ESTIMATED THYROID DOSES & PREDICTED THYROID CANCERS IN UTAH INFANTS EXPOSED TO FALLOUT I^{131}

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ABSTRACT: The inadvertent exposure of about 250,000 Utah infants to average thyroid doses estimated at 1.3-10 rads may provide a unique opportunity to establish the effects of low doses of I^{131} irradiation in children.

INTRODUCTION

Iodine-131 is produced in nuclear explosions. If cows eat forage which is contaminated with fresh fallout, I^{131} appears in their milk. If a child drinks this radioactive milk, I^{131} concentrates in his thyroid gland and irradiates it. Infants are considered to be the critical members of the population.

Dr. Robert C. Pendleton* was the first to discover that fallout from the Nevada nuclear tests of 1962 would cause significant contamination from radioactive I^{131} in Utah(1). Following his vigorous urging that steps be taken to reduce the exposure, the Utah State Department of Health recommended: (1) transfer of cows from highly contaminated pasture to stored feed, and (2) diversion of highly contaminated milk from the fresh market(2). This protective action set a precedent: it marked the first official attempt in this country to prevent the intake of fallout-contaminated food.

In analyzing the 1962 incident I became fascinated with the implications of exposures from the previous years of testing. Unknown to me at the time, this problem was also being investigated through different approaches by Dr. Harold A. Knapp then with the AEC, and by members of the St. Louis Committee on Nuclear Information. Working independently, we all came to the same conclusion: significant exposures were indicated.

The problem was complicated enormously by the fact that I^{131} was not properly recognized as a fallout hazard during the early years of testing (1951, 1952, 1953 & 1955), and, unfortunately, I^{131} was not measured in milk

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during that time. Therefore, attempts to reconstruct the probable exposures during this period must be indirect. Knapp used the gamma-ray intensity above a contaminated field as an index of its I^{131} content(3), while the St. Louis Group used this and the beta-particle disintegration rate from fallout collection trays(3). I used the observed beta activity in the air and the fission yield(3). Knapp and the St. Louis Group were concerned chiefly with exposures in Southern Utah near the Nevada Test Site, because that was where the highest individual doses were indicated. My major concern was the North-Central portion of Utah, because it contained so many more people.

During the 1963 Congressional Fallout Hearings, Dr. Eric Riess of the St. Louis Group and I both urged that a study be made of the irradiated Utah children. This study, supported by the U. S. Public Health Service, is now in progress.

Originally, the study had 2 objectives: (1) search for medical effects, and (2) estimation of radiation dosage. The medical phase is progressing well, but the dose program has lagged. An unfortunate decision was made to neglect dosimetry unless significant medical effects could definitely be established. In my opinion, this is the most serious defect in an otherwise excellent study. Waiting for possible medical effects may forfeit forever the opportunity to make the best estimates of dose. Memories fade, records are destroyed, and these children will soon reach adulthood and scatter across the nation. Even if no effects appear, the exposures should be evaluated as accurately as possible. If a safe dose exists for I^{131} in children, proper study of the 250,000 irradiated Utah infants may provide the unique chance to establish it.

In this paper I present lower and higher limits for the average doses received by Utah infants. I do this for 2 reasons. First, I hope that the uncertainty in these limits will stimulate interest in improving the dosimetry. Secondly, despite dose uncertainties, the indicated exposures are sufficient to justify continued study of the Utah children.

DOSIMETRY

Prior to the 1963 Fallout Hearings, I calculated the number of radiation-induced cancers predicted for the total population of 250,000 Utah children exposed to fallout I^{131} as infants. I have never before published these predictions nor discussed them in public, primarily because I felt that most of my estimates of dose might be somewhat unreliable. Working in isolation at the time, I was aware of I^{131} milk measurements for only 1 of the 7 years of Nevada testing: doses for the other 6 years I estimated from measurements of beta-activity in the air or from fission yield during the growing season[3]. New information now permits improved estimates for 5 of the 7 test years, and for the remaining 2 I have set lower and higher limits.

For 1962, our analysis of milk from Pendleton's 39 stations scattered throughout Utah indicated that for the daily consumption of 1 liter (1.06 quarts) of milk, the average I^{131} intake for the year was 45,000 picocuries* assuming a 3 day delay from milking to consumption[1,3]. This agreed closely with the 37,000 pCi intake reported by the U. S. Public Health Service for the Salt Lake milk pool. The corresponding infant thyroid doses** were 0.77 or 0.63 rads*** respectively.

For 1958 and 1957, USPHS analysis of the Salt Lake milk pool indicated average yearly intakes of 11,242 and 73,340 pCi I^{131} with associated infant thyroid doses of 0.2 and 1.3 rads, respectively[4].

