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CRITERIA FOR ESTABLISHING SHORT TERM PERMISSIBLE INGESTION OF FALLOUT MATERIAL

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The criteria for establishing permissible ingestion of radioactive fallout material under emergency conditions for several weeks following a nuclear detonation are dependent primarily on exposures to the,

a. gastrointestinal tract from the gross fission product activity,

b. thyroid from the isotopes of iodine and,

c. bone, principally from Sr^{90}-Y^{90}, Sr^{89}, Ba^{140}-La^{140}.

I. Doses to the Gastrointestinal Tract

The following principal assumptions are used in calculating the doses to the gastrointestinal tract of adults:

a. The calculations are based on the methods contained in reference one.

b. The fallout material is 90 percent insoluble. (See IV. Discussion below).

c. The activity decays according to the principle of $(time)^{-1.2}$.

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d. The energy delivered is all derived from the beta emissions, having a mean energy of 0.4 Mev when in the lower large intestine. (See Graph One)[2]

e. The total daily consumption of food and water is 2200 grams or milliliters.

The method of calculation is according to the following equation:

$$\frac{(\text{Total number of disintegrations occurring in organ})(\text{Energy of emissions})(8.0\text{x}10^{-9})}{(\text{Mass of Organ})} = \text{Dose (rads)} \quad (1)^{*}$$

The number of disintegrations taking place in the organ may be calculated according to equation two:

$$\text{Total number of disintegrations} = 5A_a\, t_a^{1.2} \left[t_a^{-0.2} - t_b^{-0.2} \right] \quad (2)$$

Where: A_a = number of disintegrations per unit time at time "a" after detonation.

t_a = time "a" after detonation.

t_b = time "b" later than "a".

One of the more useful forms for the criteria would be in units of permissible concentrations at time of intake. This will somewhat complicate the calculations since there will be a decrease in activity as the material passes along the gastrointestinal tract. When such calculations are made according to the above assumptions and equations, it may be seen that the critical organ is the lower large intestine except for the first hours immediately following the detonation. (Table One shows the relative doses

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* The rad is the unit of absorbed dose equal to 100 ergs per gram.

$$\frac{1.6\text{x}10^{-6}(\text{ergs/Mev})0.5\ (\text{proportion of total energy to gastrointestinal tract})}{100\ (\text{ergs/gm-rad})} = 8.0 \times 10^{-9}$$

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to parts of the gastrointestinal tract as a function of time.) Therefore, Graph Two is based on the activity at time of ingestion to produce one rad of dose to the lower intestine.

For example, Graph Two shows that if about 48 microcuries are ingested on the 24th hour after detonation, the lower large intestine may receive one rad of radiation dose. This was calculated in the following manner.

Step 1. Determine the total number of disintegrations in the lower large intestine necessary to produce 1.0 rad.

From equation (1)

$$\frac{(\text{Number of disintegrations})\ (0.4)\ 8.0 \times 10^{-9})}{150} = 1$$

$$\text{Number of disintegrations} = 4.7 \times 10^{10}$$

Step 2. Determine the activity at time of intake to produce 4.7×10^{10} disintegrations within the large intestine.

$$\frac{4.7 \times 10^{10}}{0.9} = 5.2 \times 10^{10}$$ disintegrations intake required (assuming 10% solubility).

From equation (2)

$$5.2 \times 10^{10} = (5)\ (A_{37})\ (37^{1.2})\ [37^{-0.2} - 55^{-0.2}] \quad *$$

$$A_{37} \cong 3.7 \times 10^{9} \text{ d/hr.}$$

$$A_{24} \cong 6.2 \times 10^{9} \text{ d/hr.}$$

$$A_{24} \cong 47\ \mu c$$

* If the time of intake is the 24th hour, then the start of irradiation of the lower large intestine is 24 + 13 = 37th hour, according to reference one.

Graph Two has been used in estimating radiation doses to the lower large intestine for prolonged periods of ingestion (Table Two). The following calculations are illustrative for the period of 24th to the 120th

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hour (start of intake at the beginning of the 2nd day after detonation for a duration of four days).

Step 1. Determine the number of microcuries at time of ingestion to produce 1.0 rad to the lower large intestine.

From Graph Two take the mid point of intake period (72nd hour) → 31 μc. (This is obviously an approximation since the exact times of intake during the four-day period will be unknown).

Step 2. Determine the activity at time of intake.

From equation (2)

$$31 = 5\, A_{24}\, 24^{1.2} \left[24^{-0.2} - 120^{-0.2} \right]$$

$$A_{24} \cong 0.94 \ \mu c/hr$$

Since there is assumed a 220 ml/day intake

$$0.94 \times \frac{24}{2200} \cong 0.010 \ \mu c/ml \text{ or gm}$$

II. Doses to the Thyroid

The following principal assumptions are used in calculating the doses to the adult thyroid from intake of activity from fallout material:

a. The percentages of the isotopes of iodine in mixed fission products are according to Hunter and Ballau.[3]

b. Twenty percent of the ingested I^{131} reaches the thyroid.

c. The mean energy is 0.22 Mev.

d. The thyroid weight is 20 grams. (See IV. Discussion below)

e. The percentages of shorter-lived isotopes of iodine that reach the thyroid and their doses are according to reference four.

The method of calculation of doses to the thyroid is illustrated by computing that amount of intake of fission products at the 48th hour to produce 1.0 rad.

Step 1. Determine the dose rate on the day of intake of I^{131} to produce 1.0 rad to the thyroid.

