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UCRL-12273

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ESTIMATE OF RADIATION DOSE TO THYROIDS OF THE RONGELAP CHILDREN FOLLOWING THE BRAVO EVENT

Livermore, California

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Contract No. W-7405-eng-48

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ABSTRACT

An estimate is made of the radiation dose to the thyroids of Rongelap children following the Bravo event of March 1, 1954. The available experimental data are used to estimate the dose under two alternate assumptions of mode of intake: (a) all of the intake was by inhalation, and (b) all of the intake was by oral ingestion. It is concluded that the most probable dose to the thyroid of a 3- to 4-year-old girl is in the range 700 to 1400 rad.

GENERAL INFORMATION

The cloud arrival time is given[1] as H + 4 to 6 hours. The duration of the cloud passage is less well known, but probably lies in the range of 8 to 16 hours. In all calculations we will assume that cloud passage was in the interval H + 6 to H + 18.

The residents of Rongelap were evacuated at H + 51 hours. Reliable dose-rate measurements were not obtained at that time, but the gamma dose rate 3 feet above the ground was measured as 375 mR/hour 7 days after the detonation. Assuming $t^{-1.2}$ decay, the H + 24 hour dose rate was then about 3.8 R/hour.

The sources of exposure to the thyroid which must be considered are:

(1) Whole-body gamma dose.

(2) Internal deposition of iodine isotopes.

Whole-Body Gamma Dose

The whole-body dose was estimated[1] to be 175 R. The exact method of making this estimate is not given, so an independent estimate is made below. In particular, it appears that this estimate does not include the dose from the cloud but only from fallout.

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If we assume a linear buildup of fallout from H + 6 to H + 18, $t^{-1.2}$ decay during this interval, and use the reading of 375 mR/hour at 7 days, the estimated dose from fallout during cloud passage is 47 R. The dose from the fallout from H + 18 to evacuation at H + 51 is 114 R. Experience from Sedan indicates that the dose from the cloud itself is approximately equal to the dose from fallout during cloud passage. The total estimated dose is then 47 + 47 + 114 = 208 R.

Within the error of the measurements and the accuracy of the assumptions, this estimate, which does not contain any correction for the small effect of time indoors, does not differ significantly from the value of 175 R.[1] We will, therefore, take the average whole-body gamma dose as 175 ± 25 R.

Internal Deposition of Iodine Isotopes

Unfortunately, no direct measurement was possible on the radioactive iodine content of individuals from Rongelap. Urine samples were taken from which the average thyroid burden of I^{131} has been estimated. The Los Alamos Scientific Laboratory collected pooled 24-hour samples 15 days post-detonation and estimated[2] the 1-day thyroid content as 11.2 μCi of I^{131}. USNRDL collected samples from each member of the exposed group 43 and 46 days post-detonation and, by an indirect method, estimated the average thyroid content as 6.4 μCi I^{131} at 1 day.[3,4] The LASL estimate of 11.2 μCi was obtained by direct counting of I^{131} in the urine and should be more reliable than the NRDL estimate. The value of 11.2 μCi will be used as a basis for all following considerations. This estimate was based on the assumption of 0.1% of the maximum thyroid burden being excreted in the urine on the 15th day. Variation in the biological half-life and other factors indicate that a range of 0.05 to 0.2% should be placed on this number[5] (see appendix). We, therefore, take 5.6 to 22.4 μCi as the range of adult I^{131} thyroid burden.

The pooled samples represent all age groups. The number of individuals in these age groups and the volume of urine from each age group is approximately as follows:[3,4]

Age Group	Number of Individuals	Volume of Urine (ml)	% of Total Volume
< 5	7	1,155	4.8
5 - 16	11	4,829	20.1
> 16	31	18,011	75.0

The urine samples are typical of adults and the calculated thyroid burdens are presumably also those of adults.

