TID-4500, UC-48
Biology and Medicine

LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA, LIVERMORE

Bio-Medical Research Division

UCRL-14707

# ESTIMATION OF DOSAGE TO THYROIDS OF CHILDREN IN THE U. S. FROM NUCLEAR TESTS CONDUCTED IN NEVADA DURING 1952 THROUGH 1955

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May 10, 1966

AEC Contract No. W-7405-eng-48

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# PREFACE

This report covers only those nuclear device tests conducted at NTS from 1952 through 1955. We are presently collecting and analyzing the data from all the test series. Our preliminary analyses indicate that, in most cases, these additional tests will increase the dosage estimates by less than 20%. It is anticipated that some areas will show an increase greater than 20%. For example, following Shot Diablo of the Plumbob Series in 1957, heavy fallout occurred in the region around Fargo, N. Dak. Our preliminary estimate is that this occurrence could have led to infant thyroid dosages in the range of 100 rad.

We are publishing these dosage estimates for the 1952 through 1955 tests at this time for two important reasons: 1) To solicit any additional data that are pertinent to the various aspects of this overall problem, and 2) to solicit any useful criticism that will permit the analyses to be more precise. We plan to publish an addendum to this report that will present the dosage estimates for all tests. Any additional data or useful criticism will be incorporated into the addendum.

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May 10,1966

## ABSTRACT

This report presents estimates of the thyroid dosage accumulated by children up to 5 years of age in the United States as a result of nuclear weapons tests in Nevada during 1952 through 1955. These estimates are based upon the assumption that the children were consuming 1 liter of milk per day from cows on pasture. It is not known to what extent this assumption is valid. The data, the analytical approach, and the assumptions inherent to the analysis are presented, together with the estimates.

## INTRODUCTION

This report presents estimates of the thyroid dosage accumulated by children up to 5 years of age in the United States as a result of nuclear weapons tests in Nevada during 1952 through 1955 (Tumbler-Snapper, Upshot-Knothole, and Teapot Series). It is important to point out that these are only estimates of the dosage. They are based upon cow milk as the sole source for transfer of I-131 to children and it is assumed that the cows are on pasture at the time of contamination. These estimates are presented in the form of isodose contours in Fig. 1. Our opinion is that for the average child drinking 1 liter of milk per day from cows on pasture, these estimates are in error by not more than a factor of 2 in either direction. Undoubtedly, a sizeable number of children were consuming 1 liter of milk per day from cows on pasture during this period. At the same time, there is evidence which suggests that the average child would consume only 0.5 liter of milk per day. Therefore, the most probable range of the dosage is from 0.25 to 2 times the dosage recorded in Fig. 1. It is important to emphasize that these dosage estimates include the assumption that the dairy herds were on pasture. In some areas, dairy herds may have been on stored feed during some of the fallout occurrences. This would result in lower I-131 concentrations in milk and, hence, lower thyroid dosages than those recorded in Fig. 1. The data, the analytical approach, and the assumptions inherent to the analysis are presented, together with the estimates. Thus, the reader can then make his own judgments as to the validity of the estimates.

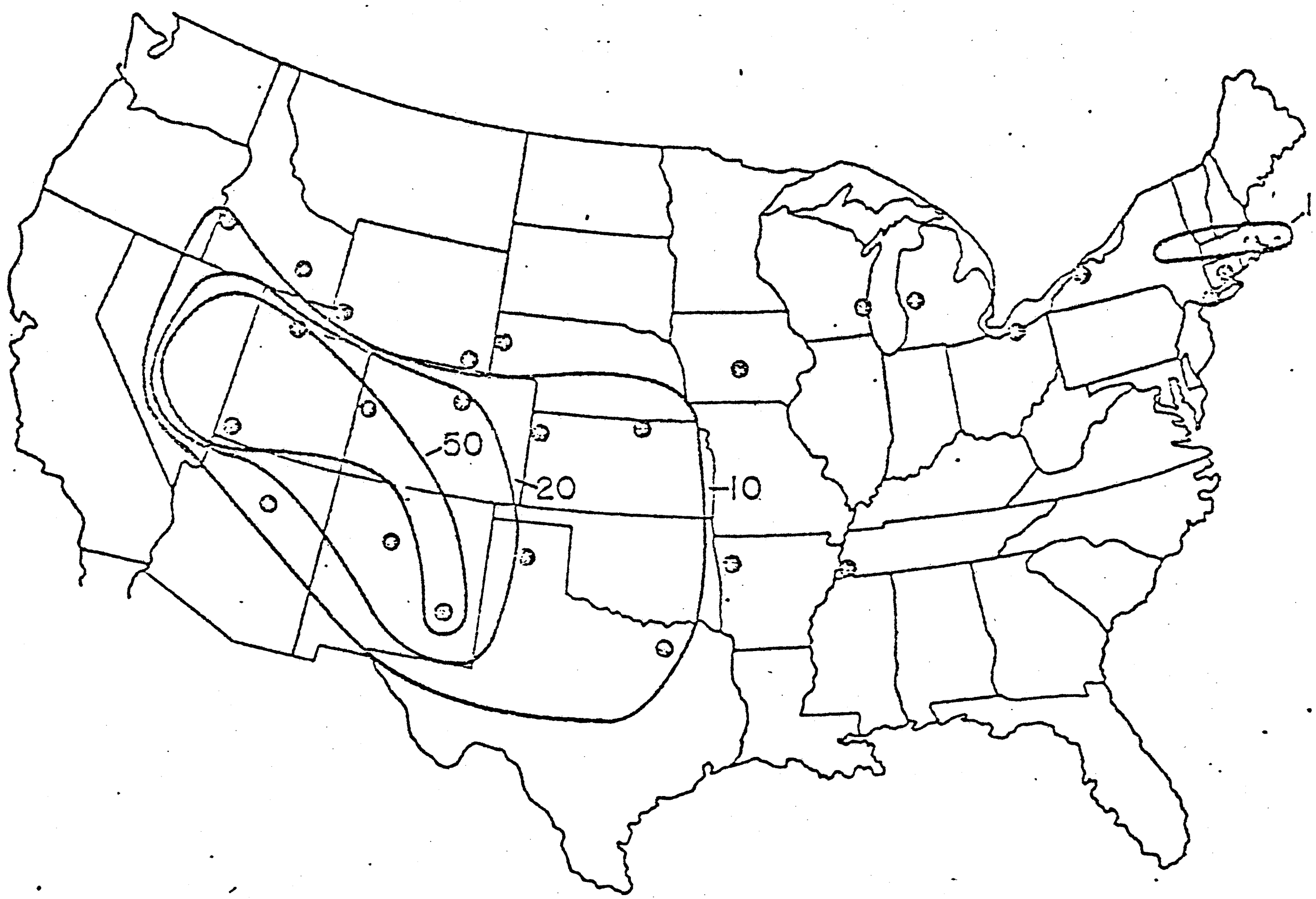


Fig. 1. Isodose contours of estimates of infant thyroid dosage (rad) resulting from nuclear device testing at the Nevada Test Site during the years 1952 through 1955.

One quick comparison of Fig. 1 with fallout observations can be made: Our evaluation indicates that forage contamination at the level of 1 $\mu$Ci(I-131)/$m^2$ leads to a dosage of 30 rad to a 2-g infant thyroid. The great majority of the early fallout in the United States resulted from devices detonated on towers. A total of 360 kt was detonated on towers during the three test series considered in this report. It has been shown that approximately 4.5% of the fission products from tower shots falls out in the United States exclusive of that fallout close to the test site.[1] Approximately 1.25 $\times 10^{11}$ $\mu$Ci of ~~I-131 is~~ produced per kiloton of fission. If the 4.5% of this I-131 were spread evenly over the United States, the deposition would be about 0.2 $\mu$Ci/$m^2$. If this were all retained on forage, it would result in a dosage of 6 rad to 2-g thyroids throughout the United States. The isodose lines of Fig. 1 reflect this over-all average, but since the fallout is not uniform they also indicate the areas where the dosage could have been considerably higher.

## BASIC DATA

The basic data used to determine these estimates are the results of the gummed-film monitoring network of the Health and Safety Laboratory[1-3] and of the Off-Site Radiological Safety Organization.[4-6] The gummed-film data were used to estimate the dosage at distances beyond 200 miles from the test site and off-site radiological safety data for the area within 200 miles. The shot dates, yields, and other pertinent data for these tests are presented in Table I.

### Gummed-Film Data

Tables IIA and IIB present the data abstracted from the reported results of the gummed-film network. These tables are arranged chronologically by test shot and present the gross beta activity, in $\mu$Ci/$m^2$/day, of the fallout collected on the gummed-film at the various sampling stations. Reference 2 indicated that the values reported for the Tumbler-Snapper Events should be increased by a factor of three (except for the very high values). This correction was the result of recalibration of their automatic counting equipment. The authors stated that the higher samples were not counted on the automatic equipment. The values below 5 $\mu$Ci/$m^2$/day were therefore increased by this factor. Also recorded in Tables IIA and IIB are the cloud arrival times and the altitude of the cloud trajectory calculated to have passed over the sampling station. The time of fallout (cloud arrival time) was estimated from the sampling date and/or the calculated trajectory as given in the references. The tables also indicate whether the fallout occurred in rain or by dry deposition.

The values recorded in Table IIA were originally given as dpm/$ft^2$/day, extrapolated to the sampling day. These were converted to $\mu$Ci/$m^2$/day as recorded in the table. The data for the Teapot Series, Table IIB, were reported as $\mu$Ci/100 $mi^2$/day extrapolated to 1 January 1956 by using the $T^{-1.2}$ relationship. These values were extrapolated back to the sampling date and converted to $\mu Ci/m^2/day$ as recorded in the table. Only values in excess of 0.5 $\mu Ci/m^2/day$ were abstracted and recorded in Table IIA and IIB. In the absence of a recent test shot, the fallout recorded at a sampling station was below 0.05 $\mu Ci/m^2/day$ and usually below 0.005 $\mu Ci/m^2/day$. Consequently, there is little doubt that a value in excess of 0.5 $\mu Ci/m^2/day$ can be assigned to a recent test shot.

## Off-Site Radiological Safety Data

The Virgin River Valley area was selected as the sole area for this anslysis. Figure 2 is a map of the Nevada-Utah area. The Virgin River Valley includes the towns of Glendale Junction, Bunkerville, and Mesquite, Nev., as well as St. George and Hurricane, Utah.

Table III presents the data abstracted from the Off-Site Radiological Safety Reports and is arranged in chronological order by test shot. The value recorded is the open-field gamma dose rate at H + 24 hr (that is, 24 hr after the explosion). If the data were given for some time other than H + 24 hr, they were corrected to this time using the $T^{-1.2}$ decay law. These data are derived from the same sources as used by the Greater St. Louis Committee for Nuclear Information; a more extensive tabulation covering the entire Nevada-Utah area may be found in the Committee's report in the 1963 hearings before the Joint Committee on Atomic Energy.[7]

# ANALYTICAL METHOD

The major route of entry to man for fallout iodine in the United States is through cow milk (see Appendix A). Therefore, the dosage estimates in this report are based upon cow milk as the sole source of the iodine. Thus, the overall approach will involve converting the fallout data in Tables IIA, IIB, and III to $\mu Ci(I\text{-}131)/m^2$, calculating the resultant concentration in cow milk, and finally, converting this into an estimate of the dosage to a 2-g infant thyroid.