$D = \frac{R}{\lambda e}$ Where: D = dose (1.0 rad)
R = dose rate on initial day
λe = effective decay constant (radiological and biological)

$$1.0 = \frac{R}{0.09}$$

R = 0.09 rads/day

Step 2. Determine the number of microcuries of I^{131} to produce 0.09 rad/day

$$\frac{X(\mu c)(2.2 \times 10^{6})(60 \times 24)(1.6 \times 10^{-6})(0.22)}{(100)(20)} = 0.09$$

X = 0.16 μc to thyroid
or
(0.16) (5) = 0.80 μc I^{131} ingested

Step 3. Determine relative doses from I^{131} and I^{short} according to Graph Three.[4]

At 48th hour, the relative contribution to total dose from I^{131} and I^{short} is about $\frac{1}{1}$.

Therefore, ingestion of 0.4 μc I^{131} (equivalent) at 48th hour will produce 1.0 rads to thyroid.

Step 4. Determine the number of microcuries of fission products required to yield the required I^{131} activity. At 48th hour, I^{131} constitutes about 2.35% of total activity. Therefore,

$$\frac{0.4}{0.023} = 17 \mu c \text{ of fission products.}$$

Graph Four shows the number of microcuries of fission products ingested at times after detonation to produce 1.0 rad to the thyroid.

III. Doses to the Bones

The three principal bone-seeking isotopes of concern are Sr^{90} - Y^{90}, Sr^{89}, and Ba^{140} - La^{140}. Evaluation of these may be made in terms of amount deposited in the bones versus maximum permissible body burdens, or in rads of dose that they deliver after deposition. Since values for maximum permissible body burdens are based on the concept that these will be maintained indefinitely in the body, they are not so valid for Sr^{89} and Ba^{140}- La^{140} when considering short periods of emergency intake.

The following principal assumptions are used in calculating the doses to the bones of adults:

a. The percentages of the isotopes of Sr^{90}-Y^{90}, Sr^{89}, and Ba^{140}-La^{140} in mixed fission products are according to Hunter and Ballau.[3]

b. The percentages of intake of these isotopes that are deposited in the bones, the energies of emissions, and their effective half lives are according to reference five - except for Sr^{90} where a 27.7 year radiological half life is used here.

c. The mass of the bones is 7,000 grams.

The method of calculation of doses to the bones is illustrated by computing the dose from Sr^{89} from the intake of 27 microcuries (See IV Discussion below) of mixed fission products on the 120th hour. Similar calculations were made for Sr^{90}-Y^{90} and Ba^{140}-La^{140} and then the three doses were added for each intake of fallout material.

Step 1. Determine the Sr^{89} to reach the bone.

According to reference 4:

The Sr^{89} content in mixed fission products on the 120th hour is 1.6%.

According to reference 5:

The intake of Sr^{89} to reach to the bones is 25%.

Therefore:

(27) (0.016) (0.25) = 0.108, to the bone.

Step 2. Determine the dose rate to the bones.

With an assumed effective energy of 0.55 Mev (reference 5).

$$\frac{(0.108)(2.2 \times 10^{6})(60 \times 24)(1.6 \times 10^{-6})(0.55)}{(100)\ (7{,}000)} = 4.3 \times 10^{-4} \text{ rads/day}$$

or 0.43 millirads/day

Step 3. Determine total dose.

$$D \text{ total} = \frac{R}{\lambda e}$$ where: R = initial dose rate; λe = effective decay constant

$$D \text{ total} = \frac{0.43}{0.0133} \cong 32 \text{ millirads}$$

IV. Discussion

A. Solubility

The solubility of fallout material varies, depending among other factors upon the surface over which the detonation occurred. The fallout material collected in soil samples at the Nevada Test Site has been quite insoluble, i.e. only a few percent in distilled water and roughly 20-30 percent in 0.1 N HCL. However, it would be expected that the activity actually present in drinking water supplies would be principally in soluble form. The water collected from a well and a cistern on the Island of Rongelap (Table Three) about 21 months after the March 1, 1954 fallout, was found to have about 80 percent of the activity in the filtrate, but there was an undetermined amount that settled to the bottom. Other data suggest the material to have been about 10-20 percent soluble in water.

In the event contaminated food is ingested it is possible that the total activity--soluble and insoluble--may find its way into the gastro-intestinal tract since at times immediately following a fallout most of this activity probably would come from the surface contamination rather than the soil-plant-animal cycle. There may then follow some solubilizing in the acid stomach with subsequent removal from the tract before reaching the lower large intestine.

It is assumed for these calculations that (a) 90% of the fallout material is insoluble when computing doses to the gastrointestinal tract, and (b) that the isotopes of iodine, strontium, and barium are all soluble when computing doses to the thyroid and to the bones. These assumptions are probably conservative, i.e. they may overestimate somewhat the radiation exposures.

B. Biological Significance.

After the estimation of radiation doses by any procedure the final step is an evaluation in terms of biological effects both for short and long terms.

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1. Gastrointestinal Tract

There have been few experiments where the gastrointestinal tract has been exposed in a manner similar to the one assumed here. In one experiment currently underway at the Medical Center of the Oak Ridge Institute of Nuclear Studies, the dosimetry is being studied in dogs using Yittrium-90. The preliminary data are in reasonable agreement with the model proposed in reference one.[6]

In another experiment,[7] rats were fed 1.0 to 6.0 millicuries of Yittrium-90 in a single feeding. Four of the 33 animals died of adeno-carcinoma of the colon and additional animals died with acute and chronic ulceration of the colon. A second group of rats was given 0.46, 0.20, or 0.06 mc of Y^{91} per feeding over a period of three months with total accumulated amounts of 31.2, 15.6 and 4.68 mc respectively. Six of the eight animals at the two higher levels died with carcinoma of the colon and no malignancies were observed at the lowest level. The authors made no estimate of radiation doses.

