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SUBJECT: Evaluation of Fission Gas adsorption Traps for ORNL-MTR-44 Loop Experiment

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Abstract

A method of predicting the performance of fission gas adsorption traps containing activated charcoal is presented. This method is applied in the evaluation of the fission gas traps designed for use in the ORNL-MTR-44 loop experiment. The method should also be applicable in evaluating fission gas traps contained in other reactor experiments.

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I. Introduction

The fission gas adsorption traps containing activated charcoal designed for use in the ORNL-MTR-44 experimental loop assembly have been evaluated under design conditions of temperature, gas flow, and experiment fission power. This evaluation is based on our most recent experimental data on adsorption of krypton by activated charcoal.

II. Operating Conditions

It has been assumed that the operating characteristics of the two charcoal traps are as follows. The loop pump purge system will contain one charcoal trap operating at -30°C with a helium flow of 200 cc/hr. This system will function to remove fission gases released from the fuel during operation of the loop experiment. Removal of these gases will be continuous during operation. The nose purge system containing a second charcoal trap will function as an indicator of a fuel leak in the loop system. This trap will also operate at -30°C with a nitrogen flow of 2 cu. ft./hr (56,600 cc/hr). Normally this purge system will contain no fission gases. In the event of a fuel leak the fission gases released into this system will be contained in the charcoal trap while the experiment is being terminated. Upon termination, the nitrogen sweep will be reduced to 0.2 cu. ft./hr. and the molten fuel allowed to solidify, thus preventing continued leakage of fuel and resulting release of gaseous fission products.

III. Evaluation

The following evaluation is based on both published (1) and unpublished experimental data on adsorption of krypton-85 from both helium and nitrogen gas streams at low temperatures.

The following relationship reported by Browning and Bolta (1) was used to apply experimental data to the operating conditions of these loop charcoal traps:

$$t_{max} = \frac{N - 1}{N} \cdot \frac{kM}{F}$$

where t_{max} = time for effluent activity to reach maximum concentration in gas stream (min.)

N = number of theoretical chambers in charcoal trap

k = adsorption capacity of charcoal for krypton in presence of sweep gas (cc/gm)

M = mass of charcoal in trap (grams)

F = flow rate of sweep gas (cc/min)

For large traps it may be assumed that $\frac{N - 1}{N} = 1$ so that the relationship becomes:

$$t_{max} = \frac{kM}{F}$$

The mathematical derivation of this relationship is contained in ORNL-2116. Values of k for krypton in either helium or nitrogen were determined at -30°C. from experimental data shown in Fig. 1 and substituted into the relationship together with the appropriate flow rate and weight of charcoal. In this manner t_{max} was determined for the particular charcoal trap. As indicated in Fig. 2 some of the fission products will emerge from a charcoal trap prior to the time, t_{max}, so that the effective holdup time is smaller than t_{max}. This effective holdup time may be designated as t_b. Based on laboratory data for low temperature adsorption it is assumed that t_b is equal to one-half of t_{max}. It is further assumed for calculation of the amounts of fission gases emerging from the traps that the maximum discharge rate is achieved at time, t_b, rather that at time, t_{max}. These assumptions will tend to underestimate the actual performance of the traps.

Data on the adsorption of xenon from helium or nitrogen streams at low temperatures are not available. The adsorption of krypton and xenon on charcoal from oxygen streams has been studied at temperatures ranging from 25° to 100°C. At 25°C the adsorption of xenon is at least 12 times as effective as that of krypton (2). At temperatures in the neighborhood of -30°C this factor is expected to be much larger; however, to allow a large margin of safety in these calculations, the factor of 12 was used.

The performances of the pump purge system trap and nose purge system trap were studied under various conditions of trap temperature and gas flow rate. The amounts of the various gaseous isotopes of krypton and xenon were calculated together with the effective holdup time (t_b) for krypton and xenon under the specified conditions. Then compensating for radioactive decay occuring during residence of the gases in the charcoal trap the amounts of the isotopes of krypton and xenon in the effluent gas stream were determined. These various situations are covered in Tables 1 through 7.

Table I

Assume that the pump purge system trap is operating at -30°C with a helium flow of 200 cc/hr and contains 2.4 kilograms of charcoal. The loop fuel fission power is 10.4 KW and all of the fission gases are injected into the charcoal trap upon birth without decay. The gas flow and loop fission power are assumed to remain constant during the time of fission gas holdup in the charcoal trap.