## Gummed-Film Data to $\mu Ci(I\text{-}131)/m^2$

### Correction for Gummed-Film Efficiency

Comparison of gummed-film results with those of pot collectors has shown that the pot values are, on the average, a factor of 1.6 higher and this correction is applied to the gummed-film data when making Sr-90 estimates.[8] Since the dry deposition velocity has been determined to be identical between the two types of samplers,[9-11] this factor is due to their different efficiencies in the collection of fallout occurring in rain and should be applied only to fallout in rain. This factor undoubtedly results from activity being washed off the gummed-film during rain, whereas the pots are absolute collectors. In the subsequent analysis, this correction for collection efficiency will be used only in an indirect way in the section titled "Retention of Fallout on Plants."

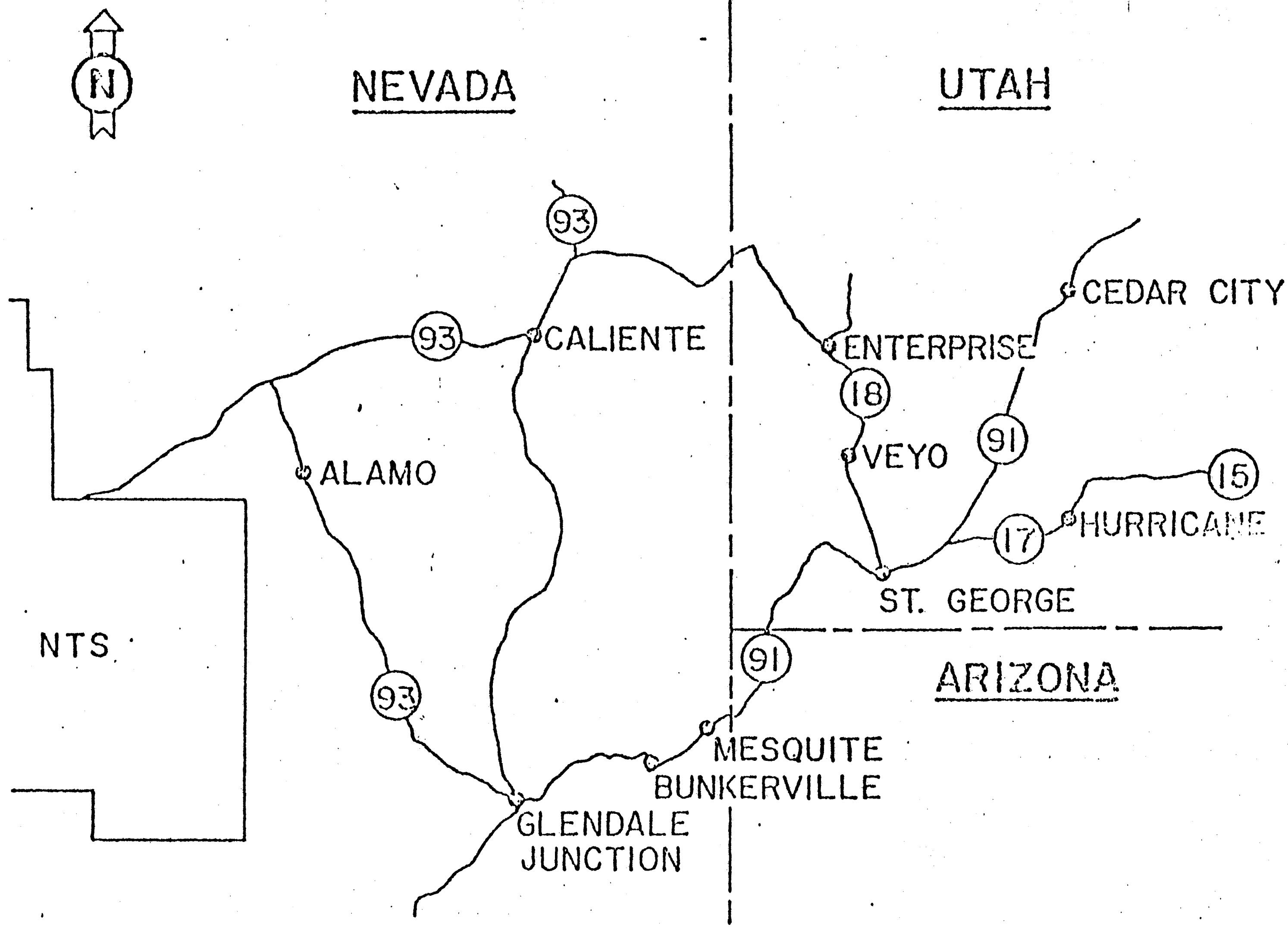


Fig. 2. Map of the Virgin River Valley area.

## Conversion to $\mu$Ci(I-131)/m$^2$

The gummed-film results are in terms of total beta activity. This can be converted to I-131 activity by assuming that the gummed-film sample is unfractionated fission products. The fraction of the total beta activity due to I-131 at various times after detonation is:

| Time (hr) | Fraction I-131 |
|---|---|
| 12 | $4.7 \times 10^{-3}$ |
| 24 | $1.0 \times 10^{-2}$ |
| 36 | $1.6 \times 10^{-2}$ |
| 48 | $2.3 \times 10^{-2}$ |
| 72 | $3.5 \times 10^{-2}$ |

Thus, the $\mu$Ci/m$^2$ values can be converted to $\mu$Ci(I-131)/m$^2$:

$$I_c = (F_t)\,(F_f)\,(B_c)$$

where

$I_c$ = I-131 on the fallout collector in $\mu$Ci/m$^2$,
$B_c$ = total beta on the fallout collector in $\mu$Ci/m$^2$,
$F_t$ = fraction of the total beta due to I-131 at the time of sample collection assuming no fractionation,

and

$F_f$ = fractionation correction.

## Determining $F_t$

The gummed-film results were extrapolated from the counting date to the sampling date using the relationship $A_t = A_0 T^{-1.2}$. In using this formula the shot date was considered as day one. This introduces an error into the calculations, the magnitude of which depends upon the time between collection and counting. Our approach to this problem has been to assume that the reported values represent debris whose age is in multiples of 24 hr and $F_t$ is chosen on that basis. Usually, the samples were counted more than two days after collection, and this could introduce an overestimate of a factor of about 1.1. The following values of $F_t$ were used:

| Day | $F_t$ |
|---|---|
| 1 | 0.01 |
| 2 | 0.02 |
| 3 | 0.03 |
| 4 | 0.04 |
| 5 | 0.05 |
| 6 | 0.06 |

<u>mr/hr to μCi(I-131)/m²</u>

Theoretical calculations indicate that 1 mr/hr at H + 24 hr should be equivalent to 100 μCi (fission products)/$m^2$. Field measurements that compared dose rate to fallout-tray and gummed-film measurements have shown this relationship to be substantially correct for these series of tests.[12] At H + 24 hr, I-131 represents approximately 1% of the total activity of unfractionated fission products. This leads to the relationship,

$$I_c = F_f\,(G)$$

where

$F_f$ = fractionation correction

and

G = gamma dose rate at H + 24 hr in mr/hr.

<u>Effect of Fractionation</u>

The fractionation correction as used in this report is

$$F_f = \frac{\text{Observed or measured fraction}}{\text{Theoretical fraction}}$$

where the theoretical fraction is $F_t$ discussed above.

Fractionation tends to enrich the radioactive cloud with the more volatile radionuclides and those that have volatile precursors. It would also cause these nuclides to become absorbed on the surface of the more numerous small particles. Hence, fractionation would cause the cloud to contain a greater relative percentage of this more volatile material as it moved downwind; Sr-89 and Sr-90, which have Kr precursors, would be expected to represent a larger fraction of the activity and Zr-95, which has refractory precursors, a smaller fraction. Furthermore, the Sr-89 and Sr-90 should be associated with the more numerous particles in the smaller size range. Moreover, as a result of this process the close-in fallout is depleted in the volatiles. For these series of tests, fractionation is most meaningful with respect to depletion in the close-in dry fallout or in the larger particles. This can be illustrated as follows: Only some 25% of the radioactivity produced in a tower shot fell out within the United States (18% within 200 miles).[1] Thus, if none of the Sr-90 or any other particular isotope fell out in the U.S., the material outside the U. S. would be enriched by a factor of only 1.33.

I-131 differs from the Sr isotopes in that it has refractory precursors, while $I_2$ and HI are volatile. Thus, the Sb and Te from which I-131 is formed would be expected to be associated with the particles. Once the I-131 is formed by the decay of tellurium, it will be highly reactive. One would expect it to react with the other materials of the fallout particle to form iodides or iodates. Under such circumstances, it would be expected to remain attached to the particle. On the other hand, compounds such as $I_2$ and HI could be formed and escape from the particle. These gases would then be expected to become adsorbed on the more numerous smaller particles and present a picture of fractionation similar to that for the a isotopes.

As of now we have found no direct measurements of the effect of fractionation on I-131 for the close-in fallout at NTS from these early series of tests. However, we have been able to use other data to arrive at an estimate of I-131 fractionation. Larson reports that tower-mounted detonations at NTS deposited from 0.5-2.0% of the Sr-89 and 1.6-7.2% of the Sr-90 produced in the first H + 12 hr.[13] These compare to some 18% of the total activity that falls out in H + 12 hr[1] and leads to $F_f$ ranging from 0.025-0.1 for Sr-89 and 0.09-0.4 for Sr-90. In the same paper, he presents data that give a $F_f$ for Sr-89 of 0.3 and for Sr-90 of 0.4. Following a kiloton-range surface shot in the UK Buffalo Series,[14] $F_f$ for Sr-89 in close-in dry fallout was determined on 1 sample to be equal to 0.05. On several other samples collected subsequent to a rainstorm, the average $F_f$ rose to 0.2. This is consistent with the rain washing out the smaller and less fractionated particles. The ratio of Ba-140/Sr-89 ranged from 15-30 at H + 24 hr following this shot. This compares to the theoretical ratio of 5 and indicates that Ba-140 was less depleted than Sr-89 by a factor of 3 to 6. Actually, the ratio of the measured Ba-140 to the theoretical Sr-89 for these data ranges between 5 and 6; this suggests that Ba was only slightly fractionated in this debris. Other data from barge shots in the Pacific showed a ratio of I-131/Sr-89 ranging from 20 to 140, and this compares to a theoretical ratio of 4.[15] Thus, the I-131 was less depleted than Sr-89 by a factor ranging from 5 to 35. The same data again gave ratios for Ba-140/Sr-89 ranging from 14 to 33 and thus show that I-131 was also less depleted than Ba-140. In fact, these data suggest that I-131 was unfractionated. This conclusion is supported by the following evidence which indicates that the I-131 does not escape from the particles after it is formed by the decay of tellurium.

The half-life of fallout I-131 on forage has been shown to be comparable to that of the refractory radionuclides when corrected for radiological decay.[16] This indicates that I-131 is lost from particles at a slow rate, if at all. Analysis of Sedan debris also indicates that I-131 was lost from fallout particles at a slow rate.[17] Thus, our estimate is that I-131 was fractionated to a small degree following these early tests. In calculating the dosage we have considered it unfractionated ($F_f$ = 1). The above considerations would indicate that this introduces little error into the estimates.

## Retention of Fallout on Plants

The major route of entry into cow milk for short-lived isotopes such as I-131 is direct ingestion of the fallout deposited on forage. The above considerations allow the estimation of the I-131 on the various fallout collectors: trays, pots, or gummed-film. It is now necessary to determine the relationship between I-131 on forage and the I-131 on the fallout collectors. The ratio of I-131 on forage to I-131 on the fallout collector determines the retention factor, $F_r$.

Field measurements indicate that small particles are retained on plants with a higher efficiency than large particles.[18-20] The data demonstrate that the retention on plants is very low for particles above 50 μ in diameter. Deposition experiments suggest that retention of particles below 20 μ in diameter is close to 100%. All in all, the data suggest a rather sharp cut-off in particle retention around 50 μ. Above 50 μ, only a few percent are retained; below 50 μ close to 100% are retained. The following are plant retention values measured in the region of 60 to 170 miles from ground zero.[14,19-20] These values were determined by the ratio $\mu Ci/m^2$ on forage to $\mu Ci/m^2$ on fallout trays.