In another experiment,[8] rats were kept alive by the use of parabiosis or para-aminoproprio phenone either pre or post whole-body irradiation of 700-1000 roentgens. Four of the 21 rats developed tumors along the gastro-intestinal tract (one each jejunum, ileum, duodenum, and colon), with four additional animals showing tumors in other organs. However, in comparing gastrointestinal versus whole-body irradiation, the question has been raised as to a possible indirect carcinogenic action in the latter case.[9] By using fast neutrons, lesser doses have been shown to produce an appreciable percentage of intestinal carcinomas in mice, but this is not so relevant to the present discussion of beta exposure.[10]

One summarizing statement of the short-term effects stated, "--- though the gastrointestinal tract is one of the sensitive systems to ionizing radiation, it also has a most remarkable regenerative and reparative capacity. It takes doses of well over a thousand roentgens to damage the gut permanently in most mammals studied, and it is capable of rapid, dramatic recovery of anatomical and functional integrity with doses in the lethal range."[11] Evaluating the data from dogs exposed to whole-body X-radiation the authors said, "--- it is suggested that doses of approximately 1,100 to 1,500 r may represent the upper limit of the possible efficacy of supportive measures in the treatment of the syndrome of acute radiation injury. With greater doses the damage to the intestinal mucosa appears irreparable and of an extent incompatible with life."[12] At the same time, it has been repeatedly indicated that the irradiation of the gastrointestinal tract plays a major role in gross whole-body effects associated with radiation syndrome.[11, 12, 13, 14, 15, 16, 17, 18, 19, 20] In fact one author[13] summarizes several experimental findings, "In producing acute intestinal radiation death, irradiation of any major portion of the exteriorized small intestine alone is almost equivalent to whole-body irradiation---."

Graph Five suggests the relative doses to the parts of the gastrointestinal tract, from ingestion of fallout material. The available experimental data does not permit a conclusive statement as to whole-body effects to be expected from such ratios of exposures. Most of these experiments are related to the criterion of death, but they do suggest

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that the major contributory factor to such effects such as nausea and vomiting associated with whole-body exposures of 100-200 roentgens, may be the result of the gastrointestinal reaction. Possibly a few hundred rads to the lower large intestine together with the concomitant lesser exposures to the upper large intestine, the small intestine and the stomach (according to Graph Five) may be in the range where radiation sickness might occur.

2. Thyroid

The study and treatment of disorders of the thyroid gland with radioiodine has led to considerable information on doses and their effects to this organ. (Only a partial list of references is noted.)[21,22, 23, 24, 25] Whereas these treatments have been principally with abnormal thyroids, much of the information may be extrapolated to normal thyroids for the purposes of this discussion. In addition there are other data based on normal thyroids in patients suffering such ailments as congestive heart failure.[26]

The picture that is clearly presented is that of the relative insensitiveness of the adult human thyroid to radiation. For example, Freedberg, Kurland, and Herman,[26] report, "---Seven days after administration of 17 and 20 millicuries of I^{131}, which delivered 14,500 and 31,000 rep, respectively, to the thyroid gland, no histologic changes were noted which could be attributed to I^{131}. --- Fourteen and twenty-four days, respectively, after administration of 59 and 26 millicuries of I^{131}, marked central destruction of the thyroid gland was noted.---" Since the first two patients expired seven days after administration of the I^{131} from pulmonary edema, it does not eliminate the possibility that the destructive

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changes might have appeared in the thyroid if these patients had survived. However, the evidence from other studies strongly indicate that if any pathological effects were to be noted in the thyroid after an exposure of some 10,000 reps they would be minimal. Likewise, the possibility of serious damage to other organs of the body, such as parathyroids and trachea which are simultaneously exposed to the I^{131} radiations, would be exceedingly small.

On long term effects, two summarizing statements may be made. "No thyroid neoplasm was found which could be attributed to I^{131}," [26] after doses to normal thyroids running into many tens of thousands of reps and after periods of observation up to more than eight hundred days. "In a series of over 400 patients treated with radioactive iodine at the Massachusetts General Hospital during the past ten years no known carcinoma of the thyroid attributable to this agent has developed. Definite answers to the question of carcinoma formation must await prolonged observation of treated patients." [23] Here the average treatment dose of I^{131} was 10 millicuries and of I^{130} 25 millicuries.

However, significantly lesser doses may be carcinogenic in children.[27] "---It has been suggested that the human thyroid is less radiosensitive than other tissues, such as bone, since after many years of treatment of Graves' disease with radioactive iodine, no cases of resulting carcinoma have been reported. The customary dosages of I^{131} in such cases yield at least 4000 rep to the gland. On the other hand, carcinoma of the thyroid found in children and young adults has almost invariably been preceded by x-ray treatment to the upper part of the body, in amounts such as to yield as little as 200 r to the infant thyroid. It has been estimated that less than 3% of such

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treated cases yield carcinoma; nevertheless, the data suggest that 200 r is a potentially carcinogenic dose to the infant thyroid. While the possibility exists that the carcinogenic action may be an indirect, hormonal one, it must still be recognized that this, like leukemia, is an instance of significant carcinogenesis by less than 1000 rep. It seems likely that the infant thyroid is unduly susceptible, but that the adult thyroid is not.---"[28]

Table Two indicates the amount of ingested fission product activity to produce one rad dose to the lower large intestine and Graph Five shows the relative doses to the gastrointestinal tract and the thyroid. It may be seen that ingestion of a given activity on the fourth and fifth days may result in nearly two and one-half times the dose to the thyroid as to the lower large intestine. For a continuous consumption of fallout material from the first hour to the 30th day the ratio of doses is about 1.7.

3. Bones

It is recognized that the intake and deposition of strontium-89 and 90 are intimately associated with the calcium in the diet. Whereas it has been assumed here that a fixed percentage of the strontium intake is deposited in the bones (Reference Five). It is realized that this method involves uncertainties, as would the necessary assumptions to generalize for a wide variety of calcium--strontium ratios and intakes

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to cover multiple categories. In situations where doses to the bones appear to be the critical criterion (such as later times after detonation than considered here), it would be necessary to make a more precise evaluation.

