This document was prepared in conjunction with work accomplished under Contract No. AT(07-2)-1 with the U.S. Department of Energy.

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DPSP-71-1152
RTR-1227

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April 28, 1971

TO: L. W. FOX, 703-A

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[redacted]

FISSION PRODUCT ACTIVITIES IN BLANKET GAS

INTRODUCTION AND SUMMARY

This report documents a method for the calculation of the concentration of isotopes of Kr and Xe in the reactor blanket gas system. These isotopes are formed by fissioning of ^{235}U exposed by fuel defects to the moderator; the radioactive gases then diffuse to the gas plenum. The effect of blanket gas leakage rate and operating and design variables on the Kr and Xe concentrations are included, together with a summary of pertinent variables for recent reactor operation.

It is estimated that current E-D operation results in a blanket gas inventory ranging from 20 to 800 curies of Kr and Xe. If cycle average values are used, and if average blanket gas leakage and venting rates are assumed, the result is a release rate of 200 to 400 curies of Kr and Xe per day.

Since about 90 percent of the activity consists of isotopes with half-lives shorter than 10 hours, the decay after release is rapid; the time for reduction of the total activity to 50% of the initial values is about 4 hours.

These estimates do not include allowance for radioactive decay during transport of the activity from the point of fission to the blanket gas. This assumption results in over-estimation of short-lived activities. A four hour delay, for example, would result in a 50% reduction in the blanket gas Kr and Xe content.

An analytical program has been started (ref. 2) to determine the transport times for Kr and Xe (which may differ) and to verify the calculational methods used in these estimates of blanket gas activities.

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CALCULATIONS

The concentrations of Kr and Xe isotopes in the blanket gas are controlled by the fission rate (power), the amount of fissioning ^{235}U exposed to the moderator and the rate of increase of that amount, the time for the gases to diffuse into the blanket gas, and the rate of removal of Kr and Xe from the blanket gas (radioactive decay and gas turnover rate).

The rate of change of the content "N" of a radioactive gas in the blanket gas is given by the expression:

$$\frac{dN}{dt} = g - (\lambda + L/V)N \qquad \text{(Eqn. 1)}$$

Where g = generation or input rate, atoms/sec

λ = decay constant, $.693/T_{\frac{1}{2}}$, sec^{-1}

L = blanket gas leakage and vent rate, scf/sec

V = blanket gas volume, scf

In most cases, the rate of change, dN/dt, is sufficiently low that a steady state condition can be assumed for a period of a few days. Then dN/dt = 0, and equation 1 becomes:

$$N = \frac{g}{\lambda + L/V} \qquad \text{(Eqn. 2)}$$

If the assumption is made that the transport from the point of fission to the blanket gas is instantaneous, g equals the fission rate, atoms/sec, times the fission yield of a given nuclide.

The amount of exposed ^{235}U core material causing the release of Kr and Xe is calculated from the dissolved fission product (e.g., 3 hr ^{92}Sr) concentrations in the moderator by the methods described in reference 1. The input rate, g, for a given isotope "I" is thus given by the following: (Eqn. 3)

$$g \text{ (atoms "I"/sec)} = \text{Total fuel power (MW)} \times 3.2 \times 10^{16} \text{ (fissions/sec per MW)} \times \text{fission yield of "I"} \times \frac{g\ ^{235}U \text{ exposed}}{g\ ^{235}U \text{ in fuel}} \text{ (corrected for burnup)}$$

This result is used in equation 2, together with the blanket gas turnover rate, L, to calculate the concentrations of isotopes. The total curies in the blanket gas are also calculated:

$$Ci(\text{"I"}) = \frac{N(\text{"I"})\ \lambda(\text{"I"})}{3.7 \times 10^{10}\ d/s/\text{curie}} \qquad \text{(Eqn. 4)}$$

$$\text{The daily release of activity (curies)} = Ci(\text{eqn. 4}) \times \frac{L\ (scfh)}{V\ scf} \times 24 \qquad \text{(Eqn. 5)}$$

