Reference copy

CLASSIFICATION CANCELLED
BY AUTHORITY OF DOC
BY [illegible] DATE JUN 15 1973

[redacted] UNCLASSIFIED

CLASSIFICATION LEVEL
(S, C, OR U)

ATOMICS INTERNATIONAL
A Division of North American Aviation, Inc.

This document is
PUBLICLY RELEASABLE
[signature]
Authorizing Official
Date: 2-11-09

NAA-SR-MEMO 9258

[redacted]

This document contains ______ pages
This is copy 1 of [redacted]

Do not remove
this sheet

CLASSIFICATION CHANGED TO [illegible] (Insert appropriate classification)
BY AUTHORITY OF R. G. [illegible] (Person authorizing change in classification)
BY [signature] (Signature of person making the change, and the date made) 3-14-66

[redacted]

CLASSIFICATION TYPE
(RD OR DI)

NAA-SR-MEMOs are working papers and may be expanded, modified, or withdrawn at any time, and are intended for internal use only.

[redacted]

This report may not be published without the approval of the Patent Branch, AEC.

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW

1st REVIEW-DATE: 5-9-97	DETERMINATION [CIRCLE NUMBER(S)]
AUTHORITY: □ ADC □ ADC ☒ ADD	1. CLASSIFICATION RETAINED
NAME: Ted Dawn	2. CLASSIFICATION CHANGED TO
2ND REVIEW-DATE: 5-9-97	3. CONTAINS NO DOE CLASSIFIED INFO
AUTHORITY: ADD	4. COORDINATE WITH
NAME: [signature]	(5.) CLASSIFICATION CANCELED
	6. CLASSIFIED INFO BRACKETED
	7. OTHER (SPECIFY):

MASTER

[redacted] UNCLASSIFIED

719-H

CLASSIFICATION LEV[redacted]
(S, C, OR U)

DISCLAIMER

[redacted] UNCLASSIFIED

ATOMICS INTERNATIONAL A Division of North American Aviation, Inc. **TECHNICAL DATA RECORD**	NAA-SR-MEMO TDR NO 9258	APPROVALS
	PAGE 1 OF 22	
AUTHOR: C. A. Willis *C. A. Willis* — DEPT & GROUP NO: 727-75	DATE 11/19/63	
	GO NO 7611	*K. E. Buttrey*
TITLE: Radiological Hazards Comparison of SNAP 9A to SNAP 10A	S/A NO 3010	TWR 54159

SECURITY CLASSIFICATION

(CHECK ONE BOX ONLY) AEC DOD — UNCL. ☐ ☐ — CONF. ☐ ☐ — [redacted] ☐

(CHECK ONE BOX ONLY) [redacted] — DEFENSE INFO. ☐

AUTHORIZED CLASSIFIER SIGNATURE: *K. E. Buttrey* DATE: 12/31/63

PROGRAM: Aerospace Safety

SUBACCOUNT TITLE: Utilization of SNAP Reactor for Short Orbital Lifetime Missions

STATEMENT OF PROBLEM: Review SNAP 9A radiological hazards, safety features, and criteria and develop criteria which limit SNAP 10A hazards to the same level.

ABSTRACT: SNAP 10A radiological hazards are compared to those from SNAP 9A as presented in the final safeguards report for the transit mission. The SNAP 9A hazard is based on a 900 year decay in orbit plus reentry burnup. It is shown that the SNAP 10A hazards are always less than those from SNAP 9A, for the same orbit life, provided:

1. Reactor shutdown is achieved prior to 8 years operation at full power.
2. Reentry burnup is achieved.

In the event that reentry burnup of SNAP 10A cannot be ensured, 400 years shutdown is required to reduce the external radiation hazard from one year of reactor operation to a safe level. Internal radiation hazards would have been reduced to the 9A level in 200 years. Post reentry criticality must also be prevented to allow meaningful comparison as criticality produces direct radiation hazards as well as short-lived radionuclides that otherwise would not be present in the case of radioisotope power source. It is, therefore, concluded that for those missions where long decay times in orbit cannot be ensured it is imperative that reentry burnup be achieved in order to eliminate external radiation hazards.

DISTRIBUTION

E. Ash 726
R. Balent 720
J. Brunings 726
K. Buttrey 727
G. Calkins 735
W. Cegelski 727
D. Cockeram 720
R. Courson 722
R. Cummings 727
R. Detterman 727
H. Dieckamp 720
R. Elliott 727
S. Fields 727
W. Flynn 727
R. Gimera 727
D. Gylfe 727
J. Hale 727
R. Hart 726
W. Henoch 724
C. Johnson 727
R. Johnson 727
J. Lewis 735
L. Maki 727
D. Mason 727
L. Mims 727
L. Moss 727
D. Oliver 727
A. Piccot 727
J. Rohlfs 727
V. Sanders 727
W. Scott 724
O. Steele 723
R. Stitt 724 Idaho
J. Susnir 727
A. Thiele 724
R. Wallerstedt 722
E. Weisner 720
A. Weitzberg
J. Wetch 720
R. Williams 720
R. Eilson
R. Eggleston 724

[redacted]

[redacted] UNCLASSIFIED

INTRODUCTION

Aerospace nuclear safety criteria are not necessarily the same as safety criteria for terrestial reactors and no special criteria have been established. Thus it appears worthwhile to review pertinent cases in which decisions have been reached, particularly since safety criteria can be expected to remain primarily "de facto" for some time.

No reactors have been used in space but radioisotope fueled generators which also present radiological haz rds, have been utilized in orbit. SNAP 9A (Reference 1) is of particular interest as it was recently approved and placed in service. Therefore, SNAP 9A radiological safety criteria and hazards are reviewed and used as a basis for SNAP 10A radiological safety criteria.

RADIOLOGICAL HAZARD

There are three types of radiological hazard, characterized by the manner in which the dose is inflicted, viz:

1. direct radiation
2. external radiation, and
3. internal radiation.

"Direct radiation" refers to the radiation emitted while the core is essentially intact and includes both the prompt radiation emitted during criticality and the radiation from fission product and activation product decay. "External radiation" denotes radiation emitted after the core is destroyed and while the radioactive material is outside the body of the person being irradiated, for example, radiation from a fuel element after core disassembly. The designation "internal radiation" means the radiation source is within the body of the exposed individual. For instance, fission products from a fuel element which fell into a reservoir might be ingested and the radiation emitted while the radioactive material was in the person's body is considered internal radiation.

The hazards from direct and external radiation normally are directly proportional to the observed or specified quantities -- rem or rem/hour-- but the situation is not so straightforward for internal radiation. The quantity of radioactive material is usually given in curies and, for any specific isotope, the internal radiation (or radiotoxicity) hazard is proportional to the number of curies. However, the quantity of radioactive material in curies is no measure of the relative hazard where different isotopes are to be compared. For example, from internal radiation the hazard from one curie of highly radiotoxic Pu-238 is 2.8×10^{6} times the hazard from one curie of mildly radiotoxic H-3, Ge-71, Nb-97 or In-131 m (Reference 2).

The internal radiation hazard from a quantity of long-lived radioactive material released to the biosphere is perhaps best characterized by the following three quantities:

1. the number of maximum permissible body burdens (MPBB)
2. the water volume required to dilute the material to its maximum permissible concentration (MPC), and
3. the air volume required to dilute to the maximum permissible concentration

The maximum permissible body burden is the amount of a radioisotope which would be expected to cause no observable damage if maintained inside a person's body indefinitely. The maximum permissible concentrations are those concentrations of an isotope in air or drinking water which would keep the amount of material in the body at the MPBB. For example, the MPBB for Pu-238 is 4×10^{-8} curies and this body burden would be maintained by continuous exposure to air containing 7×10^{-13} curies per cubic meter or to drinking water containing 5×10^{-5} curies per cubic meter.

SNAP 9A

SNAP 9A is a 22 watt thermoelectric generator fueled with 16,175 curies of Plutonium-238. The generator is expected to have a useful life of five years. In the transit mission it was placed in a polar orbit with an expected orbit-life of 900 years.