Unequal distribution of isotopes in the bones has been observed. Thus, the dotted line in Graph Five is included to suggested a possible larger dose to those regions.

Considerable data have been collected on radiation produced bone cancers. One summarizing statement that places this in proper perspective with the other factors discussed above is "--- Visible changes in the skeleton have been reported only after hundreds of rep were accumulated and tumors only after 1,500 or more."[29] When one examines Graph Five for relative doses, and reviews the data on doses versus effects to the gastrointestinal tract and possibly children's thyroids (Table Four), it would appear that exposure to the bones is not the critical factor for ingestion of fallout material under emergency conditions, for the first few weeks after a detonation.

4. Summary of Biological Effects

Table Four summarizes some possible biological effects from radiation exposures. Due to inherent uncertainties in such analyses together with expected wide biological variances among individuals, Table Four is intended only to suggest a generalized picture of doses versus effects.

The physical calculations of radiation doses made above were for adults. For equal intakes of radioactivity, children probably would receive higher exposures due to the smaller organ masses, and in the case of bones a greater deposition would be expected. Also, there is the possibility of tumor production in the thyroids of some children at relatively low radiation exposures. It would appear wise therefore to establish lower limits of intake of radioactivity for children.

C. Permissible Intake

The preceding discussion attempted to give estimates of radiation doses resulting from intake of fallout material, together with some possible biological effects. How much intake is actually permitted depends upon many factors including the essentialness of the food and water to sustaining life, and one's philosphy of acceptable biological risks and damage in the face of other possible hazards such as mass evacuation. Table Two and Graph Five give estimates of the amount of contamination in food and water to produce certain radiation doses to the critical organs. Table Four indicates possible biological effects from given doses. Using these references, command decisions may be made as to permitted intake of radioactivity.

Such evaluations as attempted here are necessary and valuable for planning purposes, but once the fallout occurs the emergency of the situation may preclude immediate analysis of the food and water supplies. Further, abstaining from ingestion of food and water because it might be contaminated could not be continued indefinitely. Therefore, the following three common sense rules are suggested:

1. Reduce the use of contaminated food and water to bare minimum until adequate monitoring can be done; use first any stored clear water and canned or covered foods; wash and scrub any contaminated foods and;

2. If the effects of lack of food and water become acute, then use whatever is available but in as limited quantities as possible. Whenever possible select what seems to be of the least likely contaminated water and/or foodstuffs; and

3. Since it is especially desirable to restrict the intake of radioactivity in children, give them first preference for food and water having the lowest degree of contamination.

In an area of heavy fallout one matter to consider is the relative hazards from the external gamma exposure versus internal doses from ingestion of the material. (Inhalation is thought to contribute only relative minor doses under the conditions discussed here). The best evidences on this point was the fallout that occurred on the Rongelapese in March 1954. Those in the highest exposure group received 175 r whole-body external gamma exposure yet their body burdens of internal emitters were relatively low (Table Five).[30] These and other data suggest that:

> If the degree of contamination of an area is such that the external gamma exposure would permit normal and continuous occupancy after a fallout, the internal hazard would not deny it.

This is based on such reasonable assumptions of (a) about 50% reduction of gamma exposure from out-of-doors doses afforded by living a part of each day in normal family dwellings, (b) washing

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and/or scrubbing contaminated foods, and (c) excluding areas where relatively little fallout occurred, but into which may be transported highly contaminated food and/or water. After longer periods of time during which the gamma dose rates in an originally highly contaminated area have decreased to acceptable levels, it probably would be necessary to evaluate the residual contamination for the bone seeking radioisotopes, especially strontium-90.

TABLE ONE

RELATIVE DOSES TO GASTROINTESTINAL TRACT FROM INGESTION OF FALLOUT MATERIAL

	Time After Detonation That Ingestion Occurs		
	1st Hour	1st Day	Limiting Case *
Lower Large Intestine	1.0	1.0	1.0
Upper Large Intestine	1.3	0.71	0.49
Small Intestine	0.26	0.054	0.03
Stomach	0.86	0.063	0.03

*Based on assumption that there is no significant decrease in activity during time of passage through gastrointestinal tract. After a week following a detonation the decrease in activity between the mid-point of time in lower large intestine is within 20% of this condition.

TABLE TWO

APPROXIMATE FISSION PRODUCT ACTIVITIES

(MICROCURIES PER MILLILITER OR GRAM x 10^2)

TO PRODUCE ONE RAD DOSE TO LOWER LARGE INTESTINES*

Duration of Ingestion (Days)	Start of Intake (Days after detonation)							
	1 (1st Hour)	2 (24th Hour)	3	4	5	10	15	20
1	35	2.5	1.9	1.7	1.4	1.1	1.1	1.0
2	24	1.7	1.1	0.89	0.81	0.62	0.57	0.53
3	15	1.3	0.82	0.65	0.56	0.41	0.40	0.37
4	13	1.0	0.65	0.53	0.46	0.33	0.30	0.29
5	12	0.9	0.57	0.44	0.39	0.28	0.25	0.22
10	9.2	0.64	0.40	0.29	0.25	0.17	0.14	0.13
15	7.8	0.53	0.33	0.26	0.21	0.13	0.11	0.09
20	7.5	0.49	0.29	0.21	0.18	0.11	0.089	0.07

*a. Activities computed at start of intake period.

b. Based on intake of 2200 milliliters or grams of water and food per day for adults.