Plant Retention (%)

| Teapot series | | Plumbob series | | UK Buffalo series | |
|---|---|---|---|---|---|
| Shot | % | Shot | % | Shot | % |
| Tesla | 1 | Diablo | 25 | #1 | 2 |
| Apple I | 1 | Shasta | 16 | #2 | 15 |
| Met | 5 | Smoky | 3 | | |
| Apple II | 2 | | | | |

While these values range from 1-25%, all but 3 are 5% or below. The 15% and 16% values were associated with rainout. Rain will wash out the smaller particles that have high retention and, hence, would raise the overall retention value. The 25% retention figure, however, cannot be set aside. In fact, it can be shown to be reasonable.

Studies of the fallout during the Upshot-Knothole Series indicated that the high levels of close-in fallout, such as those recorded in Table III, are associated with large particles of very high activity and low retention on plants.[21-23] Analysis of fallout trays demonstrated that the great majority of the activity came from particles that had activities well in excess of 1 μCi. Analysis of air samplers indicated that none of the particles on the air sampler had this high an activity and that the total activity in the sample was generally less than the mean activity of a single particle on the trays. The air samplers collect only those particles (<50 μ) that are retained on plants. These data, therefore, suggest that the retention on plants should be low. However, these same data demonstrated that there were exceptional cases during the Upshot-Knothole Series.

The following gives the air sampler data collected at St. George following Shot Annie,[4] which is one of the shots that produced high fallout levels in this area.

| Time | $\mu Ci/m^3$ (at H + 24 hr) | Mean diameter (μ) |
|---|---|---|
| H + 3 to H + 4 | $1 \times 10^{-2}$ | 5.3 |
| H + 4 to H + 9 | $1 \times 10^{-2}$ | 3.2 |

As the data show, the activity was in the range of $10^{-2}$ $\mu Ci/m^3$ and the mean diameter was 5 μ and lower. The low plant retention values shown above were associated with air sampling data similar to these.

The air sampler data collected at St. George following Shot Harry is shown below.[4] This was the other event that produced high fallout levels in this area. It is also one of the exceptional cases. The air sampler data are:

| Time | $\mu Ci/m^3$ (at H + 24 hr) | Mean diameter ($\mu$) |
|---|---|---|
| H + 4.5 to H + 6.5 | 0.43 | 42 |
| H + 6.5 to H + 9.5 | 0.56 | 18 |
| H + 9.5 to H + 13.5 | 0.10 | 26 |

These air concentrations are higher than those following Shot Annie by a factor of 50 and the mean particle diameter is around 20 $\mu$ instead of 5 $\mu$. The integrated air concentration over the time of fallout from Shot Harry is:

$$2\ (0.43) + 3\ (0.56) + 4\ (0.1) = 2.94\ \mu Ci\text{-}hr/m^3.$$

The deposition velocity for 20 $\mu$ particles of 2.5 $g/cm^3$ is about 110 m/hr. These figures lead to a calculated deposition of 110(0.00294) = 0.33 $mCi/m^2$ for particles in this size range. The fallout at St. George gave a 24 hr dose rate of 26 mr/hr and this is equivalent to a total fallout level of 2.6 $mCi/m^2$. The ratio, 0.33/2.6, would suggest that some 13% of the fallout activity could be in the size range below 50 $\mu$. Hence, the retention on plants could have been as high as 13%. The deposition velocity for 5 $\mu$ particles is about a factor of 10 lower; hence, the air data would suggest that less than about 1% of the fallout activity could be in this size range. Since the mean diameter was 5 $\mu$ following Shot Annie and the air activity was a factor of 50 lower, the particles in the size range collected by the air samplers from Shot Annie were a negligible fraction of the total fallout and the fraction retained on plants would be quite low.

Following Shot Harry of the Upshot-Knothole Series both air samples and fallout-tray samples were analyzed for particle activity.[22] The tray data indicated that 14% of the activity on the tray came from particles that had an activity less than $10^6$ dpm. All of the particles on the air samplers had an activity that fell within the range of $10^6$ dpm or less. The air samplers have a particle size cut-off of approximately 50 $\mu$ in diameter. This suggests that 14% of the fallout activity could have come from particles with diameters less than 50 $\mu$ and is in agreement with the above estimate of 13%, made by using air sampler data and particle deposition velocity, although this close an agreement is fortuitous.

The data, therefore, suggest that following Shot Harry, the retention on plants could have been as high as 15%. Following Shot Annie it could have been less than 1%. Air sampler data also suggest that the retention might have been high following Shot Simon. In the subsequent analysis we have used an average retention factor, $F_r$, equal to 0.1 for the Virgin River Valley.

As the radioactive cloud travels downwind from these close-in stations and approaches the more distant stations of the gummed-film network, the cloud travel time increases and the particle size decreases. Hence, the fraction of the total fallout retained by forage will increase. For fallout times on the order of H + 24 hr, the calculated particle sizes (Stokes' diameter) would range between 20 and 30 $\mu$. Also, at these longer fallout times turbulent eddy diffusion could bring the smaller particles to the earth's surface. Furthermore, when the fallout occurs in rain, the raindrops will carry the smaller particles down from the higher altitudes. Experimental evidence and theoretical considerations indicate that small particles ($<5\ \mu$) are deposited by dry deposition with greater efficiency on plants than on gummed-film.[11] Since the deposition velocity can only be measured by measuring the particles retained on plants, this indicates that the gummed-film would underestimate the small particles on plants, or that $F_r > 1$. At the same time, theoretical considerations and experimental evidence indicate that as the particle diameter increases to above 10 $\mu$, the gummed-film is as efficient a collector of fallout as pasture grass, or that $F_r = 1$. As Tables IIA and IIB indicate, most of the dry fallout occurred within the first H + 36 hr and occurred in Utah, Colorado, and New Mexico. Essentially all of the fallout in Albuquerque and Roswell, N. Mex., was dry while only about 50% occurred as dry fallout in Grand Junction and Denver, Colo., or Salt Lake City, Utah.

In the first 36 hours, the calculated mean particle diameter (Stokes' diameter) would be above 10 $\mu$ for which $F_r = 1$. On the other hand, turbulent eddy diffusion could bring the smaller particles which have a $F_r > 1$ to the earth's surface within this time period. Thus, the actual retention factor would be greater than unity, depending upon the particle size distribution. In the subsequent analysis, $F_r = 1.2$ was used. This value was selected because, as will be seen below, it is an average value of $F_r$ for fallout occurring in rain.

The retention of fallout in rain appears to be a function of the total rainfall or rainfall rate. Ward et al.[24] measured the retention on plants following individual rains and obtained the following results:

| Total rainfall (in.) | $F_r$ |
|---|---|
| 0.12 | 0.90 |
| 0.27 | 0.75 |
| 1.91 | 0.56 |

These values were derived from the ratio of fallout on forage to fallout in pot collectors. However, they do not apply directly to the gummed-film data. As indicated earlier, the measured activity in the pot is, on the average, 1.6 times greater than that measured on the gummed-film when the fallout occurs in rain. Thus, the above retention factors must be multiplied by 1.6 in order to apply them to the gummed-film data. Since no great improvement in the accuracy of the estimates could be achieved by considering each case individually, $F_r = (0.75)(1.6)$ or 1.2 has been used in the subsequent estimates. As indicated above, the same $F_r$ will be applied to both dry deposition and rainout in the gummed-film data.

Since I-131 on forage is

$$I_p = (F_t)(F_f)(F_r)(I_c),$$

where $I_p$ is the I-131 on forage in $\mu Ci/m^2$, then, using the relationships on pages 6 and 7, the I-131 on forage was derived from the gummed-film data of Tables IIA and IIB ($F_f = 1.0$, $F_r = 1.2$),

$$I_p = (1.2)(F_t)(B_c);$$

and from the gamma dose rate data of Table III ($F_f = 1.0$, $F_r = 0.1$),

$$I_p = (0.1)(G).$$

## Error in the Estimate of I-131 on Forage

At this time, we have been able to find only one case during this time period where the gummed-film estimate can be compared with measured I-131 on plants, and none that give I-131 in cow milk. These measurements were made in the vicinity of Pocatello, Idaho, following Shot Easy of the Tumbler-Snapper Series.[25] Our estimate from the gummed-film data is 0.06 $\mu Ci(I\text{-}131)/m^2$. The actual measurements of I-131 on plants within the fallout pattern gave values that ranged from 0.02 to 0.14 $\mu Ci(I\text{-}131)/m^2$. The mean for their 11 samples within this area is 0.054. Obviously, this close agreement is fortuitous. Pocatello could have been outside the fallout area or on the hotline and given the value of 0.14. These data do serve to illustrate what the range might be in any one case. In the average case, it is possible that the agreement is this close.

Another estimate of the possible error can be made by considering the Sr-90 data. In Fig. 3, the gummed-film estimate of Sr-90 deposition is plotted against the value determined by radiochemical analysis of soil. All the gummed-film data are corrected by the 1.6 collection-efficiency factor. The solid line represents a 1:1 correspondence. As the figure indicates, this set of points would be best fit by the two dashed regression lines drawn on the figure. The basis for this is explained below.

For those points that lie above the 1:1 correspondence line, the major source of the error is improper dating of debris. In converting the gross beta to Sr-90, it was always assumed that the measured fallout resulted from the most recent test shot. This was done even though the cloud did not pass over the collection station. Usually, the fallout recorded at a station was totally or partially from older debris (world-wide fallout) and, hence, Sr-90 represented a larger fraction of the total beta assumed. Consequently, the Sr-90 estimates were too low, as is indicated on the figure.