For 1953 and 1952, the beta activity in fallout-collection trays at Salt Lake City was 15,000,000 disintegrations per minute/ft^2 at 12 hours after the detonation of shot "Nancy" on 24 March, 1953, and 23,000,000 dpm/ft^2 at 12 hours after the detonation of shot "Easy" on 7 May, 1952. Infant thyroid doses have been calculated by the St. Louis Group as 2-12 rads for this 1953 shot and 3-13 rads for this 1952 shot (see pp. 529-530, ref. 3). A number of limitations exist in using these values. First, they are for only one shot during each year: additional shots may have caused additional contamination. Second, the measurements were made in Salt Lake City, not in the pasture lands: pasture contamination could have been higher or lower. I have used these values for yearly exposures only because I am unaware of better data (although it may exist and could be uncovered). My presumably less

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*A picocurie is 2.22 disintegrations per minute.

**Assuming 30% uptake in a 2 gram thyroid with a subsequent effective retention half-time of 7.6 days.

***A rad is the absorption of 100 ergs of energy per gram of tissue.

reliable estimates (see pg. 561, ref. 3) for these average yearly exposures were 6.3 rads for 1953 (from the fission yield) and 1.6 & 5.9 rads for 1952 (from the fission-yield and air beta activity, respectively).

For 1955 and 1951, I only have my estimates of 2.0 and 0.4 rads from the fission yields of 84 and 18 kilotons during the growing season (see pg. 561, ref. 3). Comparing my approximate fission yield estimates of dose with more reliable methods suggests that the fission-estimates averaged over a year of testing might be accurate within a factor of 10. Therefore, I have assigned dose ranges of 0.2-20 rads for 1955 and 0.04-4 rads for 1951. It is not my intent to deceive the reader into believing that the true doses are well established for the years 1955, 1953, 1952 and 1951. More work is needed.

My best estimates of the average thyroid doses for all Utah infants is summarized in Table 1 for each year of Nevada testing. Individual doses were much higher: Knapp estimated doses of 120-440 rads for infants in St. George, Utah, following the "Harry" shot of 19 May, 1953 (3). The dose for our highest station in 1962 was 9-26 times greater than our average (3).

Table 1
ESTIMATED AVERAGE THYROID DOSES TO ALL UTAH INFANTS

YEAR OF TESTING	RADS LOWER LIMIT		RADS HIGHER LIMIT	METHOD OF DOSE ESTIMATION
1962	0.63	-	0.77	S.L. MILK POOL & PENDLETON'S MILK STA.
1958		0.2		USPHS SALT LAKE MILK POOL
1957		1.3		USPHS SALT LAKE MILK POOL
1955	0.2	-	20	FISSION YIELD
1953	2	-	12	FIELD BETA ACTIVITY AFTER SHOT "NANCY"
1952	3	-	18	FIELD BETA ACTIVITY AFTER SHOT "EASY"
1951	0.04	-	4	FISSION YIELD

Next I tabulate the total number of exposed Utah infants, and compute the average dose for all of them (Table 2). The yearly births were derived from the U. S. Census (1960 & 1950). The average birth time was taken as mid-year, followed by an average delay of about 6 months before appreciable consumption of fresh cow's milk. Thus, exposures were regarded as starting during the calendar year after the calendar year in which birth occurred.

Only the infant dose has been computed. However, dose calculations can easily be extended throughout childhood using the method shown in Table 2 and correcting for the increasing mass of the thyroid with age*.

Table 2
TOTAL NUMBER OF UTAH INFANTS EXPOSED TO FALLOUT I^{131}

YEAR OF BIRTH	BIRTHS DURING YEAR	AV. THYROID DOSE (RADS) Age 0.5 to 1.5	Age 1.5 to 2.5	TOTAL DOSE
1962				
1961	26,000	0.6 - 0.8		0.6 - 0.8
1960	25,000		0.6 - 0.8	0.6 - 0.8
1959				
1958				
1957	24,000	0.2		0.2
1956	23,000	1.3	0.2	1.5
1955	22,000		1.3	1.3
1954	22,000	0.2 - 20		0.2 - 20
1953	21,000		0.2 - 20	0.2 - 20
1952	21,000	2 - 12		2 - 12
1951	20,000	3 - 18	2 - 12	5 - 30
1950	20,000	0.04- 4	3 - 18	3 - 22
1949	19,000		0.04- 4	0.04- 4
TOTAL =	243,000			
			AVERAGE DOSE =	1.3 - 10

Table 2 indicates that about 1/4 million Utah infants were exposed to fallout I^{131}, with an indicated average thyroid dose of 1.3 - 10 rads**.

