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FOLDER Subj. Review of Safety Analysis Report - SNAPTRAN 2/10A-1 - Safety Test - Rough Draft

D. E. Williams, Director
Reactors Division

JAN 11 1963

John R. Horan, Director
Health and Safety Division

REVIEW OF SAFETY ANALYSIS REPORT - SNAPTRAN 2/10A-1 - SAFETY TEST - ROUGH DRAFT

SYMBOL: HSHP:GW

The subject report has been reviewed by this Division and all of our comments have been satisfactorily resolved in meetings held between PPCo, Reactors Division and our representatives. These discussions were very beneficial to all parties concerned and should result in an excellent final report.

Since dose calculations, particularly off-site, were of extreme concern our Health Physics Branch made a completely independent set of calculations. A copy of these calculations are attached for your information. Comparison of the contractors results with ours, indicates agreement within a factor of 2-3. Considering the number of varisbles involved, this is considered to be satisfactory. As you were probably aware, concern was expressed over the ingestion dose to the child from iodine-131. The discussions brought out the fact that the contractor considered "all of the iodine in the milk from such grazing was present in one quart of milk". This resulted in a dose of 2.5 rem. Our calculations were based on the dose resulting from drinking milk (1 quart) on the first day after the test and came out to be .36 rem. If these differences are resolved, the calculations are within a factor of two of each other.

It should be pointed out that several changes in the test program plan can substantially reduce the ingestion dose. First, if the test occurs between October and April, the ingestion dose potential is nil since milk cows will be deriving only a minimum of feeding from grazing. Second, if during the grazing season (May through September) the test is restricted to a mean wind direction of $180^\circ \pm 30^\circ$ the dose potential will be considerably reduced. The number of milk cows grazing off-site in this sector is much smaller than within $210^\circ \pm 30^\circ$. Another factor in favor of considering a grid centered on 180° is that the frequency of

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winds, 6-15 mph or greater, over this sector is not appreciably different than a grid centered on 210°. Finally, there is the possibility of performing the test under a northeasterly wind. The frequency of occurrence of this wind is considerably less than the southwesterly winds and hence the test could be delayed appreciably if this plan is used. However, considerably more hazardous releases could be performed under this regine.

Enclosure:
Calculations

CC: H. Leppich

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OFFICE ▶	HSHP	HSHP	HS			
SURNAME ▶	GWehmann:dc 1-11-63 GW	WPGammill WG	JRHoran		Hq Reading File	
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SNAPTRAN SAFETY ANALYSIS CALCULATIONS

The potential doses to the critical organs as a consequence of the passing cloud resulting from the destructive test of SNAPTRAN 2/10A-1 were determined in the manner indicated below. For this specific test, the dose to the thyroid from ingestion of iodine-131 through the milk cycle appears to the controlling element. The calculations can be divided into four categories: (1) dose as a consequence of inhalation of the passing cloud; (2) dose due to deposited material entering the human body through the ingestion cycle; (3) external dose due to gamma radiation from the cloud; and (4) external dose due to the gamma radiation field created by fallout.

In the second category, the principle means of ingestion is through the milk produced by cows grazing on land where radioiodine has been deposited. It should immediately become obvious that the ingestion dose can be neglected when milk cows are not on pasture. Generally, this is considered to be from November 1st through April 30th. During the remainder of the year, the ingestion dose becomes very significant since the calculations reveal that the dose through the ingestion cycle is approximately 250-450 times the inhalation dose for iodine 131.

A. Inhalation Dose Calculations

The total integrated dose (TID) received by a person standing a distance, X (meters), downwind directly under the centerline of the cloud of radioactive material during its entire passage is given by equation (1).

$$TID = \frac{2\,Q_i}{\pi \bar{u}\, C_y C_z\, x^{2-n}} \exp\left[\frac{-h^2}{C_z^2\, x^{2-n}}\right] \qquad (1)$$

where

TID is the total integrated dose from the cloud, (curie-sec per meter 3)

Q_i is the amount of radioactive iodine of isotope, i, in the total cloud, (curies).

$\bar{u}$ is the average wind speed, (meters per second)

C_y, C_z are the virtual diffusion coefficients in the vertical and horizontal planes, respectively, (meters n/2).

h is the effective cloud height

n is the stability parameter, (dimensionless).

x is the distance downwind, (meters).