Pu-238 presents essentially no direct or external radiation hazard since both it and its daughter U-234 are alpha emitters. However, Pu-238 is one of the most hazardous radionuclides as an internal radiation source. Thus, there is no radiological hazard as long as the fuel is contained but release in the biosphere could occur and hazards could result.

UNCLASSIFIED

Obviously the SNAP 9A radiological hazards are greatest early in the life of the device. For the original Pu-239 inventory the three characteristic quantities are:

[redacted]

1. Maximum permissible body burdens: 4×10^{11}
2. Water volume for dilution to MPC: 3.2×10^{8} cubic meters*
3. Air volume for dilution to MPC: 2.3×10^{16} cubic meters**

Each of these factors might be increased by a factor of ten for non-occupational exposure. Nine hundred years decay (Figure 1) reduces each of the quantities by the factor 10^{-3} so the reentry values are 4×10^{8} MPBB, 3.2×10^{13} cubic meters of water and 2.3×10^{5} cubic meters of air. The total activity essentially ceases to decline after a thousand years because Pu-238 decays to radioactive U-234 which has a very long (2.48×10^{5} years) half life. Subsequent decay periods will be measured in millenia. However, U-234 is slightly less radiotoxic than Pu-238 (Table 1) the quasi-equilibrium quantity, 5.7 curies, constitutes 1.15×10^{8} MPBB and can be diluted to occupational MPC by 3×10^{10} cubic meters of air or 2×10^{4} cubic meters of water. An increase in decay time beyond the 900 years planned for the transit mission would not significantly reduce radiological hazards.

The safety objectives for SNAP 9A were complete fuel containment prior to reentry, maximum radiological decay in orbit, and complete reentry burnup. These objectives could not be completely achieved but were modified to the following design safety criteria:

1. absolute containment of the fuel except after (a) aerodynamic heating or (b) more than a year of corrosive attack by sea water, and
2. complete burnup and dispersal of the fuel in particles of no more than ten microns diameter above 10^{5} feet for any reentry mode.

The first criteria requires that the device maintain integrity through (1) a missile propellant explosion, (2) a missile propellant fire, (3) corrosive attack by missile propellant, sea water, the atmosphere, etc., (4) a terminal velocity impact on rock, (5) internal pressure from helium buildup, or (6) thermal conditions resulting from land burial. The second criteria requires complete burnup, even in the event of "package" (intact satellite) reentry.

Obviously, if SNAP 9A will burn up in the stratosphere, upon reentering the atmosphere from orbit, suborbital paths must be possible that will

*Eighty-five billion gallons, about one-fourth the total quantity used and wasted daily in the United States.

**5.6 million cubic miles, enough air to cover the earth's surface to a depth of 100 feet.

result in complete or partial release of the fuel to the biosphere. Consequently, a range safety criterion requires that the device be restricted to isolated areas when incomplete or low altitude burnup is possible.

Obviously these criteria are stringent. In fact, they may constitute the maximum attainable with this isotope without resorting to injection to a solar orbit. Even so, this is not an instance of zero hazard for the following reasons:

1. Failure to achieve orbit could have resulted in a large release of long lived radioactive material to the lower atmosphere and/or to the ocean.
2. A low orbit could have caused the release of a large quantity of Pu-238 to the upper atmosphere.
3. A significant quantity of Pu-238 will be released to the upper atmosphere as a consequence of the intended operation.

SNAP 10A

SNAP 10A is a compact reactor designed to operate for one year at 33 thermal kilowatts. As with other reactors, radiological hazards are a strong function of operating history. Before startup the important radioisotope is uranium-234 since there is no startup neutron source. The inventory is only 0.33 curies so that pre-startup radiological hazard is little more than one-twentieth the ultimate (minimum) SNAP 9A hazard. However, once criticality is achieved*, either accidentally or in orbit, the situation changes radically.

During criticality the radiological hazard is from direct (neutron and gamma) radiation. A "maximum credible" 70 megajoule excursion may produce lethal doses as far as twenty meters away and "emergency permissible doses" (25 rem) out to about 70 meters. Average annual permissible doses (5 rem) could be incurred 150 meters away. Direct radiation constitutes the hazard during steady power operation also. At full power (33 kilowatts) the above doses could be received at the same distances in about 33 minutes. Obviously, direct radiation is important only within a few hundred meters of the reactor. Quasi-steady-state operation releasing $2x10^4$ megajoules is conceivable if an optimum quantity of water is encountered.

*The activity produced in the zero power acceptance testing operation is negligible after a few hours shutdown.

After shutdown, radiological hazards decrease monotonically with time but several kinds of hazard must be considered. Direct radiation will persist, though with greatly reduced intensity, and core destruction could permit internal radiation hazards and external radiation hazards from reactor debris.

If criticality consisted of a power excursion without significant previous power operation -- a launch accident, for example -- the resulting radioactive material would be short lived. Release fission products might be transported downwind and the cloud containing the radioactive debris would present both external and internal radiation hazards. However, radioactive decay and atmospheric dispersal would reduce the hazard as the cloud moved so the hazard from the cloud would be confined to essentially the same area that was exposed to direct radiation. The release of excursion generated activity to water would constitute an even smaller hazard since human ingestion of contaminated water would not be likely to occur before dilution and decay minimized the hazard. Furthermore water shielding would minimize the external radiation dose. Thus, normal launch and range safety precautions provide adequate protection for both launch personnel and the public against hazards from an excursion prior to power operation. However, a power excursion after return from orbit would be in a completely uncontrolled location and obviously is unacceptable.

After power operation and shutdown the dominant hazard is determined by the operating history, the shutdown time and the physical form of the radioactive material. If the activity is contained in clad fuel elements the only hazard is external (gamma) radiation which is proportional to the gross fission product inventory. The core inventory in curies, as approximated by the Way-Wigner formula* is

$$A = 0.288\, P\, T_d^{-0.2}\left[1 - (1 + T_o/T_d)^{-0.2}\right]$$

UNCLASSIFIED

*The empirical Way-Wigner formula is not assumed superior to detailed calculations but is used here for convenience and for comparison with NAA SR MEMO 7774 calculations. The Way-Wigner formula has been shown to give reasonable agreement with detailed calculations for decay times up to a few centuries and confidence in any calculation is limited for extremely long decay times due to uncertainties in yields and decay constants.

[redacted]

after T_o years at P watts and shutdown for T_d years. For one fuel element (of 37) the self shielding factor can be taken as 0.6, geometry effects can be neglected at distances greater than one meter (Figure 2), and air shielding can be neglected at distances less than 200 meters, so in this range the dose rate is

$$\dot{D} = 60 T_d^{-0.2}\left[1 - (1 + T_o/T_d)^{-0.2}\right] R^{-2} \quad \ldots\ldots (rem/hr)$$

where R is the separation distance in meters and the power is 33.5 kilowatts. Obviously the dose rate variation with time is a strong function of the operating time (Figure 3). After a year at full power about 400 years of decay reduces the dose rate to 0.01 r per hr at a meter (Figure 4) -- a level which might be considered acceptable because it is the limit for shipment by common carrier.

Power operation also builds up radiological poisons, of which S_R-90 and I-131 are generally most important. Of these I-131 can be neglected if there is a shutdown period of even a few months before exposure because the half-life is only 8.05 days (Figure 5). Conversely, S_R-90 has a 28 year half life and so builds up and decays slowly. The S_R-90 inventory in curies is given by

$$A = 1670\left(1 - \epsilon^{-\lambda T_o}\right)\epsilon^{-\lambda T_d}$$

for a constant power of 33.5 kilowatts prior to shutdown. The decay constant (λ) is 0.0248 per year. The maximum possible activity, corresponding to a long operating time ($T_o \gg$ 28 years) and short shutdown time ($T_d \ll$ 28 years) is 1670 curies, for which the characteristic quantities are

1. Maximum permissible body burdens: 8.4×10^{8}
2. Water volume for dilution to MPC: 1.7×10^{9} cubic meters
3. Air volume for dilution to MPC: 1.7×10^{13} cubic meters

Obviously, S_R-90 compares most unfavorably with Pu-238 as a water contaminant. For the same dilution volume as the reentering SNAP 9A (3.2×10^5 cubic meters of water) the S_R-90 inventory must be 0.32 curies. Thus, one year at 33.5 kilowatts necessitates 200 years decay after shutdown (Figure 6).