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RESULTS

Equations 2, 3 and 4 are used to calculate the Kr and Xe concentrations for a typical Mark 14 fuel cycle (e.g. P-1). Results are summarized in Table 1; it should be noted that equation 2 was modified so that the results are in terms of curies per gram of exposed core. These values can then be used with actual exposed core values to calculate total curies Kr and Xe for a specific case, subject to corrections for differences in the parameters given below:

PARAMETERS USED IN CALCULATING VALUES GIVEN IN TABLE 1:

1) Total Mark 14 power = 1300 MW
2) Grams ^{235}U in Mark 14 = 4.3×10^5
3) L = 20 scf/hr (5.6×10^{-3} scf/sec)
4) V = 400 scf

TABLE 1 CALCULATED Kr AND Xe CONCENTRATIONS IN BLANKET GAS

Isotope	$T_{\frac{1}{2}}$	Fission Yield, %	λ, sec^{-1}	$\lambda + L/V$, sec^{-1}	g, atoms/sec. per $g^{235}U$	N (atoms)	N (curies) per gram ^{235}U
^{83m}Kr	1.9 hr	0.48	1.01×10^{-4}	1.15×10^{-4}	0.5×10^{12}	4.3×10^{15}	12
^{85m}Kr	4.4 hr	1.5	4.4×10^{-5}	5.8×10^{-5}	1.4×10^{12}	2.4×10^{16}	28
^{85}Kr	10.8 yr	0.3	2×10^{-9}	1.4×10^{-5}	0.3×10^{12}	2.1×10^{16}	1.1×10^{-3}
^{87}Kr	1.3 hr	2.7	1.52×10^{-4}	1.66×10^{-4}	2.6×10^{12}	1.6×10^{16}	66
^{88}Kr	2.8 hr	3.7	6.9×10^{-5}	8.3×10^{-5}	3.6×10^{12}	4.3×10^{16}	80
Total Kr							186
^{131m}Xe	12 day	0.03	$.07 \times 10^{-5}$	1.47×10^{-5}	0.03×10^{12}	2.0×10^{15}	3.8×10^{-2}
^{133m}Xe	2.3 day	0.16	$.35 \times 10^{-5}$	1.75×10^{-5}	0.15×10^{12}	8.6×10^{15}	1
^{133}Xe	5.3 day	6.5	$.15 \times 10^{-5}$	1.55×10^{-5}	6.3×10^{12}	4.1×10^{17}	17
^{135}Xe	9.2 hr	6.2	2.1×10^{-5}	3.5×10^{-5}	6.0×10^{12}	1.7×10^{17}	96
Total Xe							114
Total Kr and Xe							300 curies/g ^{235}U

$$\text{Release/day} = 300 \text{ Ci} \times \frac{20 \text{ scfh}}{400 \text{ scf}} \times 24 = 360 \text{ Ci/g}^{235}U$$

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EFFECT OF CHANGING PARAMETERS ON Kr AND Xe CONCENTRATIONS

A. Amount of Exposed Core

Figures 1,2 and 3 show the amount of ^{235}U exposed to the reactor moderator for recent enriched uranium fuel charges. An estimation of the range of values for natural uranium charges is shown in the C Area graph, figure 3.

B. Fuel Design and Operation

Differences in total fuel power and ^{235}U content for current enriched uranium fuel types and the effects they have on Kr - Xe releases are summarized in Table 2. The data include ^{235}U burnup corrections ($\sim$ mid-cycle), the reduced number of assemblies in Mark 14 cycles, and assume 20 scfh leak rate (as in Table 1).