Associated with this I^{131} are the shorter-lived isotopes I^{132}, I^{133}, and I^{135}. If the iodine entered by way of inhalation, the time of intake was H + 6 to H + 18. On the other hand, if water (and food) were the principal source, the time of ingestion would be extended from H + 6 to H + 51.

Three items contribute to the differences in dose from the various iodine isotopes. These are: (1) radioactive decay before inhalation or oral ingestion, (2) differences in the fission yields of the chains,[6] and (3) the average energy deposited in the thyroid per disintegration. These factors are presented in Table I for I^{133} and I^{135}. In the case of inhalation, uniform distribution in the cloud was assumed. For oral ingestion it was assumed that, on the average, one-third of the intake occurred at H + 10 and two-thirds at H + 30.

Table I. Ratio of doses for the two modes of intake.

	Inhalation		Oral Ingestion	
	I^{133}/I^{131}	I^{135}/I^{131}	I^{133}/I^{131}	I^{135}/I^{131}
Decay	0.68	0.31	0.487	0.148
Fission yield[6]	1.38	1.23	1.38	1.23
Energy	2.00	1.50	2.00	1.50
Net Factor	1.85	0.57	1.35	0.27

The dose to the thyroid in rads from all three isotopes is thus 3.4 times the dose due to I^{131} alone for inhalation and 2.6 times the I^{131} dose for oral ingestion. Delay in reaching the thyroid after inhalation or ingestion would lower these factors somewhat. However, the I^{132} daughter of the 78-hour Te^{132} has been neglected and would approximately compensate for decay of I^{133} and I^{135} before reaching the thyroid.

We can now proceed to estimate the dose to the thyroids of 3- to 4-year-old girls assuming (1) inhalation as the mode of intake and (2) oral ingestion.

1. Inhalation. The ratio of volume of air respired by a 3- to 4-year-old girl to that of an adult can be estimated in two ways: (a) from the maximum rate of oxygen intake[7] and (b) from the vital capacity[8] and maximum respiration rate.[7] Both methods give a ratio of about 0.3. The thyroid burden of these children would then be about 3.4 μCi with a range of 1.7 to 6.8 μCi.

Assuming the Rongelap children are similar to those of New York children, the mass of the thyroid of the children is 2.5 ± 0.6 grams.[9]

The most probable dose from I^{131} is then 150 rad and the dose from all isotopes if 510 rad. If we consider the range of thyroid burden (1.7 to 6.8 μCi) and the variation in thyroid weight (1.9 to 3.1 grams), the dose is in the range of 200 to 1350 rad.

2. Oral Ingestion. At the time of the event, the Rongelap people were on a water ration of 1 pint per day. They were warned not to drink water after the event, but most of them admitted they drank water anyway.[10] The method of collecting water by runoff from the roofs into cisterns makes it very likely that this was the main source of oral ingestion. There are reports that it "rained a little" on the afternoon of March 1 (D-Day). The village doctor reported that the "water turned yellow." As far as food is concerned, the most likely source is dried fish. Fish were dried on open racks. However, in the interviews none of them listed dried fish as having been eaten during the time before evacuation.[10] Under these circumstances it is reasonable to assume that children drank the same amount of water and, therefore, had the same intake as adults; i.e., their thyroid burdens were also 11.2 μCi of I^{131} (range 5.6 to 22.4 μCi).

The most probable dose from I^{131} is then 490 rad and the total dose 1270 rad. Considering a range in the thyroid burden (5.6 to 22.4 μCi) and a thyroid weight range of 1.9 to 3.1 grams, the range of total dose is 520 to 3300 rad.

Incidentally, LASL assumed this mode of intake and calculated a dose of 150 rad.[2] The thyroid weight used was not given, but was probably 20 grams. We would calculate 160 rad, in very good agreement with the LASL estimare.

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SUMMARY

Thyroid dose (rads) to Rongelap girsls ages 3 to 4.