Krypton holdup: 177 days　　　　Xenon holdup: 2130 days

Isotope	Half-Life T - ½	Isotope Production Atoms/sec	Number of T-½ in Trap	Emission Rate Atoms/sec	Emission Rate Curies/hr
Kr^{83m}	114m	1.59×10^{12}	2250	-	-
Kr^{85m}	4.36h	2.94×10^{12}	977	-	-
Kr^{85}	10.27y	9.4×10^{11}	0.047	1.48×10^{12}	3.09×10^{-4}
Kr^{87}	78m	8.91×10^{12}	3300	-	-
Kr^{88}	2.77h	1.29×10^{13}	1500	-	-
Xe^{131m}	12d	9.88×10^{10}	177	-	-
Xe^{133m}	2.3d	5.63×10^{11}	926	-	-
Xe^{133}	5.27d	2.33×10^{13}	404	-	-
Xe^{135}	9.13h	2.24×10^{13}	5600	-	-

Emission rate reaches a maximum at a time greater than 177.4 days after start of loop experiment: 3.09×10^{-4} curies/hr Kr^{85}

Table II

Assume that the pump purge system trap is operating at 25°C with a helium flow of 200 cc/hr. The remaining conditions are identical to those in Table I.

Krypton holdup: 16.5 days　　　Xenon holdup: 197 days

Isotope	Half-Life $T-\frac{1}{2}$	Isotope Production Atoms/sec	Number of $T-\frac{1}{2}$ in Trap	Emission Rate Atoms/sec	Emission Rate Curies/hr
Kr^{83m}	See Table I	See Table I	208	-	-
Kr^{85m}			91	-	-
Kr^{85}			0	1.53×10^{12}	3.2×10^{-4}
Kr^{87}			304	-	-
Kr^{88}			132	-	-
Xe^{131m}			16.5	-	-
Xe^{133m}			86	-	-
Xe^{133}			37.5	-	-
Xe^{135}			519	-	-

Emission rate reaches a maximum at a time greater than 16.5 days after start of loop experiment: 3.2×10^{-4} curies/hr Kr^{85}

Table III

Assume that the nose purge system trap is operating at -30°C with a nitrogen flow of 2 ft^3/hr and contains 4.3 kilograms of charcoal. The loop fuel fission power is 10.4 KW and 10% of the produced fission gases are leaked undecayed into this system through accident. The nitrogen flow and temperature are assumed to remain constant.

Krypton holdup: 5.1 hours   Xenon holdup: 25.4 days

Isotope	Half-Life T - ½	Isotope Production Atoms/sec	Number of T-½ in Trap	Emission Rate Atoms/sec	Emission Rate Curies/hr
Kr^{83m}	See Table I	1.59×10^{11}	2.67	2.48×10^{10}	0.25
Kr^{85m}		2.94×10^{11}	1.16	1.31×10^{11}	0.56
Kr^{85}		9.4×10^{10}	0	1.27×10^{11}	2.7×10^{-5}
Kr^{87}		8.91×10^{11}	3.91	5.97×10^{10}	0.86
Kr^{88}		1.29×10^{12}	1.83	3.62×10^{11}	2.45
Xe^{131m}		9.88×10^{9}	0.21	8.55×10^{9}	5.56×10^{-4}
Xe^{133m}		5.63×10^{10}	1.1	2.63×10^{10}	8.92×10^{-3}
Xe^{133}		2.33×10^{12}	0.48	1.67×10^{12}	0.25
Xe^{135}		2.24×10^{12}	6.68	2.2×10^{10}	4.5×10^{-2}

Krypton emission rate reaches a maximum at a time greater than 5.1 hours: 4.12 curies/hr

Xenon emission rate reaches a maximum at a time greater than 2.54 days 0.30 curies/hr

Total emission rate at 2.54 days 4.42 curies/hr

Table IV

Assume that the nose purge system trap is operating at 25°C. with a nitrogen flow of 2.0 ft^3/hr and contains 4.3 kilograms of charcoal. The remaining conditions are identical to those in Table III.