TABLE 2 Kr AND Xe IN BLANKET GAS - RECENT CYCLES, AVG. VALUES

Fuel Type	Fuel Power, MW	^{235}U in Fuel, g	N (Curies Kr + Xe/g ^{235}U)
Mark 14	1000	2.5×10^5	397
Mark 16	1700	6.7×10^5	252
Mark 18	1300	1.2×10^4	10,750

C. Blanket Gas Leakage and Venting

The leakage and venting rates are calculated by adding the amount of make-up He added to the system and the amount continuously flowing to level indicator bubblers. Figure 4 shows how both the blanket gas content and daily release, in terms of Ci Kr + Xe per gram ^{235}U exposed, depend on the leakage rate. The other parameters are the same as for Table 1 calculations. Normal leak/vent rates fall between 10 and 20 scfh. As shown in figure 4, this results in a blanket gas content of 300 to 350 curies per gram ^{235}U with daily releases from 210 to 360 curies per gram ^{235}U.

D. Decay of Kr and Xe

As shown in Table 1, about 90% of the total Kr and Xe curies represent isotopes with less than 10 hours half life. This results in a fairly rapid decay of total activity after release from the blanket gas. Figure 5 illustrates the decay of 300 curies of Kr + Xe (Table 1, curies/g ^{235}U) after an abrupt release from the reactor.

E. Diffusion Rate

If significant time is required for the fission product gases to diffuse from the point of fission (fuel element surfaces) through the moderator to the gas plenum, the radioactive decay will result in lower concentrations of the various isotopes than given in Table 1. This effect is greater with short half-life isotopes than with long-lived ones. Figure 5 can be used to correct Table 1 values where the axis labeled "hours after release" is considered to be "hours for diffusion to gas plenum". For instance if this time were 4 hours, total Kr and Xe activity, in the blanket gas would be 145 Ci per gram ^{235}U rather than 300 curies.

F. Current Activity Levels and Release Rates

The information from Table 2 and figures 1, 2 and 3 are summarized in Table 3 for average recent operating experience.

TABLE 3 Kr AND Xe ACTIVITY - 1970 - 71 CYCLES

Fuel Type	Avg. Exposed ^{235}U, grams	Avg. Blanket Gas Content, Ci Kr + Xe		Avg. Daily Release*, Ci Kr + Xe	
		L = 10 cfh	L = 20 cfh	L = 10 cfh	L = 20 cfh
Mark 14	0.7	162	278	195	334
Mark 16	1.3	109	328	229	393
Mark 18	5×10^{-3}	32	54	37	64

*The release values will decay as explained in section D and shown in figure 5. Both releases and blanket gas contents are overestimated by a factor dependent on gas diffusion rates as explained in section E.

The minimum 1970 - 71 blanket gas content is 20 curies (K-1, .05 $g^{235}U$) while the maximum is 800 curies (P-6, 2.0 $g^{235}U$).

REFERENCES

1. Jacobsen, W. R., memo to L. W. Fox, "Enriched Uranium Fuel Quality - Preliminary Report", RTR-1070, DPSP-69-1172, March 18, 1969 (Secret).

