed to be defective. The consistent behavior of iron-30 w/o chromium-1 w/o yttrium-clad specimens in Runs 3 and 4 suggests that these specimens may release fission products at a fairly high rate by migrates through the cladding.

On the basis of results of continued fission-gas monitoring for iodine decay to xenon after removal of the specimen loop from the reactor flux, the release fractions of iodine-133 and iodine-135 are of the same order of magnitude as their xenon daughter products. The results of washing and scrubbing various loop components to collect iodine further indicate that the release fractions of iodine-131, iodine-133, and iodine iodine-135 are all roughly equivalent.

The program described was designed to provide proof tests of the capabilities for fission-product retention of the various cladding materials. It is believed that the program was successful but no conclusions concerning mechanisms of release can be drawn from the data. Only in two experiments was any evidence of a time-dependent release mechanism, such as diffusion, obtained, and in these experiments the data were too limited for confirmation. A program aimed specifically at studying mechanisms of release would be required for this purpose.

MK:AEB:FAR:RFD/dnm

TABLE 4. SUMMARY OF FRACTIONAL RELEASE DATA

Cladding Composition, w/o	Run	Temperature, F	Sweep Gas	Cladding Thickness, mils	Maximum Average[a] Release Fraction, R/B
Niobium	1	2200	He	10	$<8.7 \times 10^{-7}$
	8	2200	He	13	$<3.3 \times 10^{-6}$
	8	2500	He	13	$<3.3 \times 10^{-6}$
	9	2500	He	13	$<2.5 \times 10^{-6}$[b]
	9	3000	He	13	$<3 \times 10^{-6}$[b]
	9	3200	He	13	$<3 \times 10^{-6}$[b]
Nb-29.6 Al-33.7 Ti	2	2200, 2500	He	13	$<8.5 \times 10^{-7}$
		--	--	--	--
Fe-30 Cr-1 Y	3	2200	He	7-10	2×10^{-2}[c]
	4	2200	He	7-10	2×10^{-2}
	10	2200	He	7-10	1.6×10^{-2}
	10	2200	O_2	7-10	2.5×10^{-2}
Fe-25 Cr-1 Y-4.67 Al	7	2200	O_2	7-10	1.6×10^{-3}
	7	2200	O_2 with H_2O	7-10	1.6×10^{-3}

(a) Release fractions apply to all xenon and krypton isotopes measured, except where noted.

(b) Xenon-133 release appeared significantly higher, 10^{-5} at 3000 and 3200 F.

(c) Krypton-87 release appeared significantly lower, 1.5×10^{-3}, than releases for remaining isotopes.