NAK LOSS

SNAP 10A is designed to shut down after a year of operation but, if the mechanism fails, operation will continue at essentially full power

[redacted]

[redacted]

until the cooling system fails. After a few years the NaK will escape, or at least cease to flow, thus reducing the system's capacity for removing heat from the core and thereby reducing power due to the temperature coefficient. Reactor power variation with time after NaK loss as calculated by Fields (Reference 3) is presented in Figure 7.

Power reduction will result in a fission product inventory decrease. Since power will vary slowly with time, after about sixty years the S_R-90 inventory will remain essentially in equilibrium with the fission process. However, the activity produced at full power adds significantly and may constitute the major portion of the S_R-90 inventory for the first century after NaK loss. The S_R-90 inventory (Figure 8) falls to 0.32 curies only after 10^4 years.

The gross fission product inventory also remains near equilibrium with reactor power. However, reentry disassembly will cause shutdown and some radioactive decay will take place in the approximately 120 seconds between disassembly and impact. Thus, the quantity of interest is not the dose rate but the average dose rate for the exposure period. The "first hour dose"; the dose received one meter from a fuel element during the first hour after a 120-second shutdown is

$$D_1 = 0.014\,P \quad \cdots (rem)$$

where P is the power in watts just before shutdown. The first hour dose is depicted in Figure 9 as a function of time after NaK loss. If the first hour dose is to be held to the non-occupational annual permissible dose (0.5 rem), an orbit life of 3000 years is required and further reduction to the more acceptable 0.01 rem limit would necessitate a very long orbit life.

Shutdown is significantly more desirable than NaK loss, and indeed, is necessary if SNAP 9A hazards are not to be exceeded.

CONCLUSION

Three considerations dominate the radiological hazards picture. First the possibility of a power excursion in an uncontrolled area must be eliminated, therefore reentry disassembly is required. Second, external dose rates in uncontrolled areas must be acceptably small so reentry burnup or 400 years decay after shutdown is necessary. Finally, the

[redacted]

internal radiation hazard should not exceed that presented by SNAP 9A so there must be a decay period of 200 years after shutdown before reentry.

It is significant that if shutdown and reentry burnup are achieved SNAP 10A is less hazardous than SNAP 9A for any orbit life (Figure 10 and 11). Moreover, inhalation is a much more likely exposure mode than is ingestion and the air contamination hazard from SNAP 9A is much greater than from SNAP 10A. In fact, only after nine centuries decay does the 9A air dilution volume fall to the maximum attainable by 10A assuming infinite operation!

[redacted]

ATOMICS INTERNATIONAL
A Division of North American Aviation, Inc.

REFERENCES

1. T. J. Dobry, "SNAP 9A Radioisotope - Fueled Generator, Final Safety Analysis for Transit Mission," MND-P-2775-2 (SRD) March, 1963

2. "Report of Committee II on Permissible Dose for Internal Radiation," (1959) Health Physics, Volume 3, June 1960

3. S. R. Fields, "Thermo-Physics Technical Note No. 24: SNAP 10A Reactor Temperatures and Power Decay in Space for Zero NaK Flow and Loss of NaK," NAA-SR-TDR 8498, May 10, 1963

[redacted]

[redacted]

TABLE 1

ISOTOPE CHARACTERISTICS

	SR^{90}	Pu^{238}	U^{234}
Maximum permissible body burden, μC	2.	0.04	0.05
Continuous occupational MPC in water, c/m3	10^{-6}	$5x10^{5}$	$3x10^{-4}$
Continuous occupational MPC in air, c/m^3	10^{-10}	$7x10^{-13}$	$2x10^{-10}$
Specific dilution volume, water, m^3/c	10^{6}	$2x10^{4}$	$3x10^{3}$
Specific dilution volume, air, m^3/c	10^{10}	$1.4x10^{12}$	$5x10^{9}$
Half life, years	28	89	$2.48x10^{5}$
Annual permissible inhalation, μC	0.73	$5x10^{-3}$	0.3
Annual permissible ingestion, μC	0.9	45	270

[redacted]