Equation (1) is time integrated concentration as expressed by O. G. Sutton. It neglects depletion of the cloud either by radioactive decay or scavenging during transit. To take into account radioactive decay, equation (1) is simply multiplied by

$$e^{-\lambda_i t}$$

where λ_i is the radiological decay constant for the isotope i, equal to $\frac{0.693}{Tr}$ (seconds $^{-1}$).

t is the time from formation of the isotope until the cloud reaches the distance in question. For this case

$$t = \frac{\text{distance}}{\text{wind speed}} \left(\frac{X}{\bar{u}}\right) \times 3600 \qquad (sec)$$

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T_r is the half life of isotope i (seconds)

While a factor for the scavenging effect is available it is not considered in these calculations, thereby offering a slight degree of conservation to the final results. It has been estimated[1] that consideration of the scavenging effect could reduce the final results by factors of 2-5.

The amount of isotope i, inhaled during passage of the entire cloud is given by

$$A_i = (TID)_i \, R \qquad (2)$$

where R is the breathing rate, (meters^3 per second)

The value obtained for equation (1) can vary quite widely depending on the meteorological parameters selected. Inasmuch as this test involves the planned release of radioactive materials, strict meteorological control of the test can insure conditions close to those chosen for calculational purposes. Meteorological parameters used are

$n = .20$ $\qquad$ $Cy = Cz = .291$

$u = 7$ m/s $\qquad$ $h = 0$ meters

These parameters reflect a "strong lapse" daytime situation with winds strong enough to insure the best atmospheric diffusion.

The choice of the effective cloud height is open to much discussion. However, since an exclusion area of minimum radius of 5000' is provided around the test facility, consideration need only be given for the inhalation doses beyond the exclusion fence. For the strong lapse condition chosen it has been shown[2] that for distances greater than a few thousand feet the effect of the cloud height is negligible.

The "source term", Q_i, in equation (1) will be dependent upon the radioactive material accumulated in the reactor during non-destructive testing of the reactor and those generated by the destructive excusion. The former may be reduced to a negligible amount by the replacement of fuel elements just prior to the destructive test. The radioactive material generated by the excusion can be expressed as

$$Q_i = \frac{\lambda N_A}{3.7 \times 10^{10}} \qquad (3)$$

where:

λ_i is the radioactive decay constant of isotope i (seconds^{-1}).

3.7×10^{10} is the number of disintergrations per second per curie.

N_A is the number of radioactive atoms generated.

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$$N_i = 3.1 \times 10^{16}\ PY_i$$

3.1×10^{16} is the number of fissions per megawatt-second.
P is the power generated, (megawatt-seconds).
Y is the fission yield of isotope i, (dimensionless).

Values for the several iodine isotopes per M_W -second at time of generation are given in Table I.

Table I. Iodine Inventory at t=0 per megawatt-second

Isotope	λ_i [3] $(Sec)^{-1}$	Yield [4] (%)	(Q_i/P) Curies/megawatt-sec
131	9.96×10^{-7}	2.9	2.42×10^{-2}
132	8.26×10^{-5}	4.4	3.04
133	9.20×10^{-6}	6.5	5.00×10^{-1}
134	2.20×10^{-4}	7.6	14.0
135	2.86×10^{-5}	5.9	1.41

The SNAPTRAN Safety Analysis Report (SAR) has conservatively estimated that the total nuclear energy release from the destructive test to be 170 Mw-sec. Based upon this value the quantities for the isotopes of iodine produced at time of generation and for several times following the excursion are given in Table II.

Table II. Iodine Inventory at Various Times for 170 M_W-sec Excursion Time

Isotope	t = 0	t = 10 min	t = 1 hr	t = 1 day	t = 10 days
I - 131	4.11	4.11	4.11	3.78	1.75
I - 132	517.	492.	384.	0.43	nil
I - 133	85.	85.	82.	38.4	.03
I - 134	2380.	2086.	1080.	nil	nil
I - 135	240.	236.	216.	20.4	nil

The above Table assumes that all of the iodine to eventually be built in is present at the time of the excursion.

The dilution factor due to atmospheric diffusion (TID_i/Q_i) for various distances, χ, is shown in Figure I for the stated meteorological parameters.