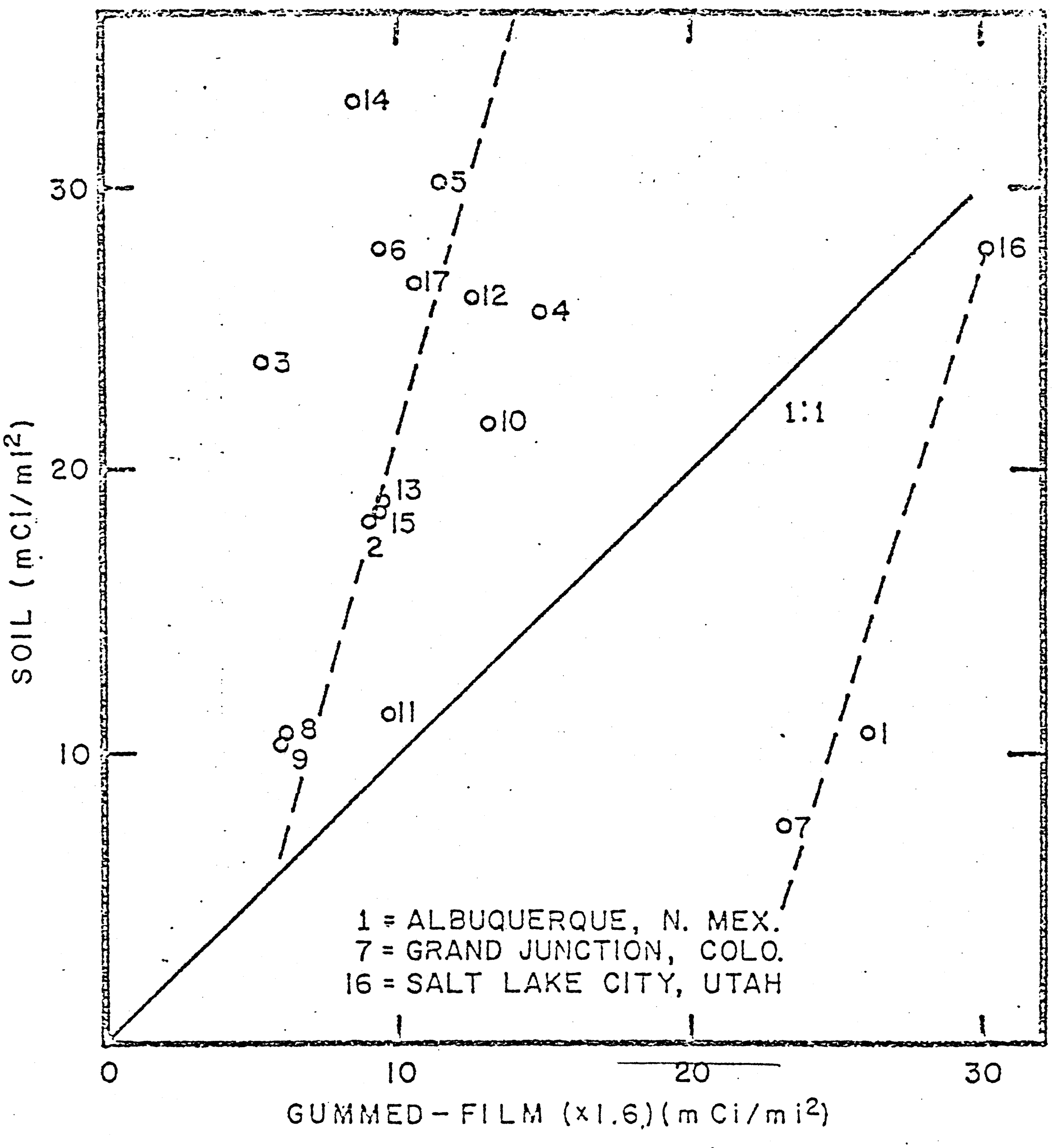


Fig. 3. Sr-90 deposition estimated from gummed-film data vs Sr-90 deposition determined by analysis of soil (from Ref. 8). The solid line represents a 1:1 correspondence; the broken lines are suggested regression lines.

This source of error would not affect the I-131 estimates, since only excessively high fallout levels occurring in the first few days after a test shot are considered. In addition, these high fallout levels were always associated with debris cloud trajectories.

The three points below the line are for Salt Lake City, Utah, Grand Junction, Colo., and Albuquerque, N. Mex. These stations received the major fraction of their total fallout during this period as fresh tropospheric debris from the Nevada Test Site. There are two sources for the error in these estimates: 1) Overestimation of the dry fallout by use of the 1.6 collection-efficiency factor that applies to rainout, and 2) overestimation of the Sr-90 due to fractionation. Again, neither of these factors would be a source of error in the I-131 estimates in this report.

There are other sources of error between the gummed-film and soil measurements. For example, the soil analysis for Grand Junction is suspected of being low by a factor of 2.[9] Thus, these data suggest that the I-131 estimates based upon the gummed-film will be in error by less than a factor of 2. Furthermore, since each isodose contour in Fig. 1 encloses several contiguous stations that show similar estimates, we are led to the conclusion that the estimate of I-131 on forage within each isodose contour was within a factor of 2 of the actual value. The data also indicate that this factor of 2 applies to the estimate of I-131 on forage in the Virgin River Valley.

However, there is an alternative interpretation of the particle retention data which suggests that the retention factor applied to particles with Stokes' diameters in the range of 20 to 30 $\mu$ might be too large. This alternative interpretation is discussed in Appendix B. However, the available data are not sufficient to justify changing the estimates in this report. They do, however, suggest that the retention factors used in these analyses tend to maximize the estimate of I-131 on forage.

## Estimate of the Concentration in Cow Milk

The estimation of the concentration of I-131 in cow milk involves three factors: 1) The amount of fallout I-131 ingested by the cow per day, 2) the half-life of I-131 on the forage, and 3) the fraction of the daily dosage secreted in cow milk. The latter factor includes the biological availability of fallout iodine.

### Conversion to $\mu$Ci/Cow-Day

It has been shown in a previous report from this Laboratory[26] that a reasonable estimate of the actual area producing forage consumed by a cow on pasture in one day is 45 $m^2$. When cows are fed by green-chop methods, this utilized area factor is reduced to 30 $m^2$/day because of better pasture management and higher yields of forage per acre. In the subsequent analysis, the figure 45 $m^2$/cow-day will be used. This, of course, will be an overestimation in areas where green-chop feeding is used. When stored feed is employed, substantially less I-131 reaches the milk. In many areas, dairy herds may be on stored feed well into the spring months. This has not been taken into account, except in Albany, N. Y., in the estimates shown in Fig. 1.

The dose ingested by the cow on the first day of contamination is

$$I_0 = \left[\frac{45\ m^2}{cow\text{-}day}\right]\left[\frac{\mu Ci(I\text{-}131)\ on\ forage}{m^2}\right].$$

The I-131 on forage is given by the relationships on page 12.

## Half-Life on Forage

The subject of the half-life of radionuclides on plants has been reviewed in a previous report from this Laboratory.[16] It was shown that the average half-life for I-131 is about 5 days, with a range of 4-6 days. A half-life of 5 days is used in this analysis.

## Concentration in Cow Milk

Another report from this Laboratory reviews the secretion of iodine in cow milk.[27] It demonstrates that, for the average case, the I-131 concentration in cow milk is given by:

$$C_M = (0.01)\ (0.8)\ I_0\ (e^{-0.139t} - e^{-0.346t})$$

where

- $C_M$ = concentration in $\mu Ci/1$,
- $I_0$ = $\mu Ci(I\text{-}131)$/cow-day on the first day of contamination,
- 0.139 = rate corresponding to the 5 day half-life on plants,
- 0.346 = rate corresponding to the 2 day half-life observed for I-131 in the blood and milk,
- 0.01 = fraction of the daily ingested dosage secreted per liter of milk,
- 0.8 = biological availability of fallout I-131,

and

- t = time in days post contamination.

The biological availability of fallout iodine was determined by using fallout material from a tower shot in the Buffalo Series of tests conducted by the British.[28]

## Estimate of Infant Thyroid Dosage

The estimation of infant thyroid dosage will depend upon four factors: 1) The daily intake of I-131, 2) the fraction of the intake incorporated in the thyroid gland, 3) the half-life of I-131 in the thyroid, and 4) the weight of the thyroid gland. For this report, the intake of I-131 is assumed to result solely from milk and the infant or child is usually assumed to consume 1 liter of milk per day. This estimate has been used in these analyses. Quite likely, most infants that are bottle-fed would be receiving canned milk in their formula rather than fresh cow milk. Hence, it may be more reasonable to apply these estimates to children that are 1 year old or older.

Reasonable estimates of the other factors are:

1) 30% uptake by the thyroid gland of the daily ingested I-131,
2) 7.5 days for the half-life in the gland, and
3) 2 grams for the weight of the gland for children from 1-5 years old.

These are the assumptions that have usually been applied to human thyroid dosage calculations, and a review of this subject by a member of this Laboratory indicates that they are in substantial agreement with experimental evidence.[29]

By using these assumptions, the total I-131 in the gland ($C_T$) at any time can be given by integration of the following equation:

$$\frac{dC_T}{dt} = 0.3\ C_M - 0.092\ C_T.$$

Substituting for $C_M$ and integration yields

$$C_T = (0.275)\ I_0\ (-0.254e^{-0.139t} + 0.047e^{-0.346t} + 0.207e^{-0.092t}).$$

The total integrated concentration in the gland ($\mu$Ci-days) is given by the area under the curve for the above equation from $t = 0$ to $t = \infty$.
This leads to

$$0.16\ I_0 = \frac{\mu\text{Ci-days}}{\text{thyroid}}.$$

This can be converted to dosage to a 2 gram thyroid using the relationship

$$10\ \text{rad} = \frac{1\ \mu\text{Ci-day}}{\text{g}},$$

and substituting for $I_0$,

$$D = 30\ I_p$$

where

$D$ = dosage in rad.

Using the relationships on page 12 for I-131 on forage, the dosage may be derived from the gummed-film data of Tables IIA and IIB:

$$D = (36)\ (F_t)\ (B_c),$$

and from the gamma dose rate data of Table III:

$$D = (3.0)\ (G).$$

## DOSAGE ESTIMATES

### Gummed-Film Network

Table IV presents the dosage calculations for a group of selected sampling sites. The table is arranged according to decreasing dosage. These estimates were used to draw the isodose lines in Fig. 1. The table gives the dosage estimate at each location for each shot that deposited fallout at that location. The total dosage estimated for each station is shown on the map in Fig. 4.

These dosage estimates apply only to milksheds where the cows are receiving fresh forage. When the cows are on stored feed, the contamination of milk with fresh fallout material would be substantially lower. This was taken into account in these estimates only at Albany, N. Y., following Shot Simon of the Upshot-Knothole Series. This fallout occurred on April 26, 1953, and as noted in Table IV could have led to an estimated dosage of about 60 rad. However, J. H. Lade of the New York State Department of Health states that the average date of first pasturing in this area is not until May 12.[30] The concentration of iodine on forage on May 12 would be reduced by a factor of 10. Accordingly, we have simply included the Albany area with the 15-rad isodose curve.

The dosage estimate for the Salt Lake City milkshed following Shot Easy of the Tumbler-Snapper Series is also a special case. The fallout occurred early and in two phases; prior to H + 6 hr it occurred as dry fallout, and from H + 6 to H + 12 it occurred in rain. Since fallout was occurring at H + 6 hr, the particle size of the dry fallout would be estimated to be large and hence plant retention to be low. Once the rain began, the smaller-size particles would be washed from the atmosphere and hence form a larger fraction of the total fallout. Accordingly, for the early dry fallout, as in St. George, we set $F_r = 0.1$. For the later fallout with rain, $F_r$ was set equal to 0.3 to account for the increase in the smaller particle sizes.

### Virgin River Valley Area

The dosage in the Virgin River Valley area was estimated by assuming that the entire milkshed received an average 24 hr gamma dose rate of 40 mr/hr. Table III indicates that this is a reasonable estimate for the composite of the various shots. Shots Annie and Harry contaminated the Utah area and Shot Simon contaminated the Nevada area.