Figure 1. Pu^{238} and Sr^{90} decay

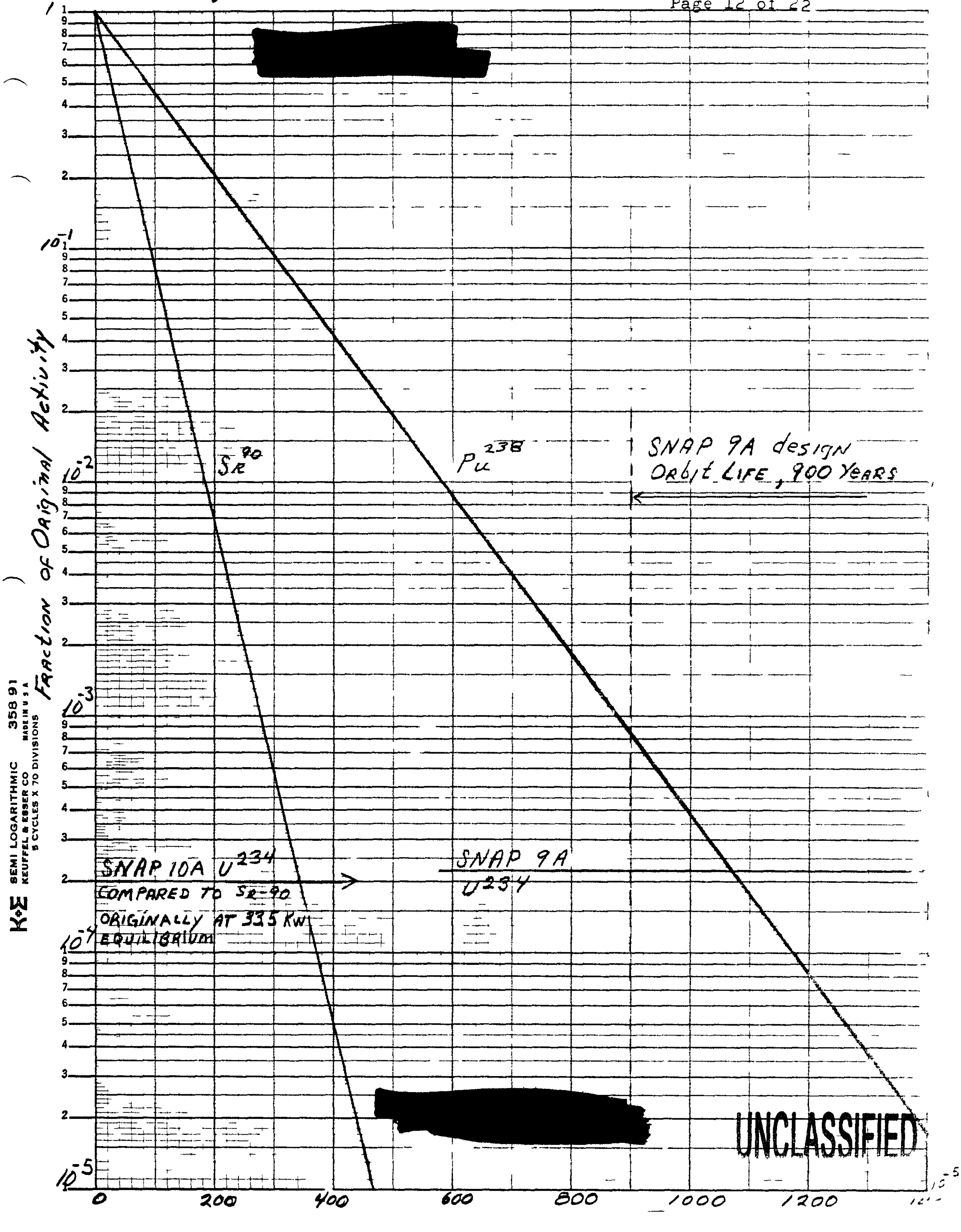
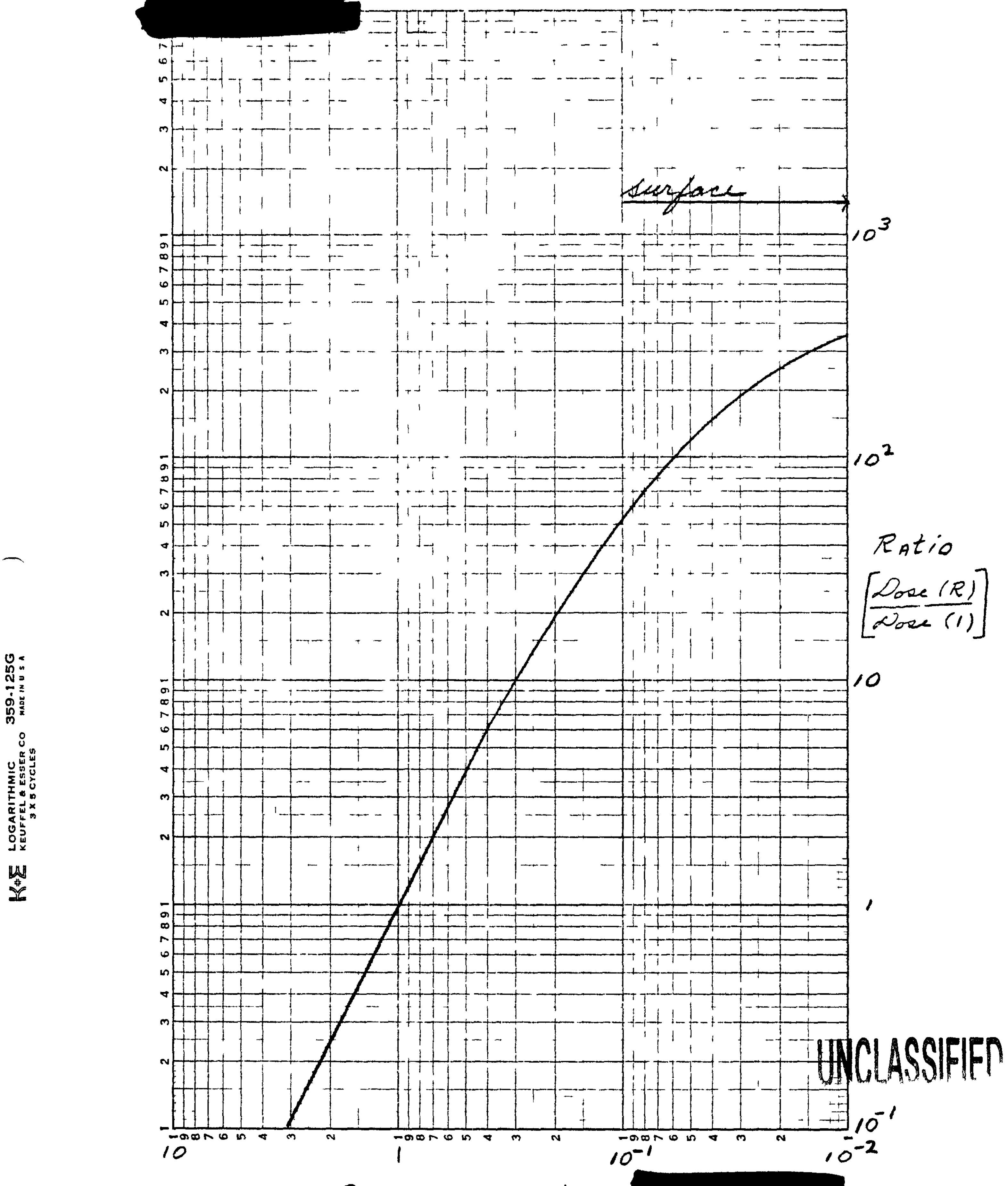


Figure 2
Variation of dose rate with distance from one fuel element

[redacted]



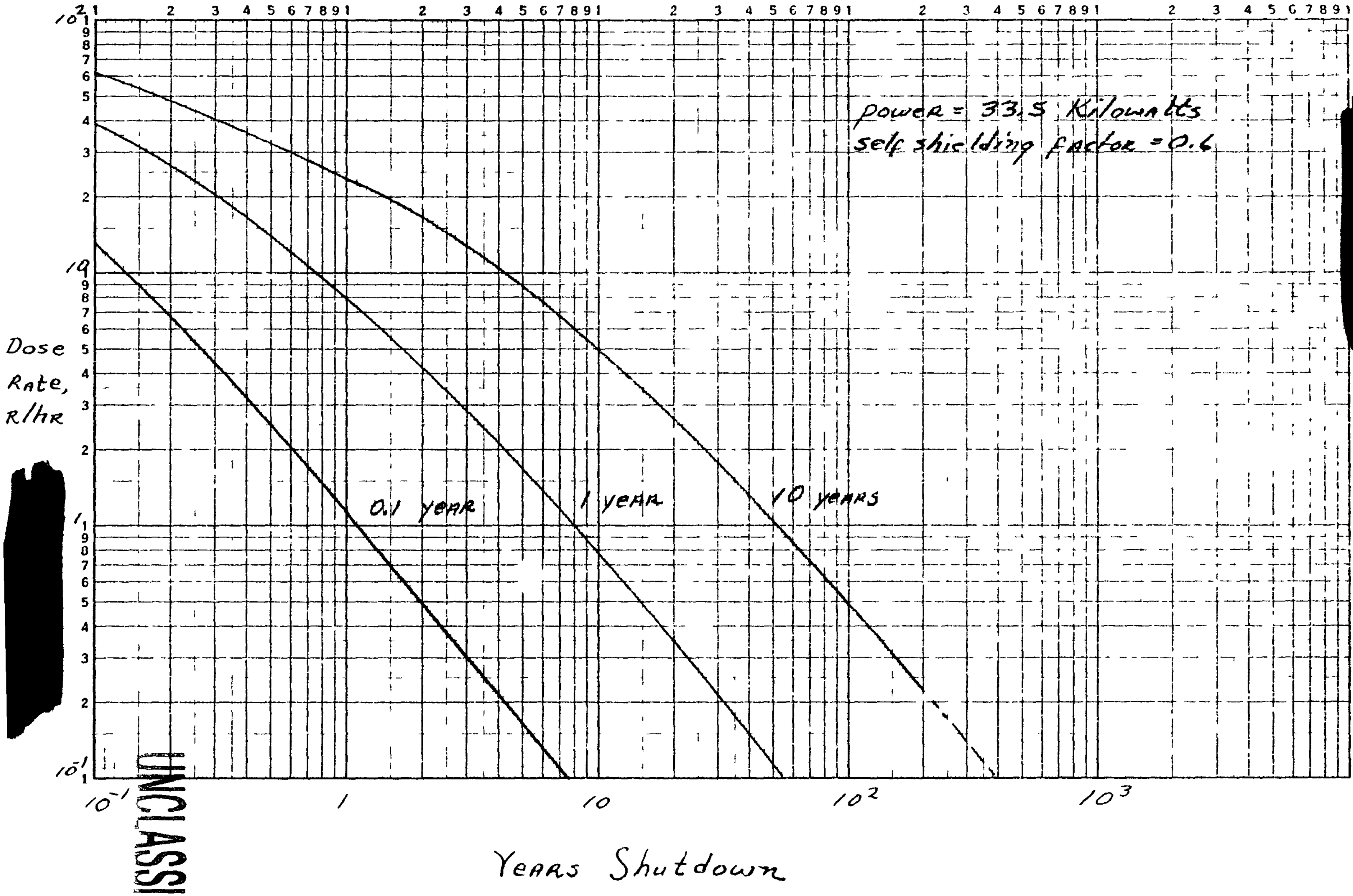
[redacted]

UNCLASSIFIED

K+E LOGARITHMIC 359-125G
KEUFFEL & ESSER CO MADE IN U.S.A.
3 X 5 CYCLES

figure 3.