The breathing rate, R, in equation (2) is also a variable. The "standard man" [5] is considered to breathe 20 meters^3 per day; half during the active 8 hours and the remaining half during his relatively inactive or resting hours. Since the test will most likely take place in the daytime it is reasonable to consider the breathing rate characteristic of the active portion of the normal day.

$$R = 10 \text{ meters}^3 \text{ per 8 hours}$$
$$= 3.47 \times 10^{-4} \text{ (meters}^3 \text{ per second)}$$

Since values have been given for all factors in equation (1) and

(2) the amount inhaled can be determined for various distances, x, downwind. When the amount inhaled of a specific isotope i, is determined, the dose to the critical organ which will be delivered by this amount can be calculated. The dose rate, D', to which the critical organ (the thyroid gland for radioiodines) at any time subsequent to the inhalation is given by equation (4).

$$D' \left(\frac{\text{rads}}{\text{sec}}\right) = A_i \text{ (curies)} \times 3.7 \times 10^{10} \left(\frac{\text{dis/sec}}{\text{Curie}}\right) \times f_a$$

$$\times \bar{E} \left(\frac{\text{Mev}}{\text{dis}}\right) \times 1.6 \times 10^{-6} \left(\frac{\text{Ergs}}{\text{Mev}}\right) \times e^{-\lambda_e t}$$

$$\div W(\text{grams}) \times 10^2 \left(\frac{\text{Ergs/gm}}{\text{Rad}}\right)$$

$$= 5.92 \times 10^2 \frac{A_i f_a \bar{E} e^{-\lambda_e t}}{W}$$

where:

- A_i is given by equation (2).
- f_a is the fraction of the amount inhaled which is deposited in the critical organ
- $\bar{E}$ is the effective energy absorbed by the critical organ per desintegration, (Mev).
- $\lambda_e = \lambda_i + \lambda_b = 0.693/T_e$, (sec^{-1})
- λ_b is the biological elimination rate for the isotope i, (sec^{-1})
- T_e is the effective half life for the isotope in the body, (sec).
- W is the mass of the critical organ, (gms).

The dose to the critical organ, delivered in time, T, is given by equation (5).

$$D_T = \int_0^T D' dt = \frac{5.92 \times 10^2 A_i f_a \bar{E} (1 - e^{-\lambda_e T})}{W \lambda_e}$$

$$= \frac{8.54 \times 10^2 A_i f_a \bar{E} T_e (1 - e^{-\lambda_e T})}{W}$$

When the time over which the dose is determined (T), is much greater than the effective half life of the isotope. The quatity $e^{\frac{.693T}{T_e}}$ becomes insignificant and equation (5) can be rewritten as.

$$D_\infty = 8.54 \times 10^2 \frac{A_i f_a \bar{E} T_e}{W} \text{ (rads)}$$

Substitution of equation (2) yields

$$D_\infty = 8.54 \times 10^2 \frac{[T/D]_i R f_a \bar{E} T_e}{W} \text{ (rads}$$

For the five predominate radioactive iodine isotopes of concern Table III lists the appropriate values of as given in reference [3].

Table III Constants for Iodine Isotopes

Isotope	f_a (%)	$\bar{E}$ (Mev)	T_e (Sec)
131	23	.23	6.57×10^5
132	23	.65	8.39×10^3
133	23	.54	7.52×10^4
134	23	.82	3.11×10^3
135	23	.52	2.42×10^4

Using these values and assuming the weight of an adults thyroid to be 20 grams [3] and using the value of R previously discussed, equation (6) can be rewritten and the values presented in Table IV.

Table IV Dose to the Thyroid by Inhalation

Iodine Isotope	$\frac{D_\infty}{A_1}$ (Rads/Curie)	D_∞ $\left(\frac{\text{Rads/curie-sec}}{m^3}\right)$
131	1.48×10^6	343
132	5.35×10^4	12.4
133	4.0×10^5	92.8
134	2.5×10^4	5.8
135	1.24×10^5	28.8

It now remains to compute the TID for each isotope at various distances making use of Figure 1 and Table II. Radioactive decay is considered for I-132, I-134 and I-135. Table V summarizes the dosages to be expected at several distances downwind.