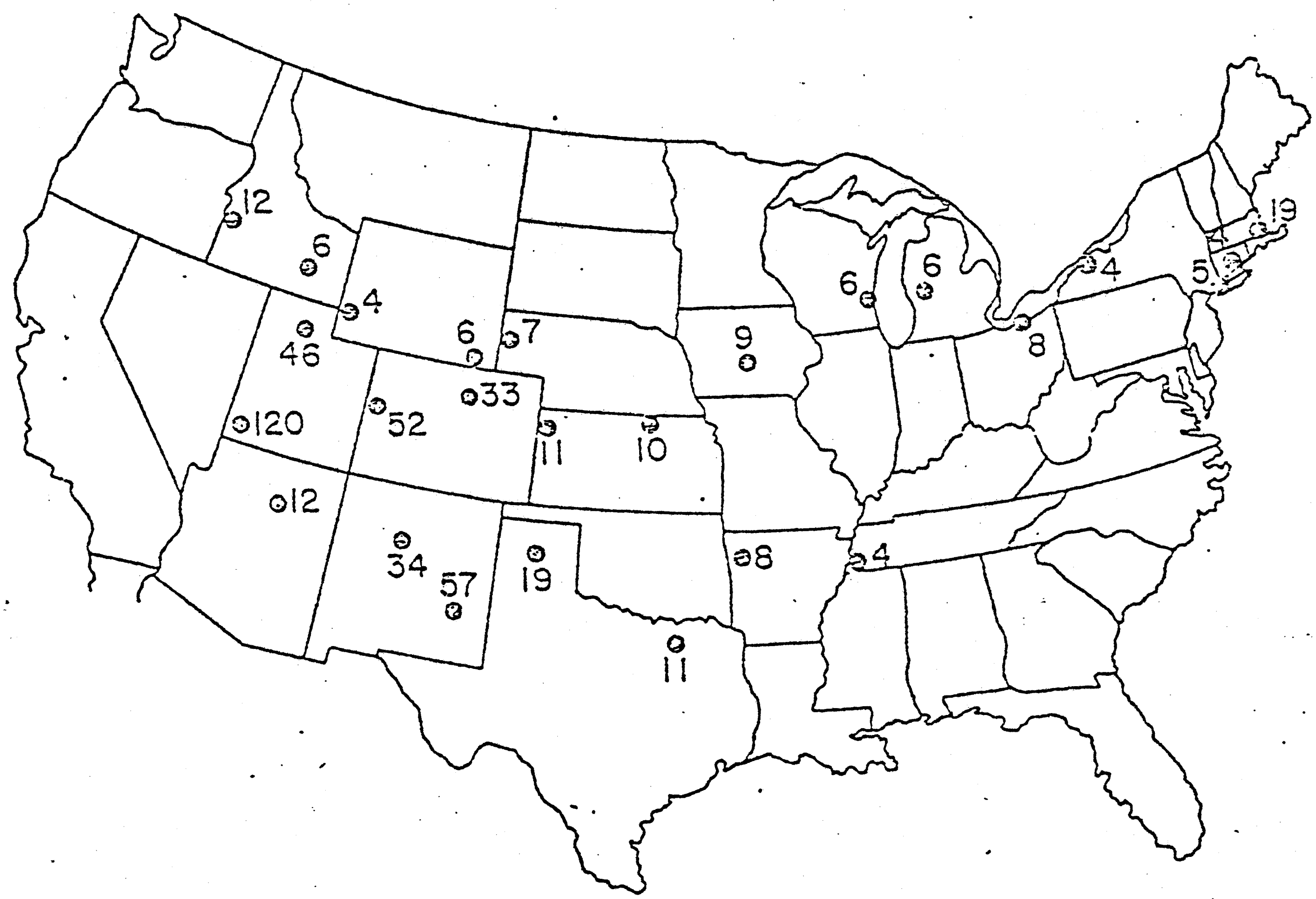


Fig. 4. Infant thyroid dosages (rad) resulting from nuclear devices testing at the Nevada Test Site during the years 1952 through 1955, estimated for various locations throughout the United States.

## Overall Error in the Estimate of Thyroid Dosage

As was previously shown, the gummed-film estimate of I-131 on forage has a probable error of less than a factor of 2. During the Teapot Series, Van Middlesworth measured the I-131 of human and cattle thyroids in Memphis, Tenn.[31] His data demonstrated peaks in the I-131 concentration corresponding to the Apple I and Zucchini shots, which are in concurrence with the gummed-film data. The human thyroid data, which we assumed were mainly adults, show that some of the adults (the ones with the highest I-131 concentrations) received a thyroid dosage of 0.2 rad during this period. This translates to a 2 rad dosage to infant thyroids. Our estimate in Table IV is 6.5 rad or a factor of 3 higher. If we assume that the highest concentrations found in these data apply to adults drinking 1 liter of milk per day, the factor of 3 difference bears some significance to the possible error in our estimate.

A balance study of I-131 was conducted in the St. Louis area in June and July, 1962.[32] In this study, the mean milk intake of the ten children involved was only 0.4 liter/day. This would suggest that while a sizeable fraction of children may consume 1 liter/day, the average child may consume only one-half as much. Consequently, the most probable range on the estimates of Table IV and Fig. 1 are from 0.25 to 2 times the recorded dosage. Thyroid burdens were also measured in this study. The measured burdens were, on the average, only one-half the calculated burdens. This suggests a lower percentage uptake or more rapid turnover than used in our estimates. However, the measured burdens were at the limit of detectability of the method. Hence, until more definitive data are available there is no strong justification for changing the estimates.

We have found no unequivocal data on milk or thyroids to compare with the estimate in the Virgin River Valley. However, the low value for $F_r$ is based upon three independent lines of evidence that are consistent. The error in this estimate has the same range as the gummed-film. The dosage thus falls in the range of 30-240 rad, with a best estimate of 120 rad.

# COMPARISON WITH OTHER ESTIMATES

The Greater St. Louis Committee for Nuclear Information, Harold Knapp, and Charles Mays made estimates of the infant thyroid dosages from these series of tests in the 1962 Joint Committee on Atomic Energy Hearings.

## Greater St. Louis Committee Estimates[7]

The Committee used two approaches to estimate the milk concentration: 1) Garner's estimate which is based upon experimental data;[33] and 2) a modification of Booker's estimate which is based upon empirical data following the Windscale accident.[34]

Garner's Estimate

Garner's estimate is similar to the one used in this paper except that $F_f$ and $F_r$ are set equal to unity and the half-life of I-131 on forage is assumed to be equal to the physical half-life of eight days. Actually, he assumes that only 25% of the fallout is retained on "edible" forage; but he then assumes that a cow utilizes 180 $m^2$/day. Since we assume 45 $m^2$/cow-day, the results are equivalent. His 25% retention is actually a correction for poor pasture utilization. Thus, estimates of dosage using this approach are too high since the half-life on plants is less than 8 days and, in many ~~cases, the~~ $F_r$ is considerably less than unity.

Booker's Estimate

Booker's estimate of the concentration of I-131 in cow milk is based upon empirical ratios obtained after the Windscale accident. He found that, on the average, the ratio between forage contamination and milk concentration was

$$10 = \frac{\mu Ci\,(I\text{-}131)\text{ on forage}/m^2}{\mu Ci\,(I\text{-}131)/l} .$$

This ratio had a range from 2 to 35. The approach used in this report gives a value of 3 for this ratio. A value of 3.3 is found for this ratio in studies conducted in the St. Louis milkshed on pasture of slightly higher yield than assumed in this report.[35] The higher value for this ratio and hence lower levels found in milk following the Windscale accident are probably attributable to the time of the year. That is, at the time of the accident, mid-October, the forage was dying back and the cows were being transferred to stored feed. Thus, the Windscale data are illustrative of the extent to which season and stored feed can modify the milk levels.

In addition, a plant retention of 0.4 was derived from the Windscale data. This compares to the values used in this report of 1.2 for the gummed-film data, and 0.10 used in the Virgin River Valley area. This retention factor was determined from soil and plant measurements made 17 days after the original contamination. It is an estimate of the original ratio of I-131 on plants to I-131 on plants plus soil. The retention factor used in this report is the ratio of I-131 on plants to I-131 on the gummed-film. In addition, the I-131 in the Windscale incident was a gaseous release from a reactor, as opposed to I-131 on fallout particles. Thus, there is no real basis for comparing these factors; they are measurements of different relationships.

Thus, in the Committee's approach based upon Booker's data, the dosage would be underestimated in the gummed-film network by a factor of 3 since the forage-to-milk ratio of 10 would appear to be too large. Furthermore, depending upon the actual forage retention factor, their estimate could be low by a factor of 9. In the Virgin River Valley area their approach overestimates the retention by a factor of 4 and underestimates the forage-to-milk ratio by a factor of 3; this re... in an overestimate of a factor of 4/3, or 1.33.

## Knapp's Estimate[36]

Knapp determined the ratio of the maximum concentration of I-131 in milk to the total I-131 in fallout at Alamo and Caliente, Nev., following the Small Boy Shot of July, 1962. He then used this to estimate milk concentration and thyroid dosage. He determined the I-131 in the total fallout from the 24-hr gamma dose rate by using the same conversion factor as is used in this report. The milk I-131 levels were determined by gamma spectrometry. The following values were found:

| | $\frac{\mu Ci\,(I\text{-}131)/m^2\ (at\ H + 24\ hr)}{\mu Ci\,(I\text{-}131)\ maximum/l}$ | |
|---|---|---|
| Location | Range | Best estimate |
| Alamo | 14-40 | 30 |
| Caliente | 3-14 | 8 |

By maximum is meant the concentration at the time when the activity reaches its maximum concentration in milk, some 3-5 days after forage contamination. The approach used in this report would give a value for this ratio of 10 in the gummed-film stations and 100 in the Virgin River Valley. Knapp's estimate of the total fallout is based upon gamma dose rate in the range of 0.1 mr/hr. In this range the measurement error is quite large and could account for the observed differences between Alamo and Caliente. The calculated particle sizes (Stokes' diameter), 30-60 $\mu$, suggest that the retention might have been lower than in the gummed-film stations. The mean of the two best estimates of the ratio is a factor of 2 greater than that for the gummed-film data. Thus, these data are not inconsistent with the analysis used in this report.

## Mays' Estimate[37]

This estimate is based upon a correlation of air beta concentration and milk concentration in Utah following the July, 1962, tests at the Nevada Test Site. In so doing, Mays arrives at an estimate of the dosage in St. George of 68 rad following the Upshot-Knothole Series. This compares favorably with our estimate of 120 rad.

It was shown earlier in this report that air samplers collect only that fallout which is retained by plants and do not collect or measure the large fallout particles that are poorly retained by plants. Therefore, the air sampler data should be expected to show a correlation with milk concentration. At the same time, his agreement with our estimate at St. George is fortuitous since the correlation between air concentration and milk concentration should depend on the particle size of the airborne material. If this correlation were developed when the mean particle diameter was 20 $\mu$, it would overestimate the milk levels by a factor of 10 when the mean diameter was 5 $\mu$. This would result, since the deposition velocity of a 20 $\mu$ particle is a factor of 10 higher than that for a 5 $\mu$ particle. The mean particle diameter of the air sampler material at St. George was about 20 $\mu$; this would suggest that Mays' correlation is appropriate for this size range. He indicates in a letter on page 1111 of the 1963 Hearings that his estimates for the Salt Lake City milkshed in 1957 and 1958 were a factor of 7 higher than the measured levels. This difference could be anticipated if the mean particle diameter of the airborne material were 5 $\mu$ during this period.

## DOSAGE FROM I-133

The corresponding equation for the concentration of I-133 in milk is

$$C_M = (0.01)\, I_0 \,(e^{-0.841t} - e^{-1.14t}) .$$

The half-life in the thyroid gland is essentially the radiological half-life of 21 hr and 1 $\mu$Ci-day(I-133) $\cong$ 20 rad. These factors lead to the relationship

$$0.5 \text{ rad} = 1\ \mu\text{Ci(I-133) on forage}/\text{m}^2 .$$

This compares with 30 rad for I-131. At 24 hr, the activity ratio (I-133/I-131) is approximately 7. Thus, in the worst case I-133 would contribute only 1/10 the dosage of I-131. This would be some 12 rad in the St. George, Utah, area.