*The enlargement of the thyroid gland with age reduces its I^{131} concentration and the resulting radiation dose from a given intake of I^{131}. For example, the intake of 1 microcurie (1,000,000 pCi) I^{131} gives a 17-rad dose to the 2-gram thyroid of a 1-year old infant; a 6.8-rad dose to the 8-gram thyroid of an 8-year old child; and a 1.7-rad dose to the 20-gram thyroid of an adult. Furthermore, the weight of evidence indicates that the radiation resistance of the thyroid increases with age(5), although the exact sequence of changes in sensitivity has not yet been established precisely.

**My earlier crude methods yielded an estimated thyroid dose averaging 4.4 rads to this population(3). I am pleased (and a little surprised) at the agreement.

The significance of these exposures is not the size of the average dose (which is small) but in the enormous number of irradiated children.

To those of you who object to my estimates, I applaude you: may your doubts lead you to establish more reliable limits!

PREDICTED THYROID CANCERS

The natural incidence of childhood thyroid cancer is extremely low. Values from Mustacchi and Cutler indicate that by age 15 years only 25 thyroid cancers are expected per 1,000,000 children(6). Thus, only about 6 "natural" childhood thyroid cancers are anticipated in the 250,000 exposed Utah children.

X-rays can induce thyroid cancer. About 20-30 years ago, it was "fashionable" in some hospitals to x-irradiate infants in the neck region for benign conditions. Thyroid cancer has followed in an unpleasantly large number of these exposed children. Beach and Dolphin(7) found reports of 132 post-irradiation thyroid malignancies in the published medical literature: the additional number of unpublished cases remains unknown. They analyzed the relation between incidence and dose in a special population of 4673 exposed children for which the individual doses were available. The incidence of thyroid cancer increased with dose to 1.7% at 500 rads. Assuming incidence proportional to dose, they derived an incidence of 35 cancers per million infants each receiving 1 rad. However, they were careful to point out that their analysis did not exclude the possibility of a curved dose-response relation: the data in their figure 5 can also be interpreted to suggest a "threshold" at perhaps 50-100 rads, below which cancers would not be induced.

There is some experimental evidence that I^{131} is less effective than x-rays. Doniach found that the I^{131} dose had to be about 10 times greater than an abrupt dose of x-rays to cause equal effects in adult rats(8). However, rats are not men*, and the relative effectiveness of I^{131} vs. x-rays in children is yet to be established. Although the I^{131} exposures in Utah were unplanned for this purpose, perhaps they can provide information of fundamental importance in radiobiology.

The dose-response relation is very difficult to establish at very low doses, because the incidence of effects is so very small. Some radiobiolgists

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*Although some women claim that men are rats.

feel that cancer induction is not proportional to dose, but that a certain "threshold" level must be exceeded before cancers can be induced. If such a threshold exists and if the doses fall below this level, no induced cancers will appear. It is possible that no cancers will result from the Utah exposures.

The number of radiation-induced thyroid cancers will now be predicted for each of the following 3 assumptions: (A) a linear dose response with I^{131} irradiation equally as effective as x-irradiation, (B) a linear dose response, but I^{131} irradiation only 1/10 as effective as x-irradiation, and (C) a high threshold. Assumption (A) probably sets an upper limit, for it is unlikely that I^{131} is more effective than x-rays. Assumption (C) certainly sets the lower limit: the number of induced cancers cannot be less than zero! Assumption (B), while between the upper and lower limits is not necessarily the best estimate, but it yields reasonable values for planning the experimental search for thyroid cancer. Predicted thyroid cancers in the 250,000 irradiated Utah children are shown in Table 3.

Table 3
PREDICTED THYROID CANCERS
IN THE 250,000 IRRADIATED UTAH CHILDREN

ASSUMPTION	AVERAGE DOSE (1.3 rad - 10 rad)
A) $\left[\frac{\text{35 Thyroid Cancers}}{10^6 \text{ Infants given 1 rad}}\right]$ (Effect of x-rays; Beach & Dolphin)	11 - 88
B) 1/10 of x-ray effect (I^{131}/x-ray RBE in rats; Doniach)	1 - 9
C) High Threshold	0
"NATURAL" INCIDENCE BY 15 YEARS AGE (from Mustacchi & Cutler)	6

Similarly, it is instructive to predict the expected number of thyroid cancers in the 565 infants in Washington county, Utah, exposed to higher thyroid doses estimated at 120-440 rads[3] following the "Harry" shot of 19 May, 1953. These predictions are shown in Table 4.