Table V - Dosage vs Distance for Iodine Isotopes

	(millirads)			
	5000 ft	5.5 miles	6.5 miles	12.0 miles
I-131	2.8	.11	.08	.02
I-132	12.7	.46	.33	.10
I-133	15.6	.63	.45	.15
I-134	26.5	.84	.58	.15
I-135	13.8	.54	.38	.13
Total Iodine	71.4	2.58	1.82	.55

The above distances were chosen as follows:

1) 5,000 feet corresponds to the exclusion area around facility
2) 5.5 miles is distance to nearest site boundary from facility
3) 6.5 miles is the distance to nearest site boundary within the test area (0°-60°N) tentatively suggested.
4) 12 miles is the distance to the nearest town within the suggested test area.

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B. Ingestion Dose Calculations

Previously it has been stated that consideration must be given to the dose to the body as the result of ingesting radioactive materials deposited from the cloud. From examination of all parameters involved, particularly fission product generation, the ingestion hazard from radioactive materials released by a nuclear excursion of an un-irradiated core can be attributed solely to the radioiodines. Therefore, it is the dose to the thyroid that is of concern.

The route that the iodine takes to reach the thyroid is through the "milk cycle". That is, radioiodines present in the cloud are deposited upon the grass which in turn in consumed by milk cows. A fraction of this iodine goes into the milk and is ultimately concentrated in the thyroid. Because of the indirect route, there are many parameters involved in ingestion calculations not present in the inhalation calculations. It has been shown that the dose due to ingestion can exceed by at least two orders of magnitude the inhalation dose. Fortunately the ingestion dose can be ignored when the cows are not on pasture. For the NRTS this is usually the case from November 1st through April 30th.

The concentration in milk resulting from cloud passage is expressed by equation (7).

$$C_m = \frac{(TID)_i \; V_g \; F_i \; F_m \; M_d}{F_w \; V_m} \qquad (7)$$

where

C_m is the concentration in milk (curies/milliliter)
$(TID)_i$ has the same units as previously noted
V_g is the rate of deposition of material on the ground, (meters per second)

$$V_g = \frac{\text{ground concentration}}{\text{air concentration}}$$

F_i is the amount of feed consumed by the cow (grams per day).
F_m is the fraction of iodine getting into the milk.
M_d is the density of milk (grams per liter).
F_w is the vegetation-to-area factor (grams per meter^2).
V_m is the daily volume of milk produced by a cow (grams per day).

Several of these parameters can vary for different localities and seasons of the year. For the NRTS the following values have been used in previous calculations.

$V_g = 2 \times 10^2$ (meters per second)
$F_i = 4 \times 10^4$ (grams per day)
$F_m = 10\%$
$F_w = 50$ (grams per meter^2)
$M_d = 10^3$ (grams per liter)
$V_m = 2 \times 10^4$ (grams per day)

Thus, equation (7) can be re-written as

$$C_m = 8 \times 10^{-2} (TID)_i \qquad (8)$$

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The equation expressing the dose to the thyroid is similar to equation (4). Thus, the dose rate for ingestion of iodine through the milk cycle is written as:

$$D'_m \left(\frac{\text{Rads}}{\text{Sec}}\right) = A_m \text{ (curies)} \times 3.7 \times 10^{10} \frac{\text{dis/sec}}{\text{curie}} \times f_w$$

$$\times \bar{E} \frac{\text{Mev}}{\text{dis}} \times 1.6 \times 10^{-6} \frac{\text{Erg}}{\text{Mev}} \times e^{-\lambda_e t}$$

$$\div W \text{ (gms)} \times 10^2 \left(\frac{\text{Ergs/gm}}{\text{Rad}}\right)$$

$$= \frac{5.92 \times 10^2 A_m f_w \bar{E}}{W} e^{-\lambda_e t} \frac{\text{Rads}}{\text{Sec}} \qquad (9)$$

where A_m

A_m is the amount of milk ingested

$$A_m = C_m \times I_h = 8.10^{-5} (TID)_i \times I_h \qquad (10)$$

I_h is the amount of milk consumed (liter)

f_w is the fraction of iodine reaching the thyroid by ingestion.

and all other symbols have the same meaning as previously stated.