Krypton holdup: 1.6 hours   Xenon holdup: 19.2 hours

Isotope	Half-Life T - ½	Isotope Production Atoms/sec	Number of T-½ in Trap	Emission Rate Atoms/sec	Emission Rate Curies/hr
Kr^{83m}	See Table III	See Table III	0.85	8.76×10^{10}	0.87
Kr^{85m}			0.37	2.28×10^{11}	0.98
Kr^{85}			0	1.6×10^{11}	3.35×10^{-5}
Kr^{87}			1.24	3.77×10^{11}	5.43
Kr^{88}			0.58	8.63×10^{11}	5.84
Xe^{131m}			0.067	9.42×10^{9}	6.13×10^{-4}
Xe^{133m}			0.35	4.42×10^{10}	0.015
Xe^{133}			0.15	2.1×10^{12}	0.312
Xe^{135}			2.12	2.12×10^{11}	1.045

Krypton emission rate reaches a maximum at a time greater than 1.6 hours: 13.12 curies/hr

Xenon emission rate reaches a maximum at a time greater than 19.2 hours: 1.37 curies/hr

Total emission rate at 19.2 hours: 14.49 curies/hr

Table V

Assume that the nose purge system trap is operating at $-30^{\circ}C$ with a nitrogen flow of 2 ft^3/hr. Immediately upon indication of 10% of the produced fission gases leaking into this system the nitrogen flow is reduced to 0.2 ft^3/hr and held constant. Remaining conditions same as on Table III.

Krypton holdup: 50.8 hours　　　　Xenon holdup: 25.4 days

Isotope	Half-Life T - ½	Isotope Production Atoms/sec	Number of T-½ in Trap	Emission Rate Atoms/sec	Emission Rate Curies/hr
Kr^{83m}	See Table III	See Table III	26.7	-	-
Kr^{85m}			11.6	9.7×10^{7}	3.2×10^{-5}
Kr^{85}			0	1.53×10^{11}	4.17×10^{-4}
Kr^{87}			39.1	-	-
Kr^{88}			18.3	-	-
Xe^{131m}			2.1	2.3×10^{9}	1.5×10^{-4}
Xe^{133m}			11	2.82×10^{7}	9.58×10^{-6}
Xe^{133}			4.8	8.36×10^{10}	1.24×10^{-2}
Xe^{135}			66.8	-	-

Krypton emission rate reaches a maximum at a time greater than 50.8 hours: 4.49×10^{-4} c/hr

Xenon emission rate reaches a maximum at a time greater than 25.4 days: 1.25×10^{-2} c/hr

Total emission rate at 25.4 days: 1.3×10^{-2} c/hr

Table VI

Assume that the nose purge system trap is operating at -30°C with a nitrogen flow of 2 ft^3/hr. The loop experiment has been operating at 10.4 KW for 1500 hours and accumulating all fission gases produced during this period. The loop fuel system ruptures and releases 50% of these accumulated fission gases without further decay in the form of a pulse of activity. The temperature remains constant and the flow rate is maintained at 2 ft^3/hr or reduced immediately to 0.2 ft^3/hr.

	At 2 ft^3/hr	At 0.2 ft^3/hr
Krypton holdup	5.08 hours	50.8 hours
Xenon holdup	2.54 days	25.4 days

Fission Gas	Curies Discharged into Trap	Curies Discharged at Gas Flow of 2 ft^3/hr	0.2 ft^3/hr
Krypton	1380	95.7	0.32
Xenon	1933	332.0	16.3
Totals	3313	427.7	16.62

Remarks: The krypton and xenon will not be discharged from the charcoal trap in the form of a brief pulse of activity but will be released over a period of time beginning at the indicated holdup time. This period of release will be of the order of hours for krypton and days for xenon at 0.2 ft^3/hr nitrogen flow. At the higher flow rate the release period will be shorter.

Table VII

Assume the same conditions as in Table VI except that the trap temperature is 25°C and remains constant.

	At 2 ft^3/hr	At 0.2 ft^3/hr
Krypton holdup	1.6 hours	16 hours
Xenon holdup	19.2 hours	192 hours

Fission Gas	Curies Discharged into Trap	Curies Discharged at Gas Flow of: 2 ft^3/hr	0.2 ft^3/hr
Krypton	1380	277	2.7
Xenon	1933	423	158.6
Totals	3313	700	161.3

See remarks contained in Table VI.

IV. Conclusions

1. The pump purge system trap should operate satisfactorily at any temperature ranging from -30°C to 25°C at a helium flow of 200 cc/hr.

2. The nose purge system trap should be refrigerated for optimum performance. The calculations shown in Tables III-V indicate that a 10% fuel leak can be handled by this trap at -30°C for a period ranging from 5 hours to 50 hours, depending upon the nitrogen flow rate. At 25°C successful holdup of krypton is marginal.