Table 4
PREDICTED THYROID CANCERS
IN THE 565 INFANTS NEAR ST. GEORGE IN 1953

ASSUMPTION	AVERAGE DOSE (120 rad - 440 rad)
1) $\left[\frac{\text{35 Thyroid Cancers}}{10^6 \text{ Infants given 1 rad}}\right]$ (Effect of x-rays; Beach & Dolphin)	2 - 9
2) 1/10 of x-ray effect (I^{131}/x-ray RBE in rats; Doniach)	0.2 - 0.9
3) High Threshold	0
"NATURAL" INCIDENCE BY 15 YEARS AGE (from Mustacchi & Cutler)	0.01

DISCUSSION

A number of conclusions follow:

1) Under the assumption of linear dose-response relations, the predicted number of induced cancers for the total state is 5-10 times higher than for the high-fallout St. George area where the studies to date have been most emphasized. Therefore, consideration should be given to expanding the studies into additional regions.

2) The advantage of studying the limited population in the St. George area is that the expected number of "natural" thyroid cancers is so low (0.01) that the observation of a single case of thyroid cancer would be highly suggestive of radiation damage, while the observation of 2 cases would constitute almost conclusive proof. However, under assumption (B) less than 1 case is predicted.

3) The "epidemic" number of thyroid cancers predicted from assumption (A) have not been observed experimentally*. This indicates that either (1) low doses are less effective rad-for-rad than higher doses, or (2) I^{131} doses are less effective than x-ray doses. Very likely, both of these effects are in operation.

*If the additional doses received in later childhood had been included, the predicted number of cancers would have been even higher.

4) Crude as these predictions are, they indicate that much value can be gained from study of the Utah children. If low doses of I^{131} are without effect in infants, verification of this hypothesis would be of fundamental importance in understanding the induction of radiation-induced cancer. (Hopefully) never again may 250,000 additional infants be irradiated with I^{131} and become available for observation. The present study should reach beyond a mere tabulation of possible effects. Its prime objective should be to establish the relationship between dose and damage: this requires attention to the dosimetry in addition to the search for effects.

5) Improvement in dose estimates should not be delayed any longer. The ground fallout pattern should be established for each one of the Nevada test shots (the conventional meteorological trajectories for material passing thousands of feet overhead are inadequate). The actual deposition of fallout should be evaluated by records of field gamma-ray intensities and fallout tray beta-activities, when available. When measurements are lacking, the deposition should be estimated from meteorological considerations. The probable fractionation (depletion or enrichment) of I^{131} relative to the other fallout products should be determined whenever possible. Possible changes in the availability of fallout particles at various distances from the test site should be considered.

From feeding records, the intake of I^{131} by milk cows in each milkshed area should be established. The intake is very low when uncontaminated feed is used[(1)]. From I^{131} intake by the cow, I^{131} contamination in the milk can be calculated. This should be done, at least for the major dairies. From the daily consumption of fresh milk, the human thyroid dose can be computed.

While it might be impractical to reconstruct the individual dose for each person in Utah, this should be done for limited areas, such as St. George. Separation of the infants drinking highly radioactive milk from those whose milk was uncontaminated (powdered, canned or from "cold" milksheds) would provide the internal "control" group needed so badly for comparison. The average dose to infants throughout the rest of Utah could be established by intensive study of a suitably selected representative sample (perhaps about 1000 children). Certainly the individual doses should be reconstructed for all children developing abnormal thyroid conditions to see if their doses differ from the general population's. In dose reconstruction, particular attention should be paid to assessment of medical x-irradiation. Is this factor important since 1950 for Utah children?

I do not pretend that refinement of dose estimates would be easy. It is a difficult task, but one which must be done to get maximum scientific value from the study. Otherwise, one is forced to use less satisfactory estimates, such as those presented in this paper.

6) Other conditions should be considered, such as the benign thyroid tumors which appear more frequently than thyroid cancers. In 73 children and adolescents treated with I^{131} for hyperthyroidism (an overactive thyroid) and followed for 2-14 years, there were 5 thyroid tumors, of which only one (a papillary adenocarcinoma) was malignant(9). In a different study, out of 18 children treated with I^{131} for hyperthyroidism, 6 thyroid tumors were observed 5-14 years later(10). More cases may appear after longer follow-up times.

A very high incidence of adenomatoid goiter (a benign thyroid tumor) has been observed in 29 children in the Marshall Islands who were exposed to heavy fallout in 1954(11). The external gamma-ray dose was about 175 rads, while the internal dose from I^{131} is estimated to be roughly 1000 rads for the younger children. No thyroid abnormalities have been observed in the 75 unexposed comparison children.

7) The Utah study has motivated careful examination of thyroid conditions in a general population. The medical information gained may be among the most important aspects to emerge from this investigation.

SUMMARY

For the 250,000 Utah infants exposed to fallout I^{131}, the average thyroid dose received by age 2.5 years is estimated to be 1.3 to 10 rads. The resulting numbers of thyroid cancer are predicted for each of 3 dose-response models. These predictions indicate that the Utah study should be continued, with additional effort devoted to improving the estimates of thyroid dose.

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