Similarly the dose, delivered in time T, is given by equation (11).

$$D_{oo} \text{ (Rads)} = 8.54 \times 10^2 \frac{A_m F_w \bar{E} T_e}{W} \qquad (11)$$

Substitution of equation (10) in (11) yields

$$D_{oo_m} \text{ (Rads)} = 6.83 \times 10^{-2} \frac{(TID)_i I_h f_w E T_e}{W}$$

The values of E and Te are the same as given in Table III and the weight of the thyroid (W) is 20 grams. The value of f_w as given in reference [3] for all radioisotopes of iodine is 0.30. Using equation (11), D_{oo_m}/A_m has been evaluated for the iodine isotopes and the values presented in Table VI.

Table IV. Dose to the Thyroid by Ingestion

Iodine Isotope	$\frac{D_{oo_m}}{A_m}$ $\left(\frac{\text{Rads}}{\text{Curie}}\right)$	$\frac{D_{oo_m}}{(TID)_i I_h}$ $\left(\text{Rads}/\frac{\text{C-sec}}{\text{m}^3} / \text{liter}\right)$
131	1.93×10^6	1.54×10^5
132	6.98×10^4	5.6×10^3
133	5.22×10^5	4.2×10^4
134	3.26×10^4	2.6×10^3
135	1.62×10^5	1.3×10^4

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The last column in Table VI gives the dose in rads per liter of milk consumed by an adult produced by a cow grazing on land which has been subject to a concentration of 1 curie-sec per meter^3.

It is extremely valuable at this point to make a comparison of the last columns in Tables IV and VI. For iodine-131 it turns out that the ingestion dose is approximately 450 times greater than the inhalation dose. The ratios of the other isotopes is smaller because of the time delay between insult by inhalation and insult by milk. It has been shown [6] that the activity of iodine-131 in milk reaches a maximum about 2 days after deposition of activity on the pasture. Since the half-life of iodine-131 is 8.1 days, this delay can be ignored without introducing a great deal of error. Since the other four isotopes have relatively much shorter half-lives, they do not constitute any real problem.

As a final illustration, consider the following example: The dose to an adult breathing air for one second containing one microcurie of iodine-131 per cubic meter of air (1 c-sec/m^3) would theoretically be 0.34 millirad while drinking of 1 liter (1 quart) of milk obtained from a cow grazing on land subjected to the same time integrated concentration (1 c-sec/m^3) would result theoretically in a dose of 154 mrem.

Thus far, theoretical calculations have been presented. On two occassions experimental data resulting from ANP tests indicate the value of the ratio for iodine-131 to be approximately 300. It seems rather remarkable, considering all of the variables, that the experimental and theoretical data agree within a factor of two.

The ingestion dose resulting from iodine-131 generated by the SNAPTRAN experiment are given in Table VII.

Table VII Ingestion Dose due to Iodine-131 (Millirad)

Isotope	Distance		
	5.5 miles	6.5 miles	12 miles
131			
Theoretical	50.	36	9
Experimental	33.	24	6

The doses given in Table V and VII apply to an adult. In considering the dose to a child several allowances must be made. First, the child's breathing rate, R (m^3/sec), will be smaller than that of an adults. It has been recently estimated that the child's breathing rate is approimately 15% of an adults. The weight, (w,grams) of a thyroid depends on the age and it has become standard practice to assume a childs thyroid to be 10% of an adults, i.e., 2 grams. Therefore, the childs inhalation dose is 1.5 times (.15/.10) of the values listed in Table V. Variations in w and R are great enough that for all intense purpose the inhalation dose of a child is considered equal to that of an adult. For ingestion doses only the breathing rate is not a factor. Consequently, the child's ingestion dose is 10 times the values listed in Table VII for an adult.