3. The nose purge system trap operating under the conditions stated in Tables VI and VII should be refrigerated to insure sufficient time to terminate the experiment and reduce the nitrogen flow. The heat load on the charcoal resulting from radioactive decay of the fission gases will be large. If the trap was operating at 25°C when this postulated accident occurred the temperature of the trap would rise and reduce the holdup time to a much lower value than the 1.6 hours at 25°C.

4. For safe operation under any of the postulated operating conditions the pump purge system trap and the nose purge system trap should be refrigerated. This refrigeration system should be capable of handling any heat generation resulting in the traps from beta decay of the adsorbed fission gases.

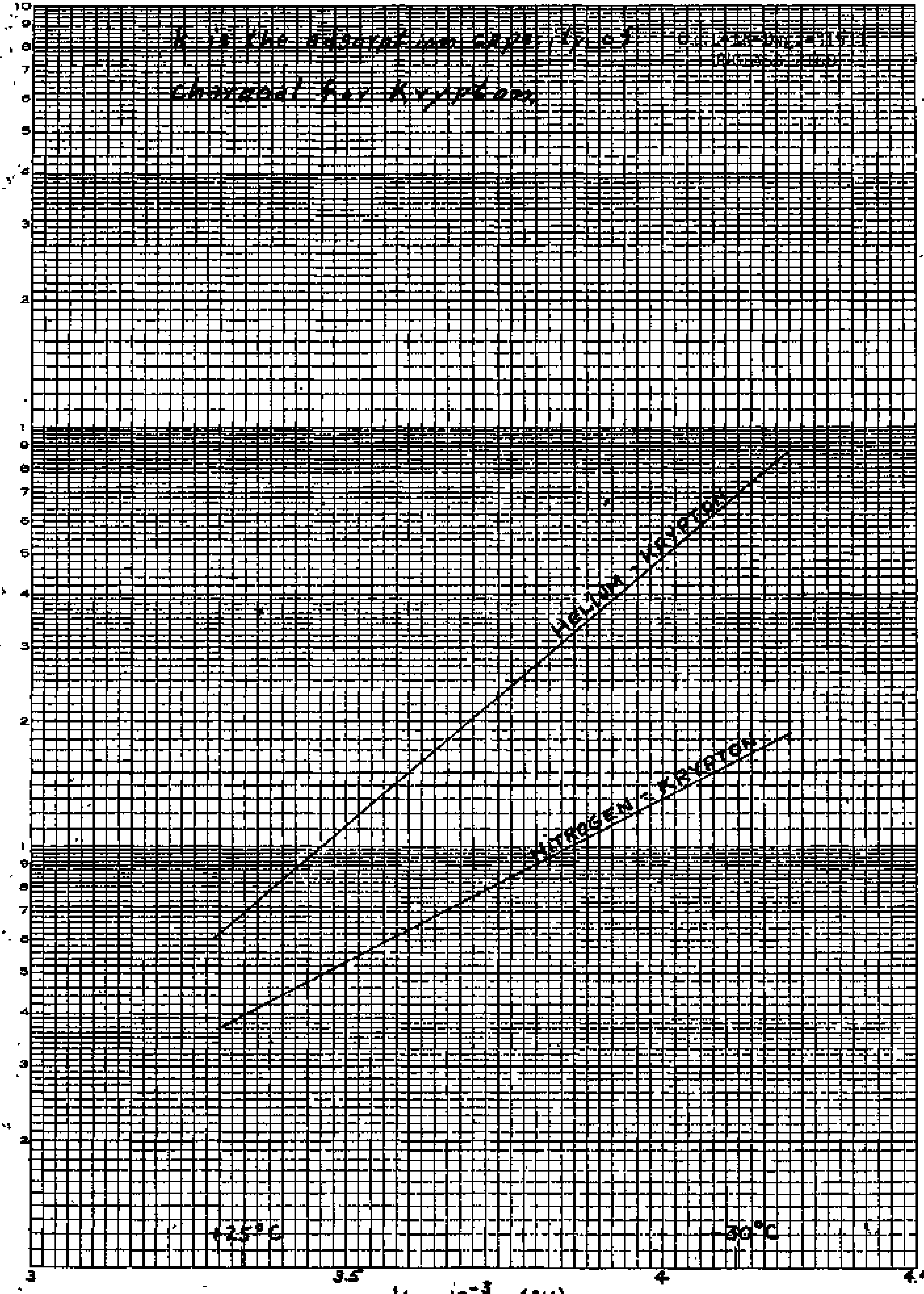
References

1. W. E. Browning and C. C. Bolta, "Measurement and Analysis of Holdup of Gas Mixtures by Charcoal Adsorption Traps", ORNL-2116, July 27, 1956.