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Table I. Tabulation of test-shot information.[38]

| | Name | Date (GCT) | Time (GCT) | Height of burst (ft) | Type of burst | Mean sea level (ft) Cloud top | Cloud base | Tropo-pause | Yield (kt) |
|---|---|---|---|---|---|---|---|---|---|
| TUMBLER-SNAPPER | | | | | | | | | |
| 1 | Able | 1/4/52 | 1700 | 793 | Air | 16,000 | | 42,000 | 1 |
| 2 | Baker | 15/4/52 | 1730 | 1,050 | Air | 16,000 | 10,000 | 38,000 | 1 |
| 3 | Charlie | 22/4/52 | 1730 | 3,447 | Air | 42,000 | 31,000 | 38,000 | 31 |
| 4 | Dog | 1/5/52 | 1630 | 1,040 | Air | 42,000 | 28,000 | 38,000 | 19 |
| 5 | Easy | 7/5/52 | 1215 | 300 | Tower | 34,000 | | 41,000 | 12 |
| 6 | Fox | 25/5/52 | 1200 | 300 | Tower | 41,000 | | 37,000 | 11 |
| 7 | George | 1/6/52 | 1155 | 300 | Tower | 37,000 | | 37,000 | 15 |
| 8 | How | 5/6/52 | 1155 | 300 | Tower | 41,000 | | 40,000 | 14 |
| UPSHOT-KNOTHOLE | | | | | | | | | |
| 1 | Annie | 17/3/53 | 1320 | 300 | Tower | 41,000 | 28,000 | 36,000 | 16 |
| 2 | Nancy | 24/3/53 | 1310 | 300 | Tower | 42,000 | 26,000 | 40,000 | 24 |
| 3 | Ruth | 31/3/53 | 1300 | 300 | Tower | 14,000 | 11,000 | 36,000 | 0.2 |
| 4 | Dixie | 6/4/53 | 1530 | 6,020 | Air | 43,000 | 33,000 | 36,000 | 11 |
| 5 | Ray | 11/4/53 | 1245 | 100 | Tower | 13,000 | 8,000 | 38,000 | 0.2 |
| 6 | Badger | 18/4/53 | 1235 | 300 | Tower | 35,000 | 23,000 | 39,000 | 23 |
| 7 | Simon | 25/4/53 | 1230 | 300 | Tower | 45,000 | 31,000 | 38,000 | 43 |
| 8 | Encore | 8/5/53 | 1530 | 2,425 | Air | 41,000 | 29,000 | 39,000 | 27 |
| 9 | Harry | 19/5/53 | 1205 | 300 | Tower | 43,000 | 27,000 | 42,000 | 32 |
| 10 | Grable | 25/5/53 | 1530 | 524 | 280 mm gun | 38,000 | 23,000 | 38,000 | 15 |
| 11 | Climax | 4/6/53 | 1115 | 1,334 | Air | 43,000 | 35,000 | 49,000 | 61 |
| TEAPOT | | | | | | | | | |
| 1 | Wasp | 18/2/55 | 2000 | 762 | Air | 22,000 | 15,000 | | 1 |
| 2 | Moth | 22/2/55 | 1345 | 300 | Tower | 25,000 | 16,000 | | 2 |
| 3 | Tesla | 1/3/55 | 1330 | 300 | Tower | 30,000 | 18,000 | 38,000 | 7 |
| 4 | Turk | 7/3/55 | 1320 | 500 | Tower | 44,000 | 36,000 | 40,000 | 43 |
| 5 | Hornet | 12/3/55 | 1320 | 300 | Tower | 35,000 | 27,000 | 38,000 | 4 |
| 6 | Bee | 22/3/55 | 1305 | 500 | Tower | 40,000 | 29,000 | 37,000 | 8 |

Table I. Tabulation of test-shot information (continued).

| | | | | | | Mean sea level (ft) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Name | Date (GCT) | Time (GCT) | Height of burst (ft) | Type of burst | Cloud top | Cloud base | Tropo-pause | Yield (kt) |
| TEAPOT (Cont.) | | | | | | | | | |
| 7 | Ess | 23/3/55 | 2030 | -67 | UG | 12,000 | | 39,000 | 1 |
| 8 | Apple I | 29/3/55 | 1255 | 500 | Tower | 32,000 | 22,000 | 39,000 | 14 |
| 9 | Wasp Prime | 29/3/55 | 1800 | 740 | Air | 32,000 | | 40,000 | 3 |
| 10 | HA | 6/4/55 | 1800 | 36,620 (MSL) | Air | 55,000 | | 31,000 | 3 |
| 11 | Post | 9/4/55 | 1230 | 300 | Tower | 16,000 | 13,000 | | 2 |
| 12 | Met | 15/4/55 | 1915 | 400 | Tower | 40,000 | 31,000 | 37,000 | 22 |
| 13 | Apple II | 5/5/55 | 1210 | 500 | Tower | 43,000 | 34,000 | 41,000 | 29 |
| 14 | Zucchini | 15/5/55 | 1200 | 500 | Tower | 35,000 | 25,000 | 44,000 | 28 |

Table IIA. Gummed-film network data for Tumbler-Snapper and Upshot-Knothole series.

| Sampling station | Cloud arrival time (H + hr) | Altitude of trajectory (ft) | Dry (D) or rain (R) | $\mu Ci/m^2$ |
|---|---|---|---|---|
| **TUMBLER-SNAPPER SERIES** | | | | |
| Shot Able 1 kt 793 ft air | | | | |
| Salt Lake City, Utah | 24 | 10,000 | R | 2.3 |
| ~~Rock Springs~~, Wyo. | 30 | 10,000 | R | 0.5 |
| Scottsbluff, Nebr. | 42 | 16,000 | R | 1.8 |
| Kansas (3 stations) | 24 | 16,000 | R | 1.8 |
| Colombia, Mo. | 36 | 16,000 | R | 0.5 |
| Shot Charlie 31 kt 3500 ft air | | | | |
| Flagstaff, Ariz. | 48 | 24,000 | R | 0.9 |
| Montgomery, Ala. | 48 | 30,000 | R | 0.6 |
| Southeast Coast | 72 | 30,000 | R | 0.8 |
| Shot Easy 12 kt 300 ft tower | | | | |
| Salt Lake City, Utah | 6 | all levels | D | 16.5 |
| Salt Lake City, Utah | 6 to 12 | all levels | R | 40.0 |
| Pocatello, Idaho | 12 | all levels | R | 5.0 |
| Rock Springs, Wyo. | 12 | all levels | R | 7.5 |
| Billings, Mont. | 18 | all levels | R | 0.5 |
| Rapid City, S. Dak. | 24 | all levels | R | 5.0 |
| Scottsbluff, Nebr. | 24 | all levels | R | 2.5 |
| Shot Fox 11 kt 300 kt tower | | | | |
| Grand Junction, Colo. | 24 | all levels | R | 7.5 |
| Goodland, Kans. | 30 | all levels | R | 1.5 |
| Scottsbluff, Nebr. | 30 | 18,000 up | R | 1.8 |
| Des Moines, Iowa | 36 | 18,000 up | R | 3.0 |
| St. Cloud, Minn. | 48 | 18,000 up | R | 1.2 |
| Shot George 15 kt 300 ft tower | | | | |
| Pocatello, Idaho | 24 | 10,000 | D | 7.0 |
| Rapid City, S. Dak. | 36 | 18,000 | D | 1.3 |
| Tucson, Ariz. | 36 | ? | D | 2.5 |
| Roswell, N. Mex. | 36 | ? | D | 2.5 |
| Grand Junction, Colo. | 36 | ? | D | 1.0 |
| Concordia, Kans. | 48 | ? | D | 3.0 |
| Peoria, Ill. | 42 | 24,000 up | R | 5.0 |
| Terra Haute, Ind. | 48 | 24,000 up | R | 7.5 |
| Fort Wayne, Ind. | 48 | 24,000 up | R | 1.5 |
| Grand Rapids, Mich. | 48 | 24,000 up | R | 6.0 |
| Milwaukee, Wis. | 48 | 24,000 up | R | 5.0 |
| Toledo, Ohio | 48 | 24,000 up | R | 1.5 |
| Upper N. Y. and Pa. | 60 | 24,000 up | R | 1.5 |

Table IIA. Gummed-film network data for Tumbler-Snapper and Upshot-Knothole series (continued).

| Sampling station | Cloud arrival time (H + hr) | Altitude of trajectory (ft) | Dry (D) or rain (R) | $\mu Ci/m^2$ |
|---|---|---|---|---|
| | | Shot How 14 kt 300 ft tower | | |
| Boise, Idaho | 24 | all levels | R | 30.0 |
| Boise, Idaho | 36 | all levels | D | 2.0 |
| Pocatello, Idaho | 24 | all levels | D | 2.5 |
| Pocatello, Idaho | 36 | all levels | D | 0.6 |
| Rock Springs, Wyo. | 24 | all levels | D | 0.6 |
| Helena, Mont. | 24 | all levels | R | 20.0 |
| | | UPSHOT-KNOTHOLE SERIES | | |
| | | Shot Annie 16 kt 300 ft tower | | |
| Raton, N. Mex. | 24 | 18,000 up | D | 1.5 |
| Raton, N. Mex. | 30 | 18,000 up | D | 1.0 |
| Roswell, N. Mex. | 30 | 18,000 up | D | 0.8 |
| Dallas, Tex. | 36 | 18,000 up | D | 5.0 |
| Memphis, Tenn. | 36 | 18,000 up | D | 3.2 |
| Knoxville, Tenn. | 36 | 18,000 up | R | 8.5 |
| New York, N. Y. | 48 | 18,000 up | R | 5.0 |
| Philadelphia, Pa. | 48 | 18,000 up | R | 2.5 |
| | | Shot Nancy 24 kt 300 ft tower | | |
| Salt Lake City, Utah | 18 | 18,000 up | D | 75.0 |
| Salt Lake City, Utah | 39 | 18,000 up | D | 5.0 |
| Casper, Wyo. | 18 | 18,000 up | D | 10.0 |
| Casper, Wyo. | 30 | 18,000 up | D | 1.5 |
| Rapid City, S. Dak. | 36 | 18,000 up | D | 3.5 |
| Willstop, N. Dak. | 36 | 10,000 up | D | 5.0 |
| | | Shot Ruth 0.2 kt 300 kt tower | | |
| Phoenix, Ariz. | 18 | all levels | D | 1.5 |
| Las Vegas, Nev. | 6 | all levels | D | 1.5 |
| | | Shot Dixie 11 kt 6000 ft air | | |
| Raton, N. Mex. | 24 | ? | R | 0.5 |
| Kansas (3 stations) | 24 | ? | R | 0.5 |
| Boston, Mass. | 36 | ? | R | 25.0 |
| Providence, R. I. | 36 | ? | R | 5.0 |
| | | Shot Ray 0.2 kt 100 ft tower | | |
| Yuma, Ariz. | 24 | 10,000 | D | 2.5 |
| | | Shot Badger 23 kt 300 ft tower | | |
| Las Vegas, Nev. | 12 | all levels | D | 5.0 |
| Las Vegas, Nev. | 30 | all levels | D | 2.5 |
| Flagstaff, Ariz. | 18 | 18,000 up | D | 0.5 |
| Albuquerque, N. Mex. | 18 | 18,000 up | D | 12.5 |
| Albuquerque, N. Mex. | 36 | 18,000 up | D | 2.5 |

Table IIA. Gummed-film network data for Tumbler-Snapper and Upshot-Knothole series (continued).