	Inhalation			Oral Ingestion		
	Min	Max	Most probable	Min	Max	Most probable
Whole-body	150	200	175	150	200	175
Radioiodine	200	1350	510	520	3300	1270
Total	350	1550	685	670	3500	1445

The actual intake was undoubtedly a combination of the two modes of intake. The most probable dose is, therefore, in the range 700 to 1400 rad.

REFERENCES

[1] Sondhaus, Sharp, Bond, and Cronkite, "Radiation Characteristics of the Fallout Material and Determination of the Dose of Radiation," Chapter I of TID-5358, Some Effects of Ionizing Radiation on Human Beings.

[2] P. Harris, personal communication, cited by both References 3 and 4.

[3] Cohn, Rinehart, Gong, Robertson, Milne, Bond, and Cronkite, "Internal Deposition of Radionuclides in Human Beings and Animals," Chapter V of TID-5358.

[4] Cohn, Rinehart, Gong, Robertson, Milne, Chapman, and Bond, "Internal Radioactive Contamination of Human Beings Accidentally Exposed to Radioactive Fallout Material," USNRDL-TR-86.

[5] Ng, Yook, private communication (1964).

[6] The fission yields for U^{238} with high-energy neutrons as given by Weaver, Strom, and Kileen, NRDL-TR-633, were used.

[7] Handbook of Biological Data, William B. Spector, Ed., p. 352 (W. B. Saunders, Philadelphia, 1956).

[8] Documenta Geigy Scientific Tables, 5th Ed., p. 254 (S. Karger, Basel, Switzerland, 1959).

[9] Mochizviki, Mowafy, and Pasternack, Health Physics, 9, 1299-1301 (1963).

[10] Sharp and Chapman, "Exposure of Marshall Islanders and American Military Personnel to Fallout," WT-938 (1957).

APPENDIX

CALCULATION OF URINARY RADIOIODINE EXCRETION

Yook C. Ng

Radioiodine appearing in urine, except for that during a relatively short period following exposure, originates from the thyroid. In the calculation for urinary radioiodine it was assumed that iodine is released from the thyroid only as thyroxine, and that the release of thyroxine and its subsequent degradation in the extrathyroidal hormonal space can be adequately described assuming first-order kinetics. Ranges for normal biological half-life of iodine in the thyroid and normal turnover rate of extrathyroidal thyroxine were selected from the best available data in the literature. The uptake of radioiodine was assumed to be exponential with a half-period of increase of 4.5 hours, and 60% of the iodine released when extrathyroidal thyroxine is degraded was assumed to be excreted in urine.

Rates of urinary radioiodine excretion were calculated from the resulting expression shown below.

$$\frac{dI_U}{dt} = 0.60\ LKI_{Tf}\ \frac{e^{-(K+\lambda)t} - e^{-(L+\lambda)t}}{L - K} - \frac{e^{-(J+K+\lambda)t} - e^{-(L+\lambda)t}}{L - J - K}$$

where

I_U = radioiodine content of urine

L = rate of turnover of extrathyroidal thyroxine

K = rate constant for the release of iodine from the thyroid

I_{Tf} = peak radioiodine content of the thyroid

λ = physical decay constant for I^{131}

J = rate constant for the uptake of radioiodine in the thyroid

t = time.

A summary of the calculations made to determine the normal range of urinary radioiodine excretion at 15 days appears below.

Urinary radioiodine excretion at 15 days.

J day^{-1}	K $day^{-1} \times 10^3$	L $day^{-1} \times 10^2$	$\frac{dI_U}{dt}$ % of I_{Tf}/day
3.7	4.85	7.2	0.050
3.7	4.85	13.8	0.066
3.7	17.15	7.2	0.16
3.7	17.15	13.8	0.21

On the basis of these calculations, the normal range of urinary radioiodine excretion at 15 days was estimated to be 0.05 to 0.2% of the peak thyroid content.

The problem outlined above is a practical application of an analytical study on the uptake and excretion of iodine in man which will be described more fully in a UCRL report entitled, "The Dynamics of Iodine in Man."