2. RTA-1247-R, "Analyses of Radioactive Isotopes of Ar, Kr, and Xe in Gas Samples" April 29, 1971.

FIGURE 1 CALCULATED EXPOSED CORE, P AREA

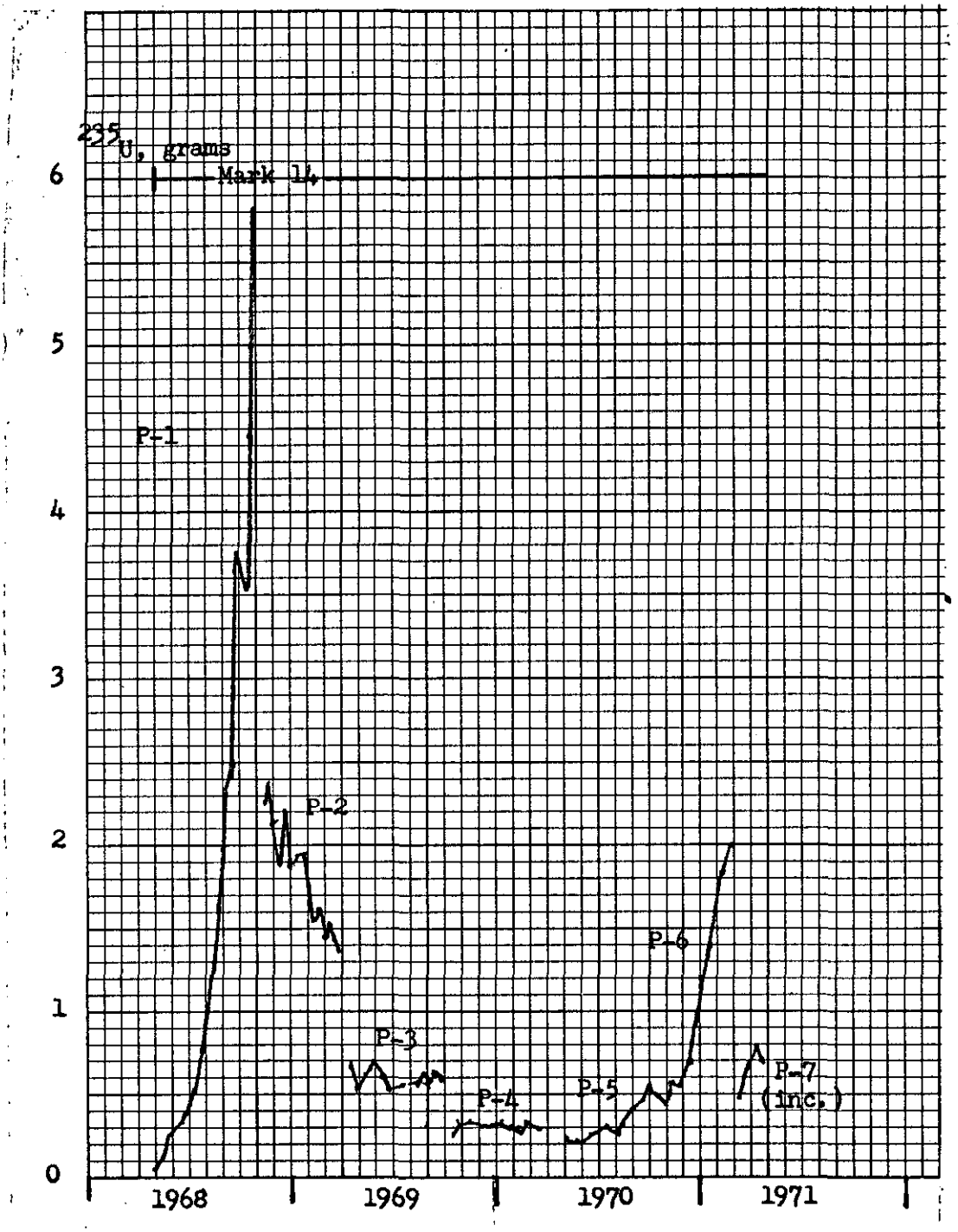