Dose Rate at one Meter from a fuel Element for Various Operating Times



[redacted]

[redacted]

UNCLASSIFIED

UNCLASSIFIED

NAA-SR-MEMO 9258
Date: 11/19/63
Page 14 of 22

FIGURE 4

Dose Rate at a Meter from a fuel Element After One Year at 33.5 Kilowatts

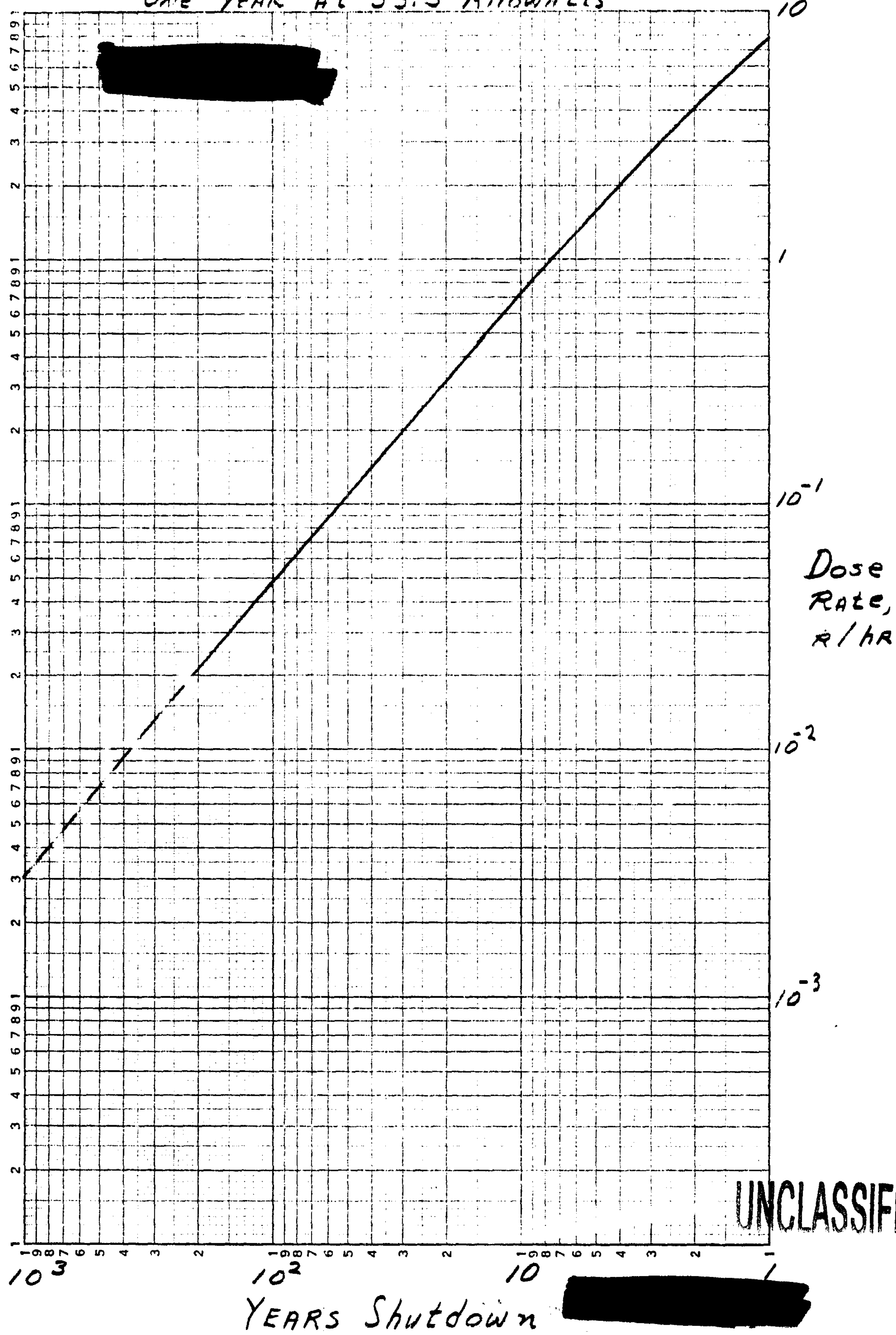
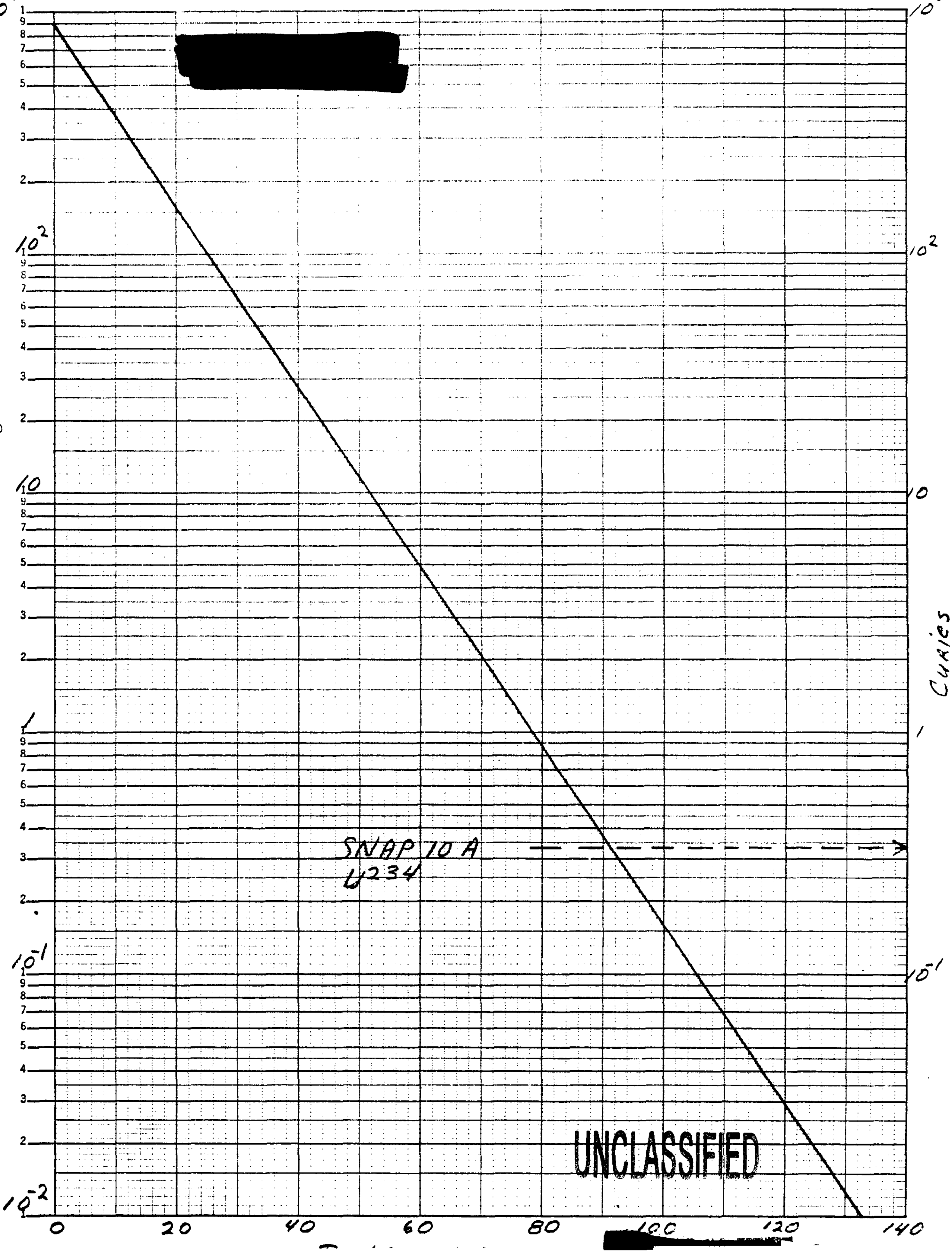