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C. External Dose from Cloud due to Gamma Radiation

The external exposure from submersion within a large cloud within a cloud with a time integrated concentration, TID , (curie-second per cubic meters) of radioactive material having an effective energy E (Mev/dis) has been estimated by Burnett [8] not to exceed:

$$D = .26\, E\, (TID)_\gamma \quad rem \tag{12}$$

From a short burst from a critical assembly the amount of gamma activity (curies) generated can be estimated by equation (13).

$$Q_\gamma = 1.82\, P\, t^{-1.2} \quad curies \tag{13}$$

where P is the power in watt-seconds
t is the fission product cooling time (seconds)
and for this case $t = 3600\, x/u$

therefore, the time integrated air concentration can be written

$$(TID)_\gamma = \left(\frac{\psi}{Q_\gamma}\right) Q_\gamma = 1.82 \left(\frac{\psi}{Q_\gamma}\right) P \left(\frac{x}{u}\right)^{-1.2} \quad (c\text{-sec}/m^3)$$

Using a wind speed of 15 mph. Table VIII lists the gamma activity, corrected for radioactive decay, for various distances downwind for the SNAPTRAN 2/10 A-1 experiment

Table VIII Gamma Activity (Curies) Verses Distance

	Distance			
	5000 ft	5.5 miles	6.5 miles	12 miles
Curies	4.3×10^5	2.0×10^5	1.6×10^5	8.2×10^4

Multiplying the values in Table VIII by the appropriate dilution factors as shown in Figure I yields the time integrated air concentration. These are summarized in Table IX.

Table IX Time Integrated Air Concentration $(TID)_\gamma$ Verses Distance

Distance	$(TID)_\gamma$
5000 ft	8.6×10^{-1}
5.5 miles	1.6×10^{-2}
6.5 miles	9.6×10^{-3}
12.0 miles	1.6×10^{-3}

If an average energy of 0.7 Mev/dis is assumed, the external dose in millirem using equation (12) are given in Table X.

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Table X Total External Dose Due to Gamma Radiation from Cloud

Distance	Dose (Millirem)
5000 ft	160.
5.5 miles	3.0
6.5 miles	1.8
12.0 miles	.30

D. External Dose Due to Gamma Radiation from Fallout

The external dose rate due to fallout can be obtained from the following equation (14)

$$D_{F_r} = (TID)_\gamma \, V_g \, K \tag{14}$$

where

$(TID)_\gamma$ is time integrated concentration of gamma activity (curie-sec/m^3)

V_g is deposition of velocity (m/sec) and has the same value as used previously (.02 m/sec)

K is a factor converting activity per unit area to dose rate. It has been estimated [9] that one curie per square meter of fresh mixed fission product (average energy of gamma radiation is 0.7 Mev/dis) will give a gamma-radiation field of between 10 and 20 r/hr. For these calculations the upper limit was used. Therefore,

$$1 \frac{C}{m^2} = 20 \text{ r/hr}$$

Hence, equation (14) can be re-written as:

$$D_{F_r} = 0.4 (TID)_\gamma \qquad r/hr$$

The total infinity dose, D_F, can be found by the integration of equation 14 a. Thus

$$D_F = D_{F_r} \int_{T_1 = 1hr}^{T_2 = \infty} t^{-1.2} \, dt$$

$$= 5 D_{F_r} = 2 (TID)_\gamma$$

The values of $(TID)_\gamma$ for the various distances are the same one previously given in Table IX. Therefore the total external dose due to gamma-radiation from fallout is summarized in Table XI.

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Table XI Total External Dose Due to Gamma Radiation due to Fallout in Millirem

Distance	Dose (millirem)
5000 ft	1720
5.5 miles	32
6.5 miles	19
12. miles	3

E. Summary

A summary of the total dose that may be expected from the radioactive cloud generated by a nuclear excursion of 170 megawatt seconds for the distances is given in Table XII.

Table XII Summary of Doses to an Adult from SNAPTRAN 2/10A-1 (millirem)

Distance from IET	Cloud	Fallout	Thyroid Inhalation	Thyroid Ingestion	Total
5000 ft	160	1720	70	-*	1950
5.5 miles	3.0	32	2.6	50(500)#	88 (538)
6.5 miles	1.8	19	1.8	36(360)	59 (383)
12.0 miles	.3	3	.55	9 (90)	13 (94)

* Not computed since no grazing is permitted in the test area.