2. R. A. McNees, et al., HRP Quar. Prog. Rep., January 31, 1958, ORNL-2493.

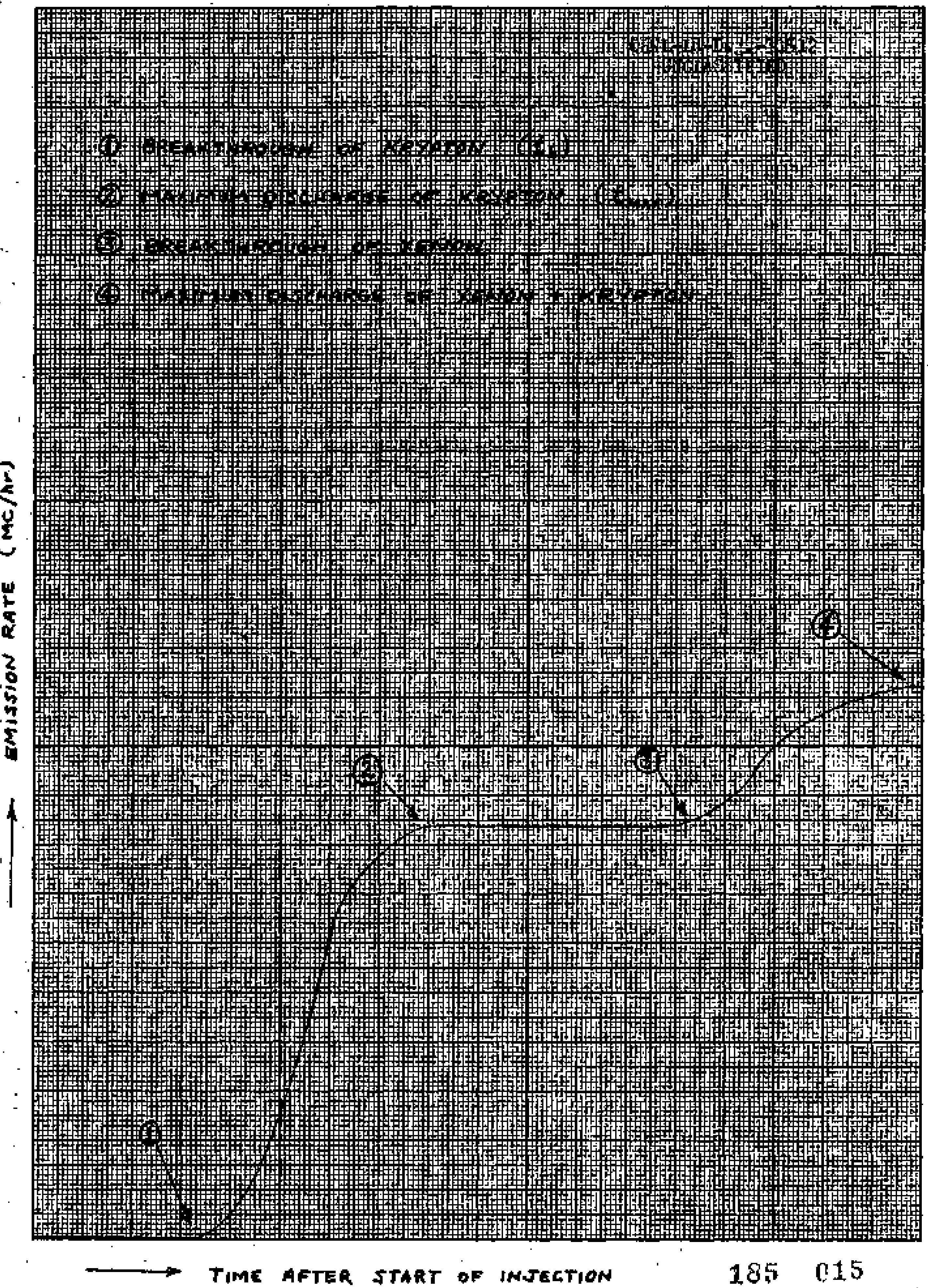
EFFECT OF TEMPERATURE ON k

Fig. 1



EMISSION RATE OF KRYPTON AND XENON FROM TRAP WITH CONTINUOUS CONSTANT INJECTION OF FISSION GASES

FIG. 2



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