| Sampling station | Cloud arrival time (H + 24 hr) | Altitude of trajectory (ft) | Dry (D) or rain (R) | $\mu Ci/m^2$ |
|---|---|---|---|---|
| | | Shot Badger (cont) | | |
| Abilene, Tex. | 24 | 18,000 up | D | 0.5 |
| Port Arthur, Tex. | 36 | 18,000 up | D | 7.5 |
| New Orleans, La. | 42 | 18,000 up | D | 3.0 |
| | | Shot Simon 43 kt 300 ft tower | | |
| Salt Lake City, Utah | 30 | 10,000 | D | 1.0 |
| Rock Springs, Wyo. | 36 | 10,000 | D | 0.5 |
| Cheyenne, Wyo. | 42 | 10,000 | D | 0.5 |
| Flagstaff, Ariz. | 18 | 18,000 up | D | 20.0 |
| Flagstaff, Ariz. | 30 | 18,000 up | D | 2.5 |
| Grand Junction, Colo. | 36 | 18,000 up | D | 15.0 |
| Grand Junction, Colo. | 56 | 18,000 up | D | 1.0 |
| Albuquerque, N. Mex. | 36 | 18,000 up | D | 15.0 |
| Roswell, N. Mex. | 18 | 18,000 up | D | 0.5 |
| Roswell, N. Mex. | 36 | 18,000 up | D | 65.0 |
| Roswell, N. Mex. | 56 | 18,000 up | D | 5.0 |
| Amarillo, Tex. | 42 | 18,000 up | D | 5.0 |
| Amarillo, Tex. | 60 | 18,000 up | D | 1.5 |
| Dallas, Tex. | 42 | 18,000 up | D | 3.0 |
| Dallas, Tex. | 60 | 18,000 up | D | 1.0 |
| Wichita, Kans. | 60 | 18,000 up | D | 2.5 |
| Concordia, Kans. | 60 | 18,000 up | D | 1.0 |
| New Orleans, La. | 60 | 18,000 up | D | 1.0 |
| Jackson, Miss. | 72 | 18,000 up | D | 1.0 |
| Memphis, Tenn. | 72 | 18,000 up | R | 1.0 |
| St. Louis, Mo. | 80 | 18,000 up | R | 0.5 |
| Milwaukee, Wis. | 80 | 18,000 up | R | 0.5 |
| Grand Rapids, Mich. | 80 | 18,000 up | R | 0.5 |
| Albany, N. Y. | 36 | 40,000 | R | 80.0 |
| New Haven, Conn. | 42 | 40,000 | R | 5.0 |
| Caribou, Maine | 56 | 40,000 | R | 1.3 |
| | | Shot Encore 27 kt 2500 ft air | | |
| Williston, N. Dak. | 24 | 30,000 | R | 5.0 |
| Billings, Mont. | 30 | 18,000 | R | 2.0 |
| | | Shot Harry 32 kt 300 ft tower | | |
| Grand Junction, Colo. | 18 | 18,000 | R | 55.0 |
| Raton, N. Mex. | 18 | 18,000 up | D | 10.0 |
| Albuquerque, N. Mex. | 18 | 18,000 up | D | 40.0 |
| Albuquerque, N. Mex. | 30 | 18,000 up | D | 2.5 |
| Roswell, N. Mex. | 18 | 18,000 up | D | 1.5 |
| Amarillo, Tex. | 18 | 18,000 up | D | 8.0 |
| Concordia, Kans. | 30 | 18,000 up | R | 5.5 |
| Wichita, Kans. | 36 | 18,000 up | R | 2.5 |
| Kansas City, Kans. | 36 | 18,000 up | R | 2.5 |
| Des Moines, Iowa | 42 | 18,000 up | R | 7.5 |
| Marquette, Mich. | 42 | 18,000 up | R | 5.0 |
| Green Bay, Wis. | 42 | 18,000 up | R | 1.8 |

Table IIA. Gummed-film network data for Tumbler-Snapper and Upshot-Knothole series (continued).

| Sampling station | Cloud arrival time (H + 24 hr) | Altitude of trajectory (ft) | Dry (D) or rain (R) | $\mu Ci/m^2$ |
|---|---|---|---|---|
| | | Shot Harry (cont) | | |
| Milwaukee, Wis. | 42 | 18,000 up | R | 1.2 |
| Minneapolis, Minn. | 42 | 18,000 up | R | 2.5 |
| Pittsburg, Pa. | 56 | 18,000 up | R | 1.0 |

Table IIB. Gummed-film network d... from Operation Teapot Series.

| Sampling station | Cloud arrival time (H + hr) | Altitude of trajectory (ft) | Dry (D) or rain (R) | $\mu Ci/m^2$ |
|---|---|---|---|---|
| | Shot Wasp 1 kt 762 ft air | | | |
| Yuma, Ariz. | 24 | ? | D | 9.4 |
| | Shot Telsa 7 kt 300 ft tower | | | |
| Denver, Colo. | 30 | all levels | D | 2.9 |
| | Shot Turk 43 kt 500 ft tower | | | |
| Grand Junction, Colo. | 30 | 18,000 up | D | 10.2 |
| Denver, Colo. | 36 | 18,000 up | D | 23.6 |
| Goodland, Kans. | 48 | 18,000 up | D | 5.0 |
| Concordia, Kans. | 48 | 18,000 up | D | 1.5 |
| Scottsbluff, Nebr. | 48 | 18,000 up | D | 1.1 |
| Chicago, Ill. | 60 | 18,000 up | D | 0.6 |
| Cleveland, Ohio | 60 | 18,000 up | D | 1.7 |
| Cleveland, Ohio | 80 | 18,000 up | R | 0.4 |
| New York, N. Y. | 60 | 18,000 up | R | 1.1 |
| | Shot Hornet 4 kt 300 ft tower | | | |
| Flagstaff, Ariz. | 18 | 18,000 | D | 6.4 |
| Roswell, N. Mex. | 30 | 18,000 | D | 0.8 |
| Jackson, Miss. | 36 | 18,000 | R | 1.1 |
| Ind., Ill., Wis., Mich. | 60 | 30,000 | R | 0.5 |
| | Shot Bee 8 kt 300 ft tower | | | |
| Dallas, Tex. | 42 | 18,000 | D | 0.6 |
| | Shot Apple I 14 kt 500 ft tower and Shot Wasp Prime 3 kt 700 ft air | | | |
| Albuquerque, N. Mex. | 18 | 18,000 up | D | 1.2 |
| Albuquerque, N. Mex. | 30 | 18,000 up | D | 0.3 |
| Roswell, N. Mex. | 18 | 18,000 up | D | 1.4 |
| Roswell, N. Mex. | 30 | 18,000 up | D | 0.8 |
| Amarillo, Tex. | 36 | 18,000 up | D | 2.3 |
| Las Vegas, Nev. | 30 | ? | D | 3.2 |
| Grand Junction, Colo. | 30 | 18,000 up | R | 0.8 |
| Pocatello, Idaho | 18 | 10,000 | R | 5.8 |
| | Shot Post 2 kt 300 ft tower | | | |
| Salt Lake City, Utah | 12 | 10,000 | R | 5.3 |
| Casper, Wyo. | 18 | 10,000 | R | 1.6 |
| Grand Junction, Colo. | 18 | 14,000 | R | 2.3 |

Table IIIB. Gummed-film network data from Operation Teapot Series (continued).

| Sampling station | Cloud arrival time (H + hr) | Altitude of trajectory (ft) | Dry (D) or rain (R) | $\mu Ci/m^2$ |
|---|---|---|---|---|
| | Shot Met 22 kt 400 ft tower | | | |
| Grand Junction, Colo. | 24 | all levels | D | 11.2 |
| Grand Junction, Colo. | 48 | all levels | D | 2.9 |
| Grand Junction, Colo. | 72 | all levels | R | 0.8 |
| Grand Junction, Colo. | 96 | all levels | R | 0.6 |
| Denver, Colo. | 24 | all levels | D | 15.5 |
| Denver, Colo. | 48 | all levels | D | 3.2 |
| Denver, Colo. | 72 | all levels | D | 0.4 |
| Goodland, Kans. | 30 | all levels | D | 1.3 |
| Wichita, Kans. | 36 | all levels | D | 3.8 |
| Concordia, Kans. | 36 | all levels | D | 0.9 |
| Scottsbluff, Nebr. | 30 | all levels | R | 2.0 |
| Huron, S. Dak. | 60 | 10,000 | R | 0.5 |
| Fargo, N. Dak. | 60 | 10,000 | R | 0.8 |
| Detroit, Mich. | 36 | 30,000 up | R | 3.6 |
| Cleveland, Ohio | 36 | 30,000 up | R | 7.1 |
| Buffalo, N. Y. | 42 | 30,000 up | R | 2.4 |
| Buffalo, N. Y. | 60 | 30,000 up | R | 0.7 |
| Rochester, N. Y. | 60 | 30,000 up | R | 2.0 |
| New Haven, Conn. | 60 | 30,000 up | R | 0.8 |
| Boston, Mass. | 60 | 30,000 up | R | 0.7 |
| | Shot Apple II 29 ft 500 ft tower | | | |
| Salt Lake City, Utah | 18 | all levels | D | 11.8 |
| Salt Lake City, Utah | 30 | all levels | D | 4.5 |
| Cheyenne, Wyo. | 18 | all levels | D | 6.5 |
| Cheyenne, Wyo. | 48 | all levels | D | 2.1 |
| Cheyenne, Wyo. | 72 | all levels | D | 0.3 |
| Colorado Springs, Colo. | 18 | all levels | D | 0.7 |
| Colorado Springs, Colo. | 48 | all levels | D | 7.7 |
| Colorado Springs, Colo. | 72 | all levels | D | 0.6 |
| Denver, Colo. | 48 | all levels | D | 4.7 |
| Denver, Colo. | 72 | all levels | D | 0.7 |
| Pueblo, Colo. | 48 | all levels | D | 5.2 |
| Pueblo, Colo. | 72 | all levels | D | 0.3 |
| Goodland, Kans. | 48 | all levels | D | 4.4 |
| Goodland, Kans. | 72 | all levels | D | 0.5 |
| Goodland, Kans. | 96 | all levels | D | 0.4 |
| Green Bay, Wis. | 48 | all levels | R | 1.2 |
| Milwaukee, Wis. | 48 | all levels | R | 0.9 |
| Scottsbluff, Nebr. | 96 | all levels | R | 0.3 |
| Des Moines, Iowa | 72 | all levels | R | 0.9 |
| Des Moines, Iowa | 96 | all levels | R | 0.4 |
| St. Louis, Mo. | 72 | all levels | R | 1.3 |
| Louisville, Ky. | 72 | all levels | R | 1.3 |
| Chicago, Ill. | 72 | all levels | R | 0.6 |
| Flagstaff, Ariz. | 24 | ? | D | 3.4 |
| Amarillo, Tex. | 48 | ? | D | 2.3 |
| Amarillo, Tex. | 72 | ? | D | 1.5 |
| Dallas, Tex. | 72 | ? | R | 1.7 |
| Dallas, Tex. | 96 | ? | R | 0.3 |
| Fort Smith, Ark. | 72 | ? | R | 2.7 |
| New Orleans, La. | 72 | ? | D | 0.9 |

Table III. Off-site radiological safety data.

| Sampling station | mr/hr at 24 hr |
|---|---|
| UPSHOT-KNOTHOLE SERIES | |
| Shot Annie | |
| St. George, Utah | 5.0 |
| 1 mile N. of St. George | 18.0 |
| 4 miles N. of St. George | 16.0 |
| Hurricane, Utah | 6.0 |
| Shot Simon | |
| Glendale Junction, Nev. | 0.2 |
| 11 miles N. of Glendale Junction | 4.0 |
| 13 miles N. of Glendale Junction | 16.0 |
| 17 miles N. of Glendale Junction | 40.0 |
| 19 miles N. of Glendale Junction | 60.0 |
| 23 miles N. of Glendale Junction | 40.0 |
| 30 miles N. of Glendale Junction | 3.0 |
| Bunkerville, Nev. | 40.0 |
| Mesquite, Nev. | 14.0 |
| 24 miles W. of Mesquite | 115.0 |
| Shot Harry | |
| Bunkerville, Nev. | 1.5 |
| Mesquite, Nev. | 3.2 |
| St. George, Utah | 26.0 |
| Hurricane, Utah | 30.0 |
| Veyo, Utah | 22.0 |
| Washington, Utah | 13.0 |
| TEAPOT SERIES | |
| Shot Telsa | |
| St. George, Utah | 1.8 |
| Hurricane, Utah | 0.8 |
| Shot Zucchini | |
| Glendale Junction, Nev. | 4.0 |
| Mesquite, Nev. | 1.3 |
| St. George, Utah | 1.2 |