FIGURE 2 CALCULATED EXPOSED CORE, K AREA

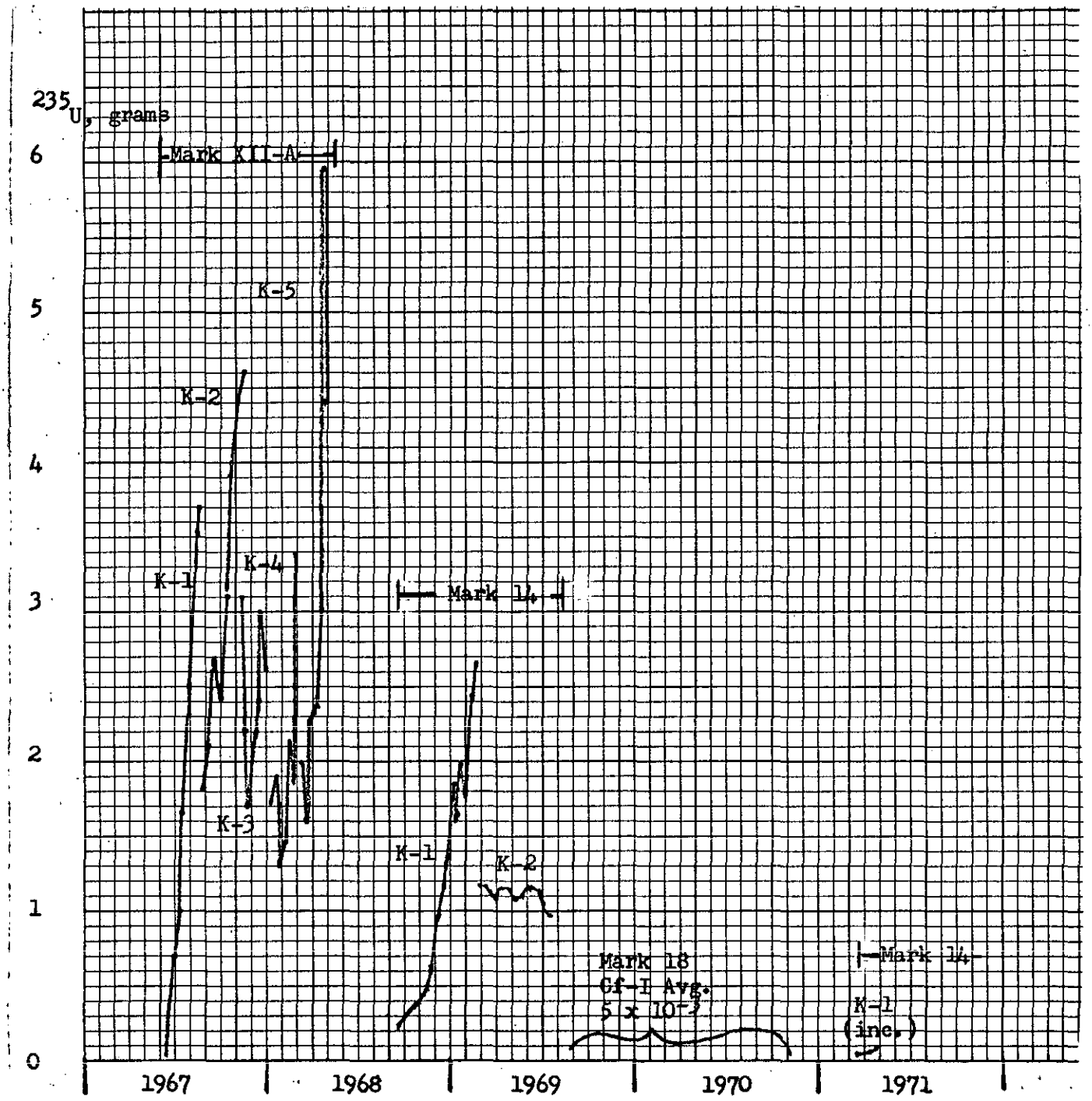

FIGURE 3 CALCULATED EXPOSED CORE, C AREA