Figure 5. I^{131} Decay from 33.5 Kilowatt Saturation

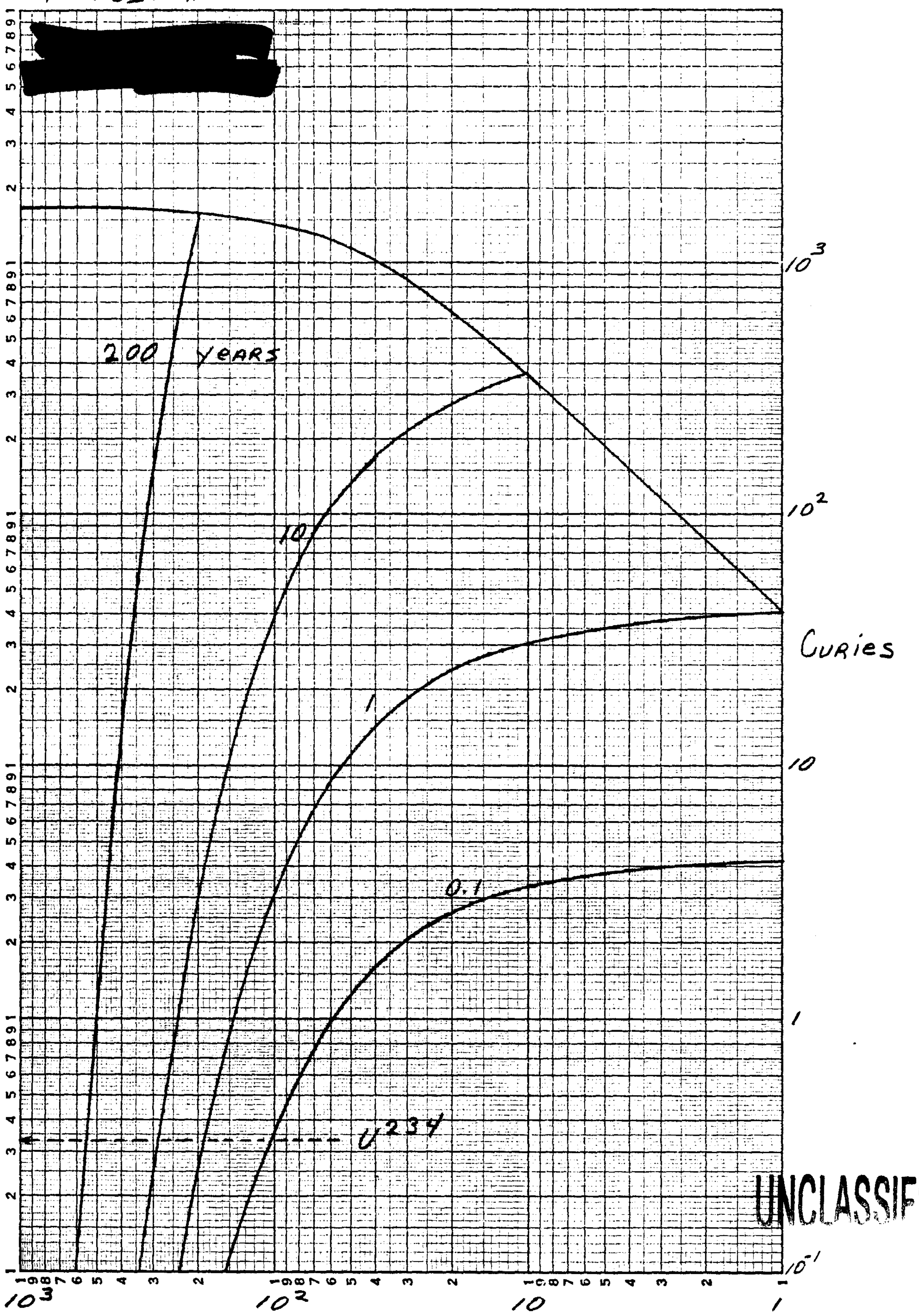


[redacted]

UNCLASSIFIED

Figure 6

Sr^{90} Buildup and Decay for Various Operating Periods at 33.5 Kilowatts



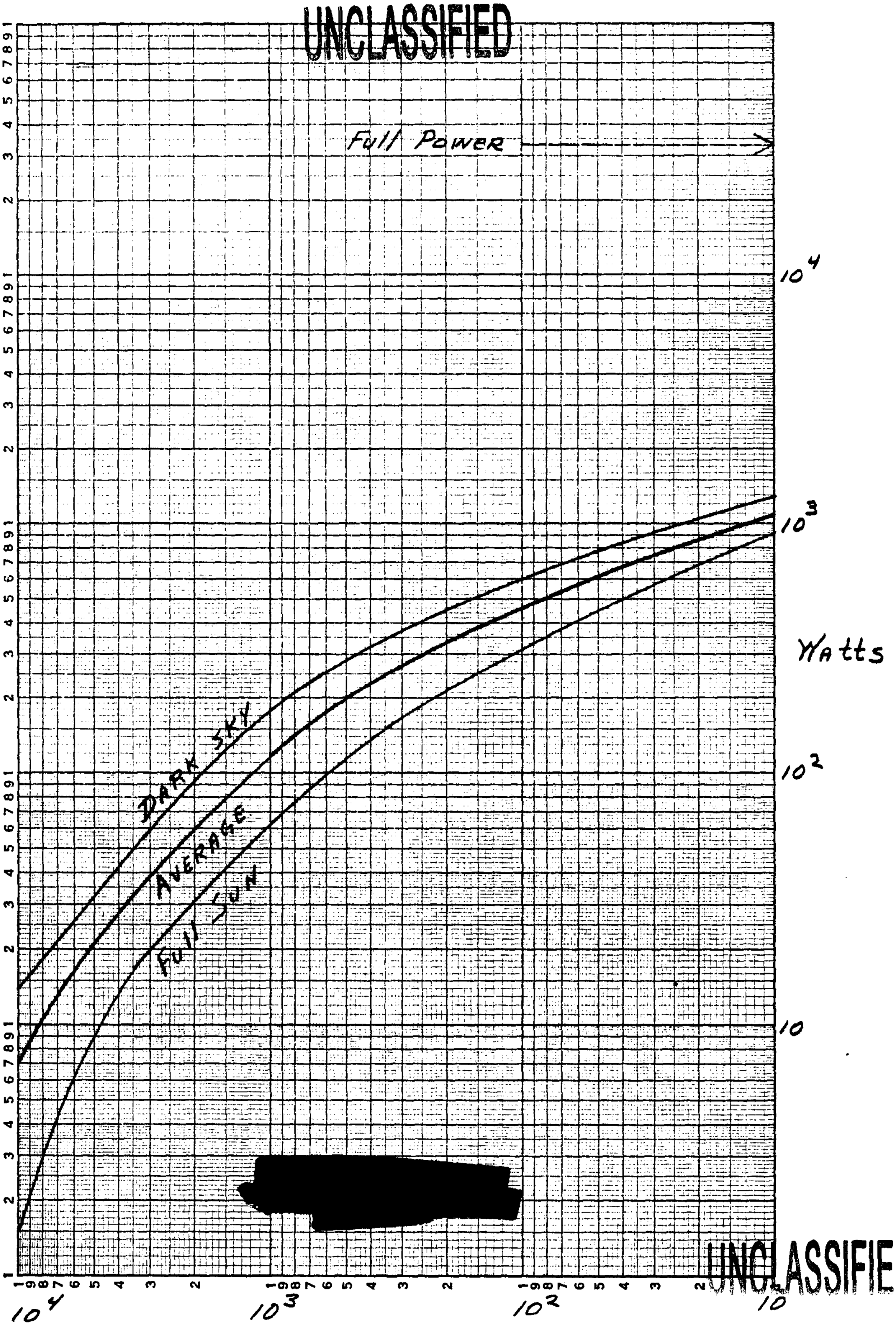
V... [redacted]