TABLE THREE

CONCENTRATIONS IN WATER ON ISLANDS IN THE PACIFIC AND ESTIMATED GAMMA DOSE RATES AT D + 1, THREE FEET ABOVE GROUND

Date	Location	Gross Fission Product Activity (d/m/ml)
	Rongelap Island (3.5 roentgens per hour)	
D + 2	Cistern - Rongelap Islands	~ 50,000 - 75,000
D + 34	" "	~ 5,500
D + 34	Openwell "	~ 2,000
D + 300	Cistern "	~ 3
D + 330	" "	~ 4
D + 600	" "	~ 5.5
D + 600	Openwell "	~ 0.5
D + 600	Cistern (With collapsed roof)	~ 1.3
	Kabelle Island (19 roentgens per hour)	
D + 330	Ground water	~ 48
	Eniwetok Island (8.5 roentgens per hour)	
D + 330	Cistern	~ 25
	Enibuk Island (1.3 roentgens per hour)	
D + 600	Standing water from can, drum, etc.	~ 1.4

TABLE FOUR

SOME POSSIBLE BIOLOGICAL EFFECTS FROM RADIATION DOSES

TO SPECIFIC ORGANS *

Dose (Rads)	Gastrointestinal Tract	Thyroid	Bones
10,000		Minor changes in structure	
			Tumor production
	Permanent or serious damage -- survival threatened		
1,000	Tumor Production		
			Minor changes in structure
	Immediate effects such as nausea and vomiting		
		Potential carcinogenic dose to thyroids of few percent of children and adolescents	
100			

*Lesser short term effects would be expected from the same doses distributed in time.

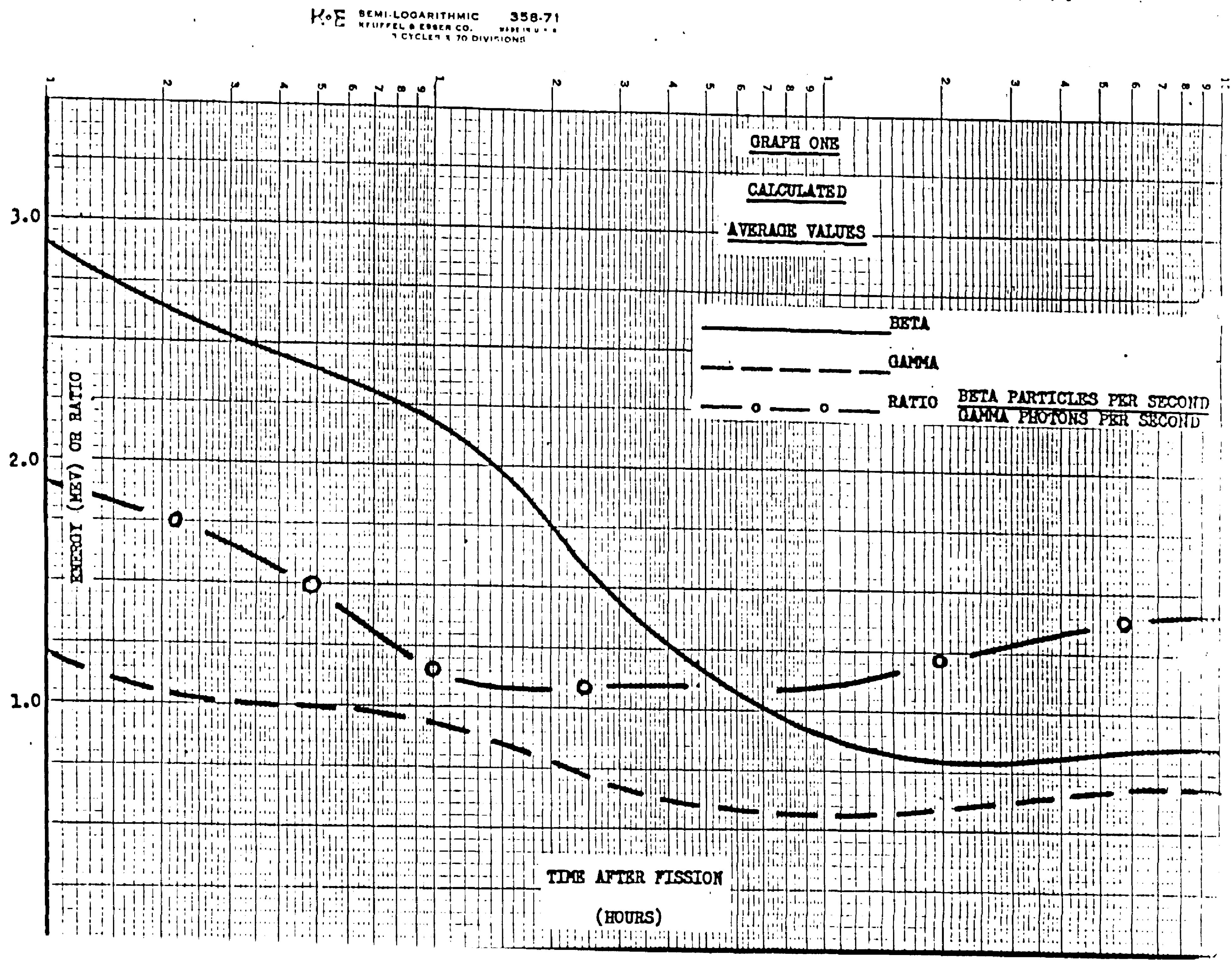
[redacted]

TABLE FIVE

MEAN BODY BURDEN OF RONGELAPESE

Radioisotopes	Estimated Activity at One Day (μc)
Sr^{89}	1.6 - 22
Ba^{140}	0.34 - 2.7
Rare earth group	1.2
I^{131} (in thyroid)	6.4 - 11.2
Ru^{103}	0.013
Ca^{45}	0.019
Fissile material	0.016 (μgm)

[redacted]