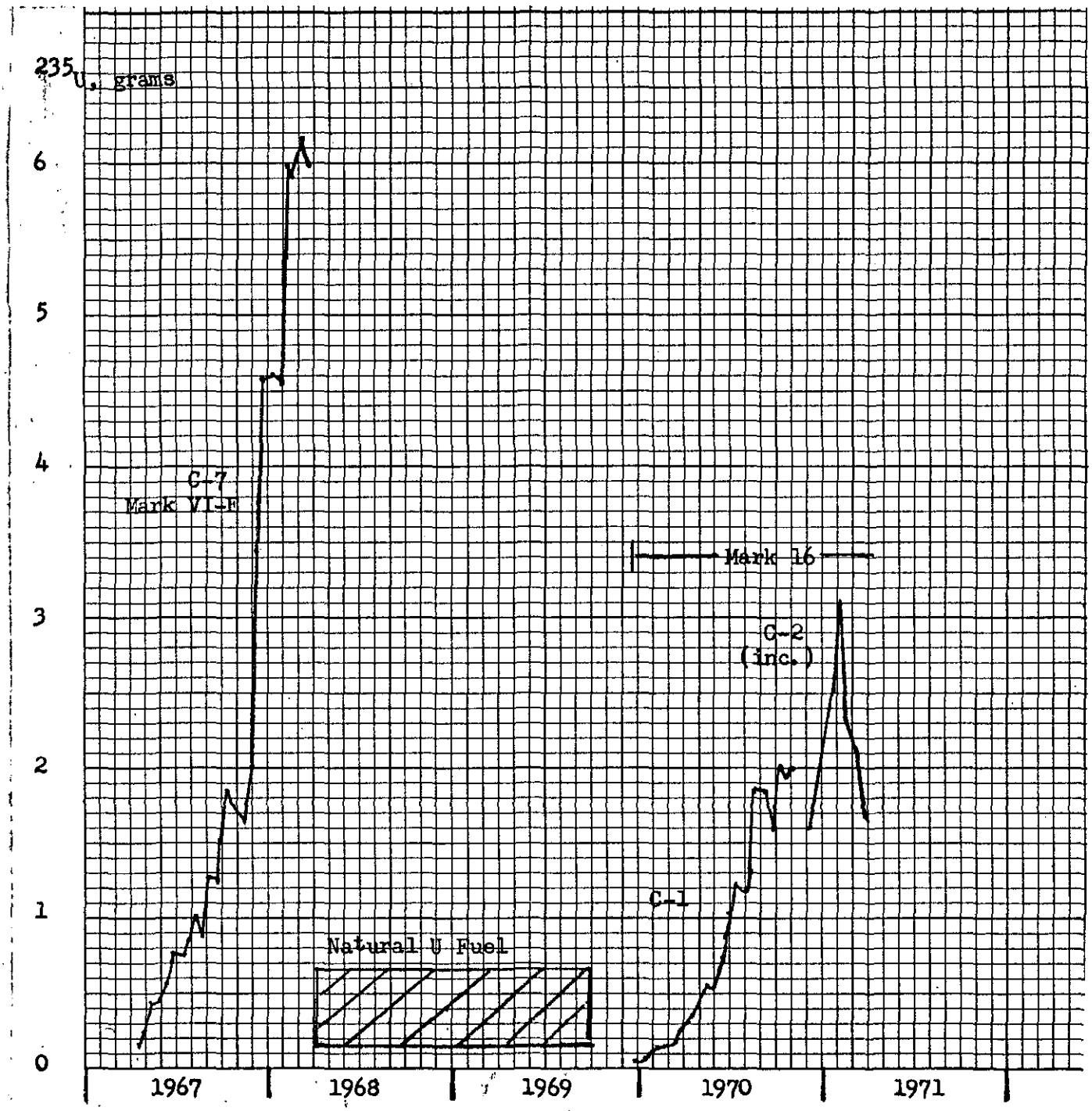

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FIGURE 4 EFFECT OF BLANKET GAS LEAK/VENT RATE ON BLANKET GAS CONTENT AND DAILY RELEASE