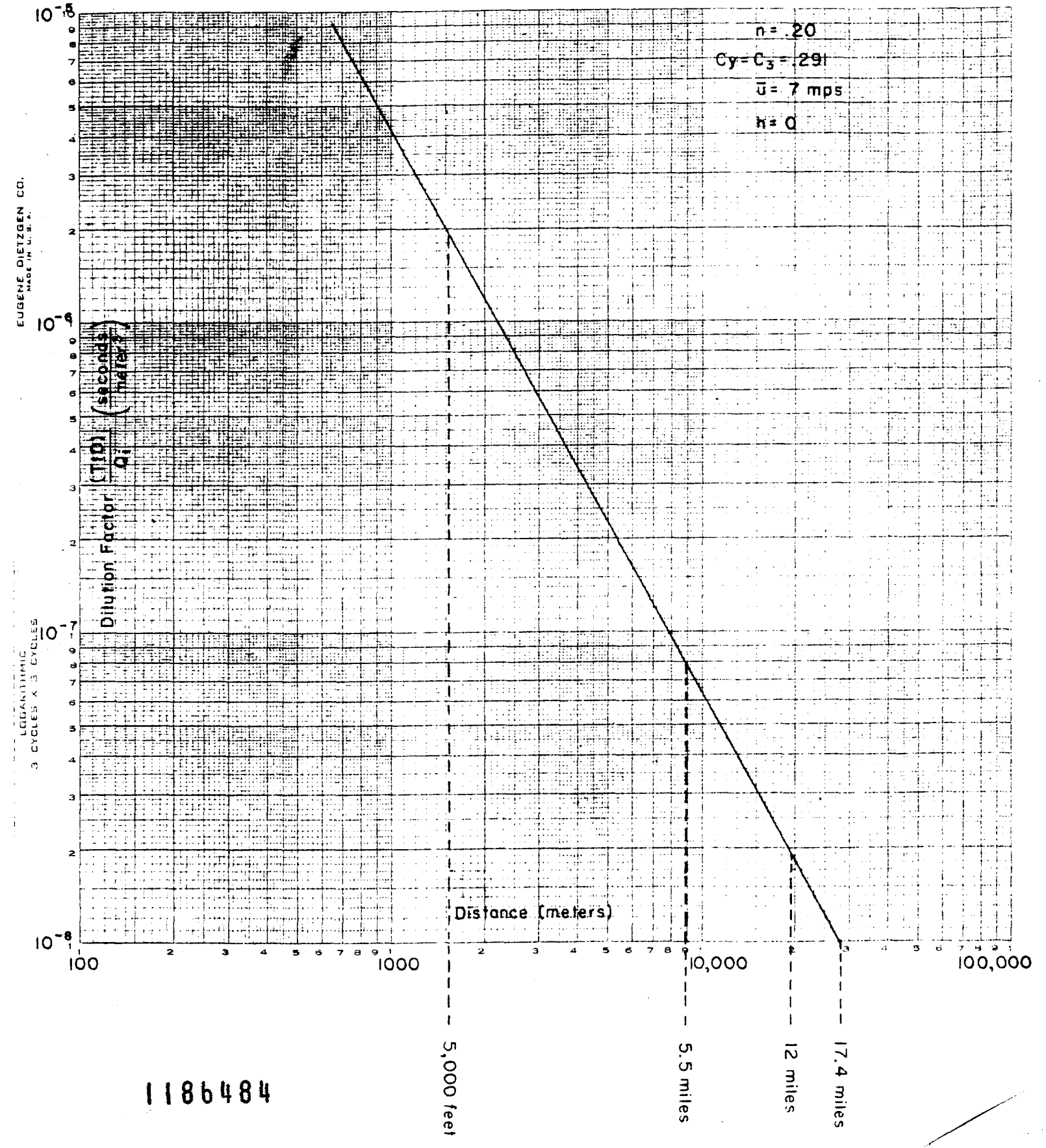
\# The values in paranthesis are the dose to a child.

From Table XI it can readily be seen that the ingestion of iodine is the major contributor to the total doses in the off-site areas and that the child drinking milk will receive the highest dose. It must be pointed out that these ingestion dose values were the result of drinking only a quart of milk on the first day. If it is assumed that a person were to continue drinking a quart each day and assuming only radioactive decay, the total ingestion dose would be approximately eleven (11) times the first days dose.

However, as Table XI indicates, conservative calculations indicate that the dose to a child, assuming he drinks only one quart of milk, at the nearest off-site boundary lying within the proposed test grid is with the 0.5 rem to the thyroid per year value established by I. D. Announcement 163, December 19, 1961.

FIGURE I

DILUTION FACTOR VS. DISTANCE



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