K&E SEMI-LOGARITHMIC 358-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS
GRAPH ONE
CALCULATED
AVERAGE VALUES
BETA
GAMMA
RATIO
BETA PARTICLES PER SECOND
GAMMA PHOTONS PER SECOND
ENERGY (MEV) OR RATIO
3.0
2.0
1.0
TIME AFTER FISSION
(HOURS)

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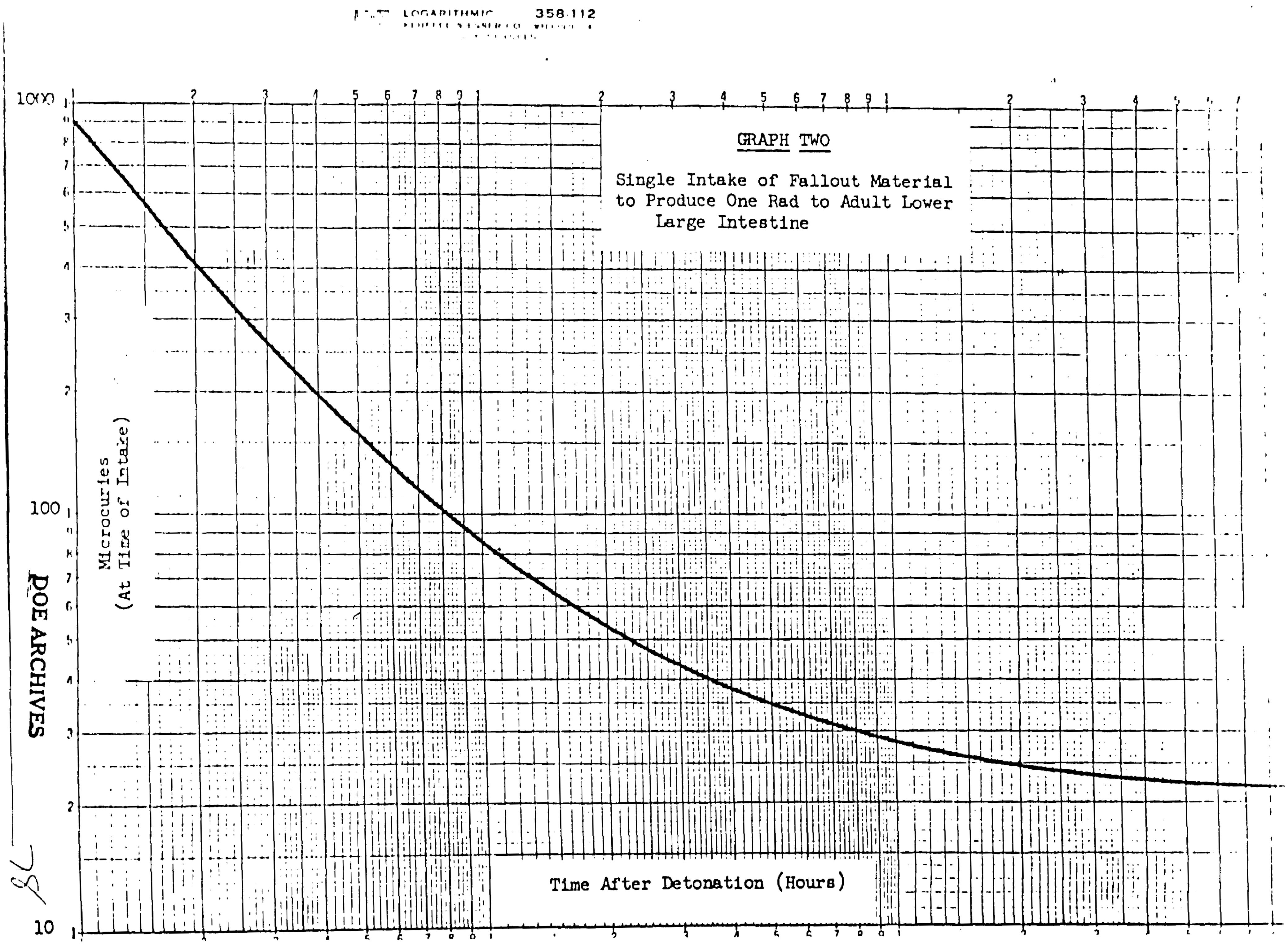
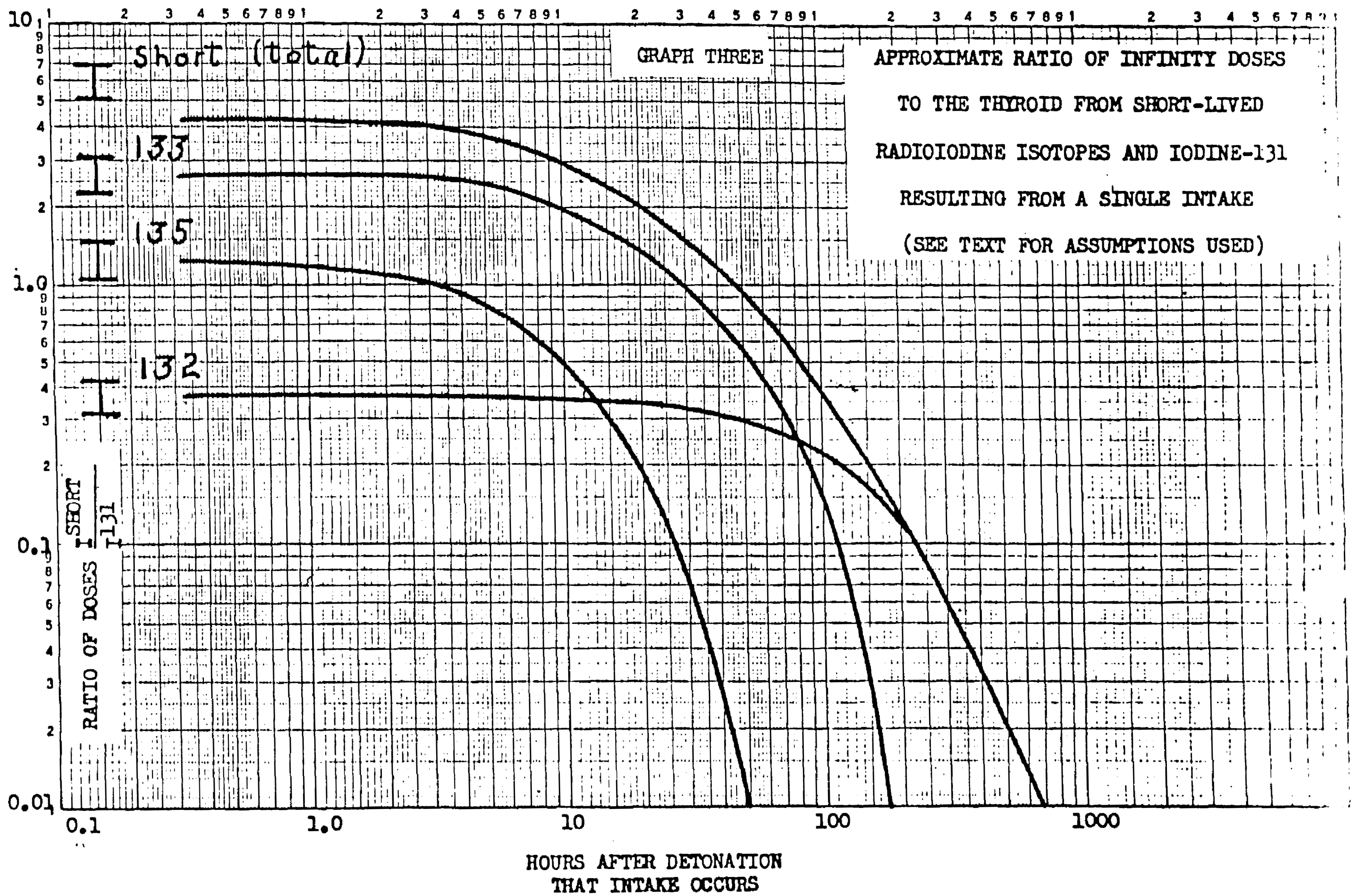