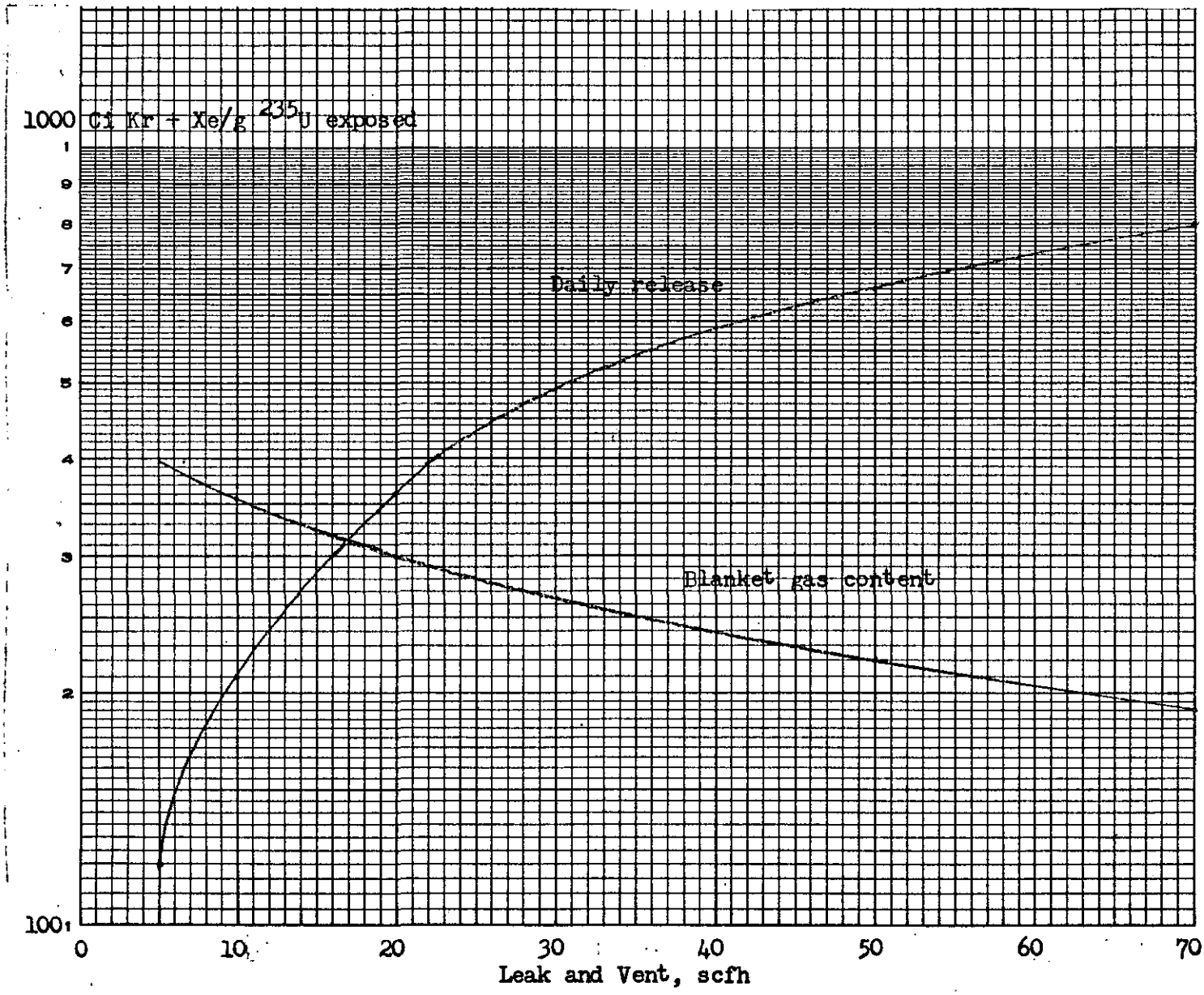

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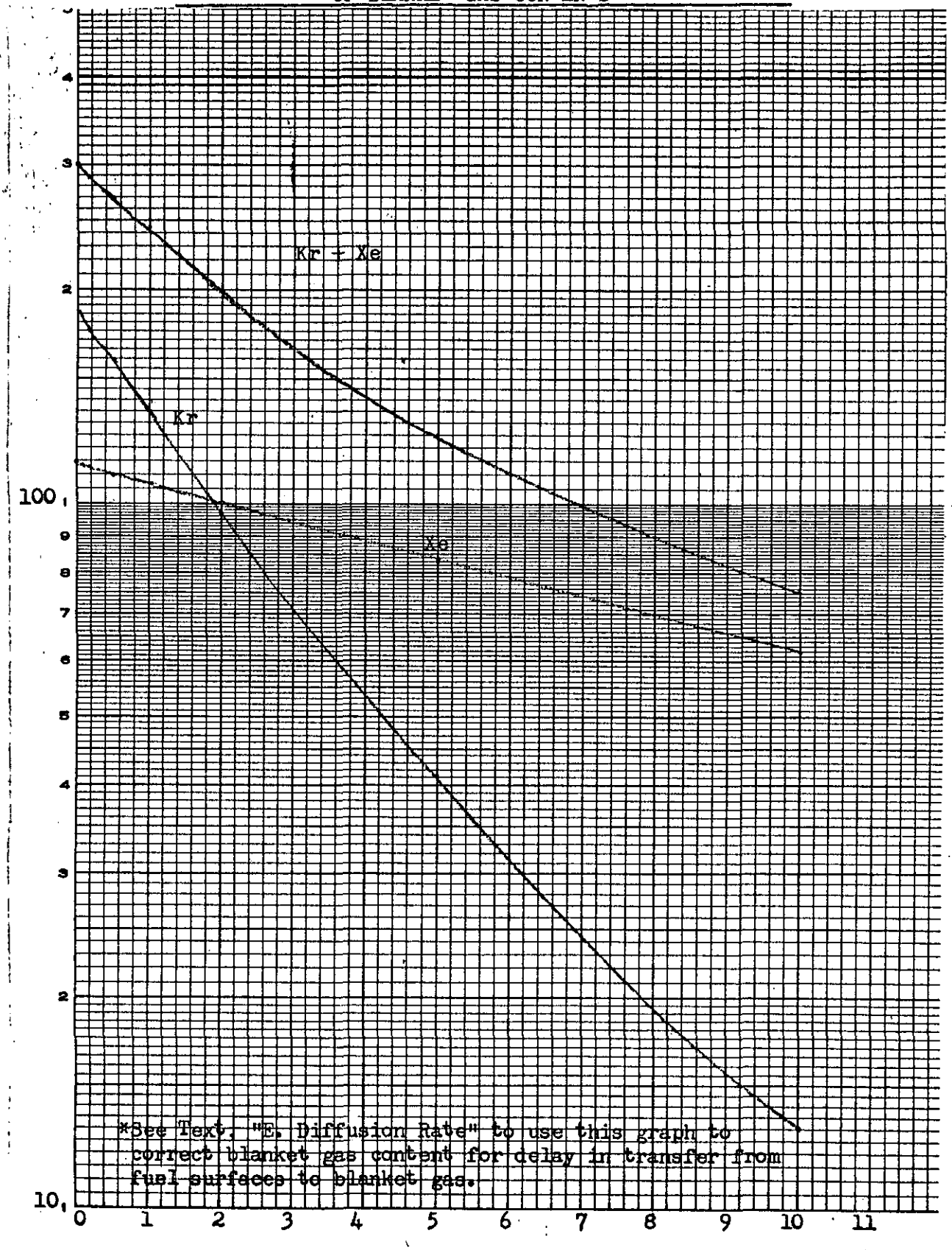
FIGURE 5 DECAY OF Kr AND Xe - AFTER ABRUPT RELEASE OF BLANKET GAS CONTENTS*



*See Text, "E. Diffusion Rate" to use this graph to correct blanket gas content for delay in transfer from fuel surfaces to blanket gas.