[redacted]

FIGURE 7

Power Decline after NaK Loss

UNCLASSIFIED



[redacted]

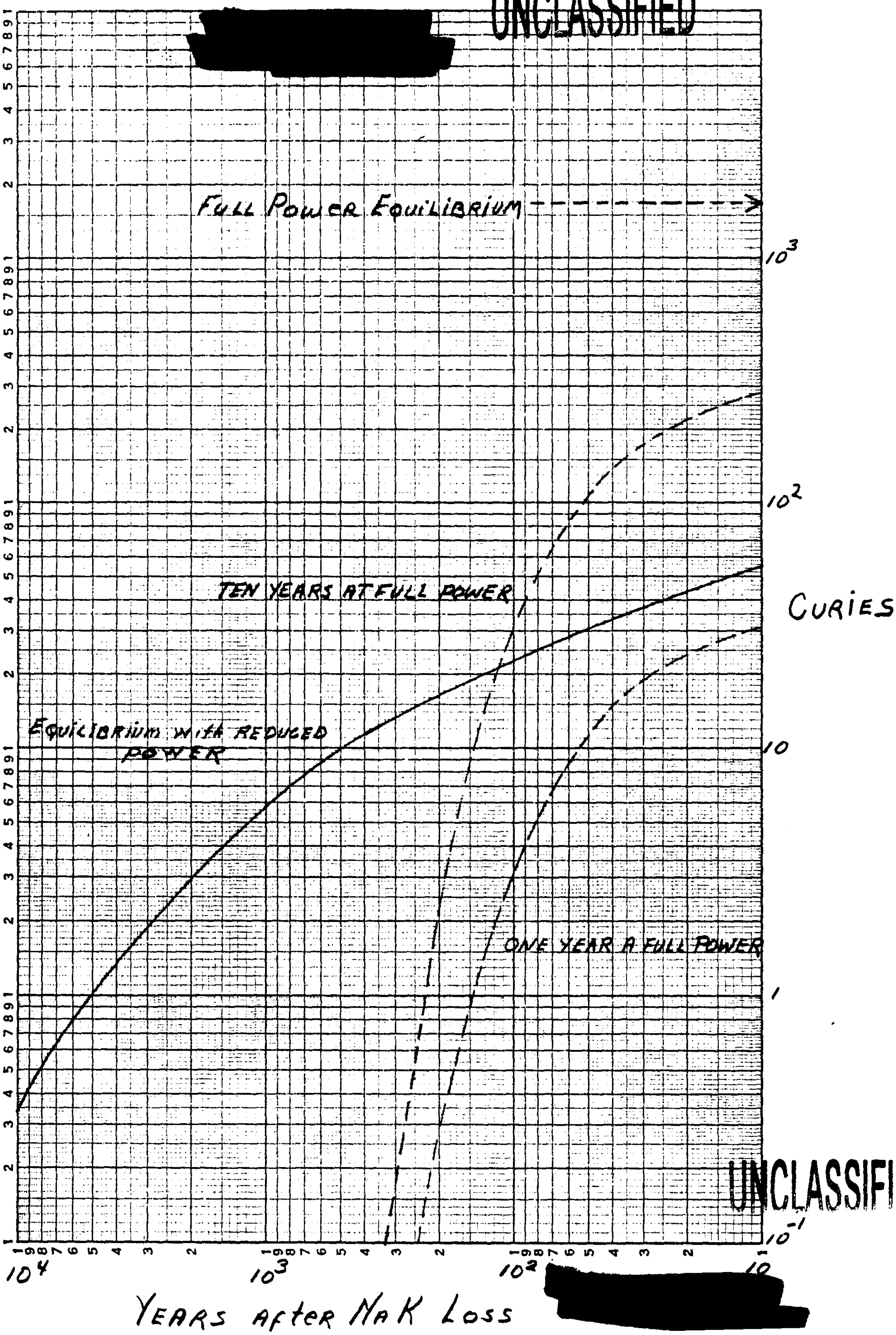
Years after NaK Loss

UNCLASSIFIED

UNCLASSIFIED

Figure 8

Sr^{90} Inventory after NaK Loss

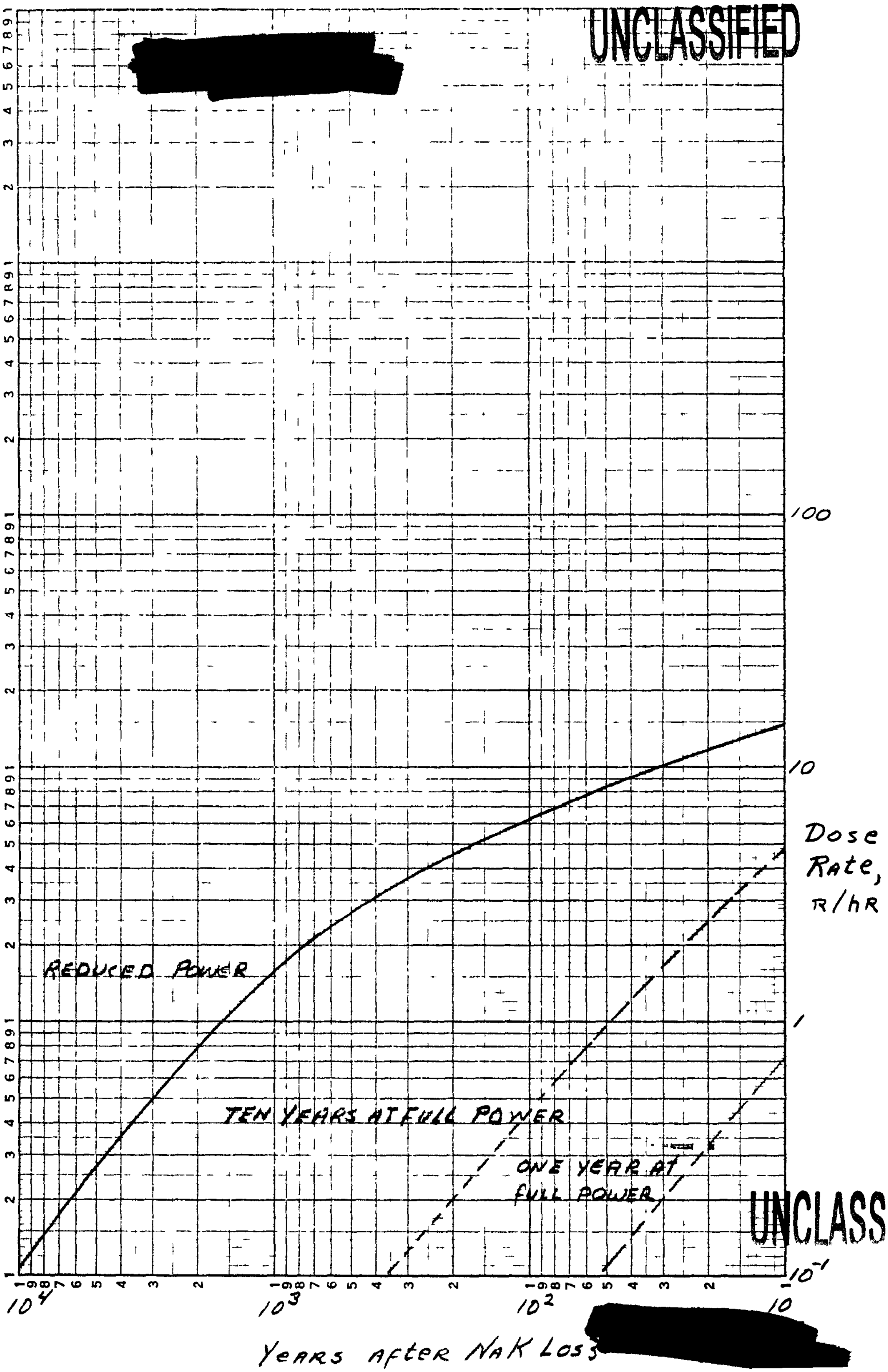


UNCLASSIFIED

FIGURE 9

Average Dose rate at a meter from a fuel element during the first hour after impact