LOGARITHMIC 358-112
GRAPH TWO
Single Intake of Fallout Material to Produce One Rad to Adult Lower Large Intestine
Microcuries (At Time of Intake)
Time After Detonation (Hours)
1000
100
10


GRAPH THREE
APPROXIMATE RATIO OF INFINITY DOSES
TO THE THYROID FROM SHORT-LIVED
RADIOIODINE ISOTOPES AND IODINE-131
RESULTING FROM A SINGLE INTAKE
(SEE TEXT FOR ASSUMPTIONS USED)
Short (total)
133
135
132
RATIO OF DOSES I SHORT / I-131
HOURS AFTER DETONATION
THAT INTAKE OCCURS
0.1
1.0
10
100
1000
10
1.0
0.1
0.01

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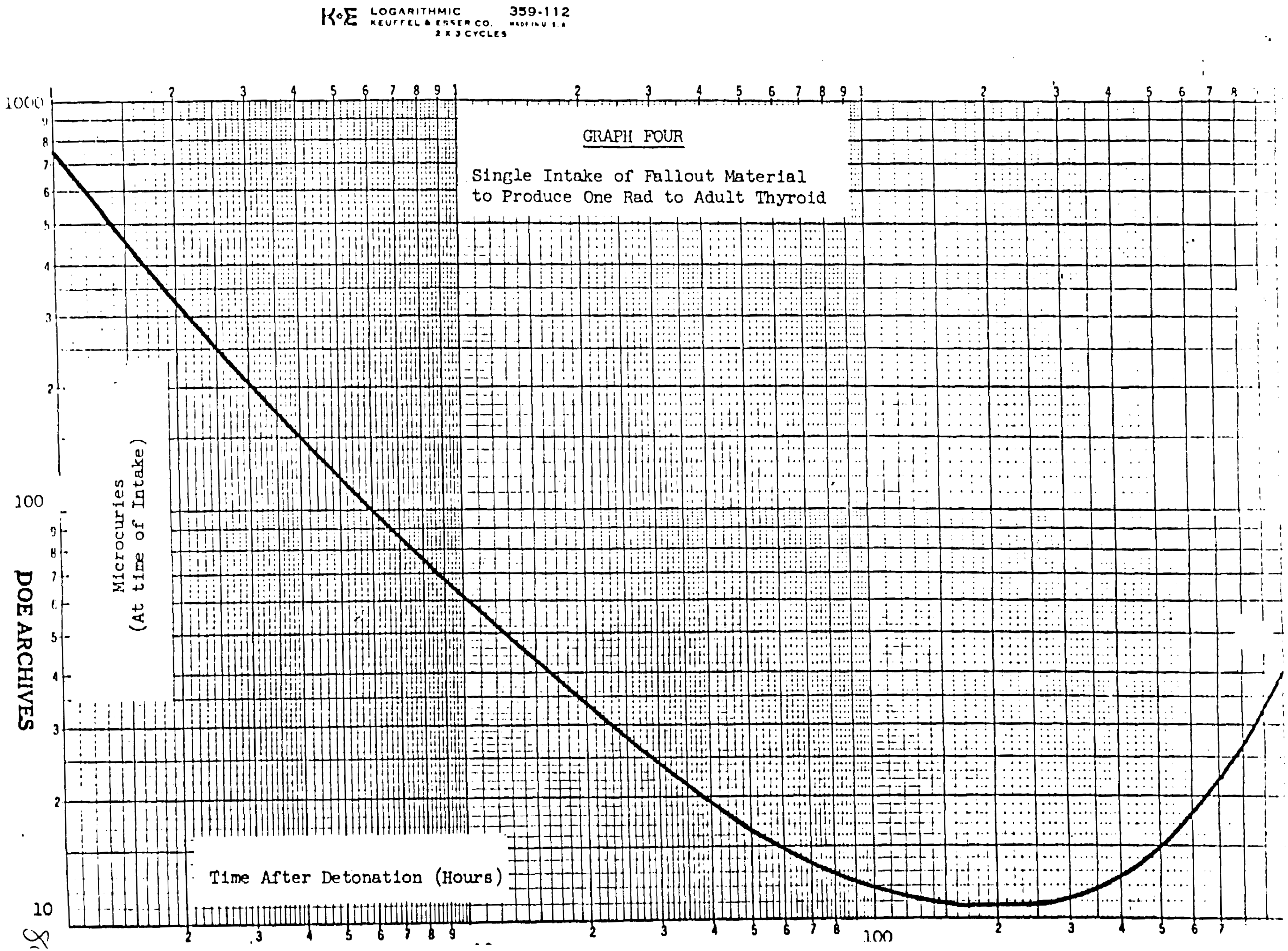
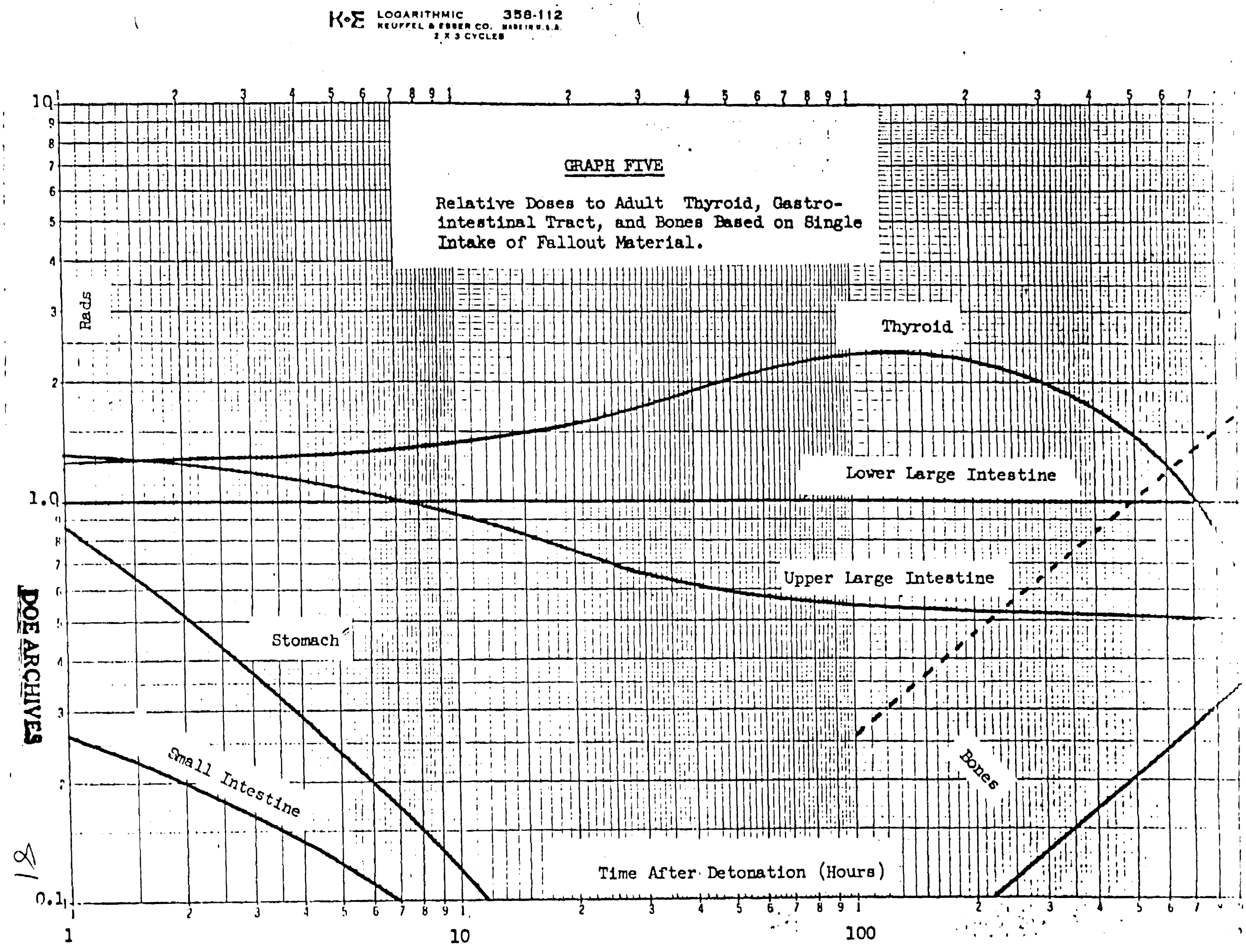

K&E LOGARITHMIC 359-112
KEUFFEL & ESSER CO.
2 X 3 CYCLES
GRAPH FOUR
Single Intake of Fallout Material
to Produce One Rad to Adult Thyroid
Microcuries
(At time of Intake)
Time After Detonation (Hours)
1000
100
10



K·E LOGARITHMIC 358-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
GRAPH FIVE
Relative Doses to Adult Thyroid, Gastro-intestinal Tract, and Bones Based on Single Intake of Fallout Material.
Rads
Thyroid
Lower Large Intestine
Upper Large Intestine
Stomach
Small Intestine
Bones
Time After Detonation (Hours)
10
1.0
0.1
1
10
100
DOE ARCHIVES

[redacted]

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