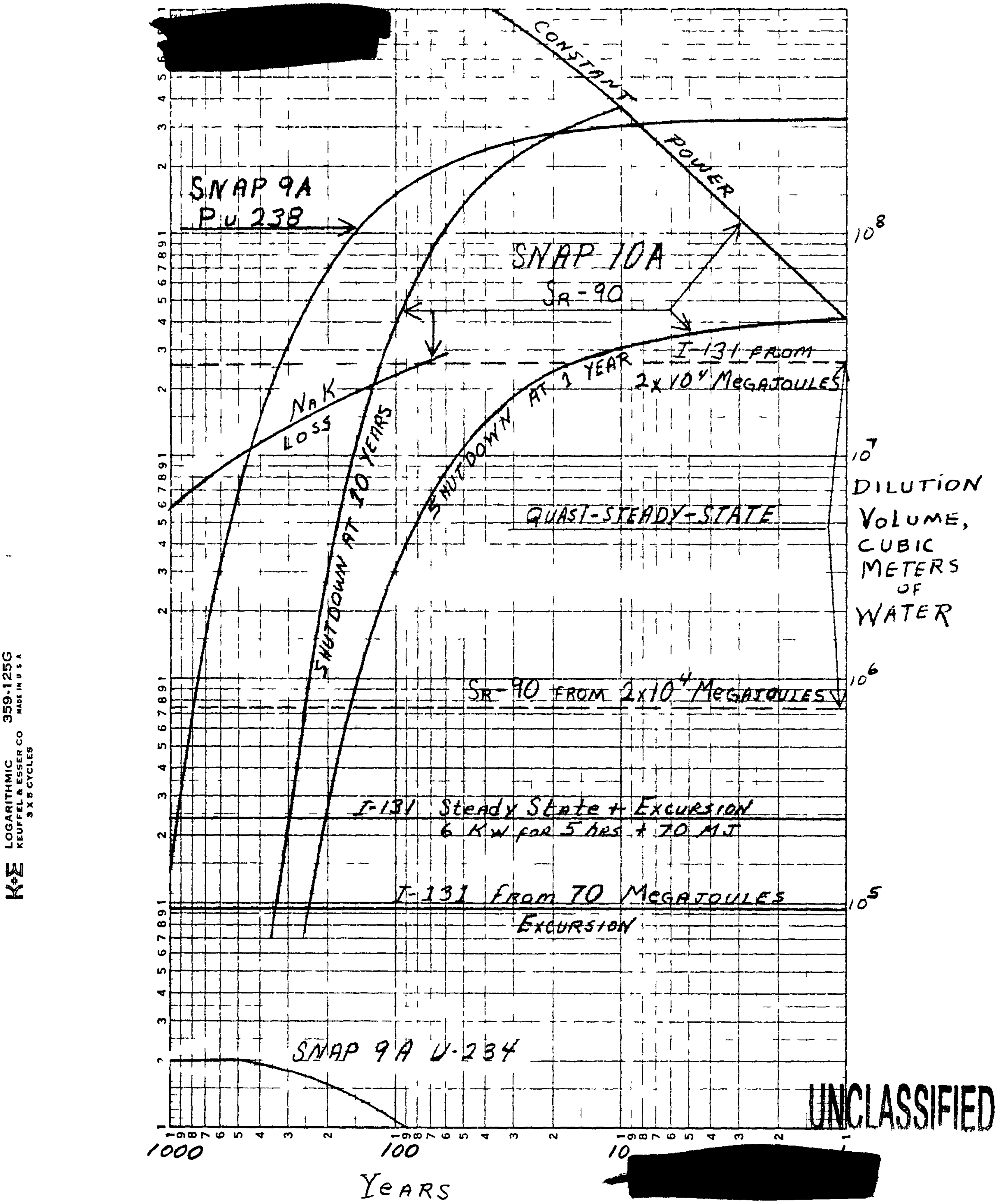
UNCLASSIFIED



UNCLASSIFIED

FIGURE 10

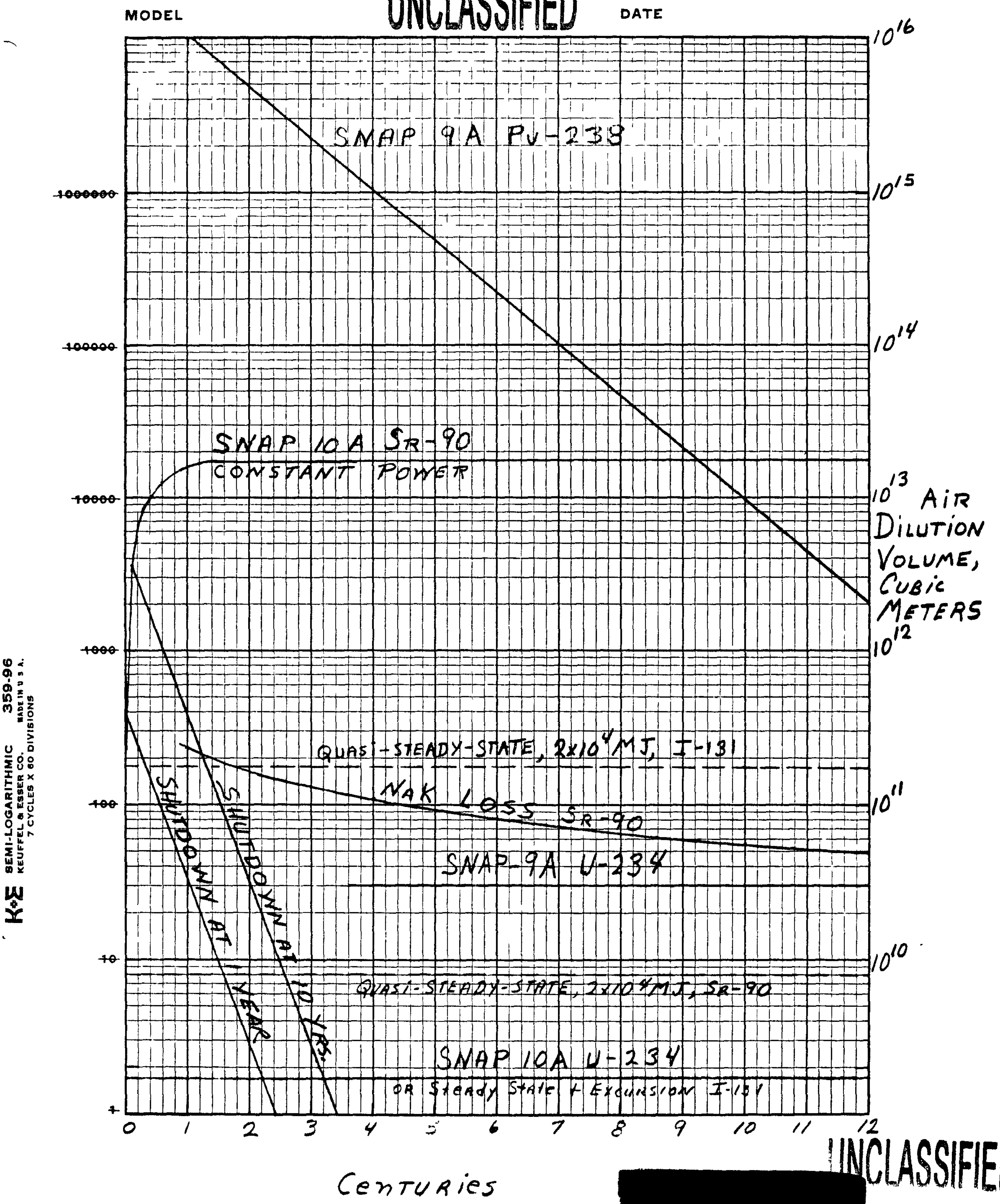
WATER DILUTION VOLUMES



[redacted]

FIGURE 11
AIR DILUTION VOLUMES

UNCLASSIFIED



UNCLASSIFIED

[redacted]