Table IV. Dose calculation for selected sampling stations.

| Shot | | Dosage (rads) |
|---|---|---|
| SALT LAKE CITY, UTAH | | |
| Tumbler-Snapper Series | | |
| Able | | 0.8 |
| Easy† | ( 6.0) | 0.6 |
| Easy† | (14.3) | 4.3 |
| Upshot-Knothole Series | | |
| Nancy | | 27.0 |
| Nancy | | 3.6 |
| Simon | | 0.7 |
| Teapot Series | | |
| Post | | 1.9 |
| Apple II | | 4.2 |
| Apple II | | 3.2 |
| Total | (61.7) | 46.3 |
| ALBANY, N. Y.‡ | | |
| Upshot-Knothole Series | | |
| Simon | (57.6) | 15.0 |
| Total | (57.6) | 15.0 |
| ROSWELL, N. MEX. | | |
| Tumbler-Snapper Series | | |
| George | | 1.8 |
| Upshot-Knothole Series | | |
| Annie | | 0.7 |
| Simon | | 0.4 |
| Simon | | 46.8 |
| Simon | | 5.4 |
| Harry | | 0.7 |
| Teapot Series | | |
| Hornet | | 0.6 |
| Apple I | | 0.5 |
| Apple I | | 0.5 |
| Zucchini | | 1.3 |
| Total | | 56.9 |

Table IV. Dose calculation for selected sampling stations (continued).

| Shot | Dosage (rads) |
|---|---|
| GRAND JUNCTION, COLO. | |
| Tumbler-Snapper Series | |
| Fox | 2.9 |
| George | 0.7 |
| Upshot-Knothole Series | |
| Simon | 10.8 |
| Simon | 1.1 |
| Harry | 19.8 |
| Teapot Series | |
| Turk | 7.3 |
| Apple I | 0.3 |
| Post | 0.8 |
| Met | 4.0 |
| Met | 2.0 |
| Met | 0.9 |
| Met | 0.9 |
| Total | 51.5 |
| ALBUQUERQUE, N. MEX. | |
| Upshot-Knothole Series | |
| Badger | 4.7 |
| Badger | 1.8 |
| Simon | 10.8 |
| Harry | 14.4 |
| Harry | 1.8 |
| Teapot Series | |
| Apple I | 0.4 |
| Apple I | 0.2 |
| Total | 34.1 |
| DENVER, COLO. | |
| Teapot Series | |
| Telsa | 2.1 |
| Turk | 17.0 |
| Met | 5.6 |
| Met | 2.3 |
| Met | 0.4 |
| Apple II | 3.4 |
| Apple II | 0.8 |
| Zucchini | 0.4 |
| Zucchini | |
| | 0.9 |
| Total | 32.9 |

Table IV. Dose calculation for selected sampling stations (continued).

| Shot | Dosage (rads) |
|---|---|
| AMARILLO, TEX. | |
| Upshot-Knothole Series | |
| Simon | 3.6 |
| Simon | 1.8 |
| Harry | 2.9 |
| Teapot Series | |
| Apple I | 1.7 |
| Apple II | 2.0 |
| Apple II | 1.6 |
| Zucchini | 4.8 |
| Zucchini | 0.9 |
| Total | 19.3 |
| BOSTON, MASS. | |
| Upshot-Knothole Series | |
| Dixie | 18.0 |
| Teapot Series | |
| Met | 0.8 |
| Total | 18.8 |
| FLAGSTAFF, ARIZ. | |
| Tumbler-Snapper Series | |
| Charlie | 0.7 |
| Upshot-Knothole Series | |
| Badger | 0.4 |
| Simon | 7.2 |
| Simon | 1.8 |
| Teapot Series | |
| Hornet | 2.3 |
| Total | 12.4 |
| BOISE, IDAHO | |
| Tumbler-Snapper Series | |
| How | 10.8 |
| How | 1.4 |
| Total | 12.2 |

Table IV. Dose calculation for selected sampling stations (continued).

| Shot | Dosage (rads) |
|---|---|
| DALLAS, TEX. | |
| Upshot-Knothole Series | |
| Annie | 3.6 |
| Simon | 2.2 |
| Simon | 1.1 |
| Teapot Series | |
| Bee | 0.4 |
| Apple II | 1.8 |
| Apple II | 0.4 |
| Zucchini | 1.6 |
| Total | 11.1 |
| GOODLAND, KANS. | |
| Tumbler-Snapper Series | |
| Able | 0.7 |
| Fox | 1.1 |
| Upshot-Knothole Series | |
| Dixie | 0.4 |
| Teapot Series | |
| Turk | 3.6 |
| Met | 0.9 |
| Apple II | 3.2 |
| Apple II | 0.5 |
| Apple II | 0.6 |
| Total | 11.0 |
| CONCORDIA, KANS. | |
| Tumbler-Snapper Series | |
| Able | 0.7 |
| George | 2.2 |

Table IV. Dose calculation for selected sampling stations (continued).

| Shot | Dosage (rads) |
|---|---|
| CONCORDIA, KANS. (continued) | |
| Upshot-Knothole Series | |
| Dixie | 0.4 |
| Simon | 1.1 |
| Harry | 4.0 |
| Teapot Series | |
| Turk | 1.1 |
| Met | 0.6 |
| Total | 10.1 |
| DES MOINES, IOWA | |
| Tumbler-Snapper Series | |
| Fox | 2.2 |
| Upshot-Knothole Series | |
| Harry | 5.4 |
| Teapot Series | |
| Apple II | 1.0 |
| Apple II | 0.6 |
| Total | 9.2 |
| FORT SMITH, ARK. | |
| Teapot Series | |
| Apple II | 2.9 |
| Zucchini | 2.0 |
| Zucchini | 3.5 |
| Total | 8.4 |
| CLEVELAND, OHIO | |
| Teapot Series | |
| Turk | 1.9 |
| Turk | 0.6 |
| Met | 5.1 |
| Total | 7.6 |

Table IV. Dose calculation for selected sampling stations (continued).

| Shot | Dosage (rads) |
|---|---|
| SCOTTSBLUFF, NEBR. | |
| Tumbler-Snapper Series | |
| Able | 1.4 |
| Easy | 1.1 |
| Fox | 1.4 |
| Teapot Series | |
| Turk | 0.8 |
| Met | 1.4 |
| Apple II | 1.2 |
| Total | 7.3 |
| CHEYENNE, WYO. | |
| Upshot-Knothole Series | |
| Simon | 0.4 |
| Teapot Series | |
| Apple II | 2.3 |
| Apple II | 1.5 |
| Apple II | 0.3 |
| Zucchini | 1.2 |
| Zucchini | 0.5 |
| Total | 6.2 |
| MILWAUKEE, WIS. | |
| Tumbler-Snapper Series | |
| George | 3.6 |
| Upshot-Knothole Series | |
| Simon | 0.7 |
| Harry | 0.7 |
| Teapot Series | |
| Hornet | 0.5 |
| Apple II | 0.6 |
| Total | 6.1 |

Table IV. Dose calculation for selected sampling stations (continued).

| Shot | Dosage (rads) |
|---|---|
| POCATELLO, IDAHO | |
| Tumbler-Snapper Series | |
| Easy | 1.8 |
| George | 2.5 |
| How | 1.1 |
| How | 0.4 |
| Total | 5.8 |
| GRAND RAPIDS, MICH. | |
| Tumbler-Snapper Series | |
| George | 4.3 |
| Upshot-Knothole Series | |
| Simon | 0.7 |
| Teapot Series | |
| Hornet | 0.5 |
| Total | 5.5 |
| NEW YORK, N. Y. | |
| Upshot-Knothole Series | |
| Annie | 3.6 |
| Teapot Series | |
| Turk | 1.2 |
| Total | 4.8 |
| NEW HAVEN, CONN. | |
| Upshot-Knothole Series | |
| Simon | 3.6 |
| Teapot Series | |
| Met | 0.8 |
| Total | 4.4 |

Table IV. Dose calculation for selected sampling stations (continued).

| Shot | Dosage (rads) |
|---|---|
| MEMPHIS, TENN. | |
| Upshot-Knothole Series | |
| Annie | 2.2 |
| Simon | 1.1 |
| Teapot Series | |
| Zucchini | 0.9 |
| Total | 4.2 |
| ROCK SPRINGS, WYO. | |
| Tumbler-Snapper Series | |
| Able | 0.4 |
| Easy | 2.9 |
| How | 0.4 |
| Upshot-Knothole Series | |
| Simon | 0.4 |
| Total | 4.1 |
| ROCHESTER, N. Y. | |
| Tumbler-Snapper Series | |
| George | 1.8 |
| Teapot Series | |
| Met | 2.2 |
| Total | 4.0 |

†See page 17 of text.
‡See page 17 of text.

# APPENDIX

## COMPARISON OF THE THYROID DOSAGE V THE COW MILK ROUTE WITH THAT FROM INHALATION OR DIRECT INGESTION OF CONTAMINATED FOODS

It is generally conceded that the most hazardous route of entry of I-131 to man is through the plant — cow milk food chain. The basis for this is that when other ~~sources~~ of I-131 intake are below acceptable limits, the I-131 content of milk can be well above tolerance and lead to unacceptable dosages to persons consuming 1 liter of milk per day. Following the Windscale accident in Great Britain, it was determined that the only hazard from I-131 was via cow milk.[A1] It is the purpose of Appendix A to indicate the magnitude of the possible dosage from sources other than milk.

### Inhalation

The relationship between the potential dosage via cow milk ($D_M$) and that via inhalation ($D_R$) can be illustrated by determining the maximum of the ratio $D_R/D_M$. The maximum will occur when the particle size of the airborne debris is small (5 $\mu$ in diameter), since the deposition on forage will be at a minimum and yet all the particles are in the respirable range.

An average value for the respiratory minute volume for adults is 10 l/min, or 0.6 $m^3$/hr. Although the minute volume for children is smaller, we shall use the adult value. Furthermore, we shall assume that all of the inhaled particles are retained in the lungs. These assumptions thus maximize the estimate. Using these assumptions, the respiratory intake ($I_R$) is:

$$I_R = 0.6\ A$$

where A is the integrated I-131 concentration in air in $\mu$Ci-hr/$m^3$. If it is assumed that 30% of the inhaled I-131 goes to a 2-g thyroid, that the half-life of I-131 in the gland is 7.5 days, and that 1 $\mu$Ci-day = 10 rad (these were the assumptions used in the body of this report), then the dosage in rad from inhalation ($D_R$) is:

$$D_R = 10\ A.$$

Since the particles are assumed to be 5 $\mu$ in diameter, they have the minimum deposition velocity on forage, i.e., 18 m/hr. Thus, the concentration of I-131 on forage is:

$$I_p = 18\ A.$$

As indicated in the body of this report, the dosage in rad to a 2-g thyroid via the cow milk route ($D_M$) is:

$$D_M = 30\ I_p = 540\ A.$$

Therefore, for children drinking 1 liter of milk per day from cows on pasture, the maximum in the ratio of $D_R/D_M$ is:

$$\frac{D_R}{D_M} = \frac{10A}{540A} \approx 0.02.$$

Thus, the maximum dosage from the inhalation of I-131 would be only a few hundredths of the dosage estimate based on cow milk as given in this report.

## Direct Ingestion

The direct ingestion of contaminated leafy vegetables, such as lettuce or spinach, is another route for transferring fallout I-131 to man. Let us assume that a child would ingest, each day, the leafy material covering 1 $ft^2$ of ground. (This is a lot of spinach.) This compares with the 45 $m^2$ or 482 $ft^2$ foraged by a cow each day. Since the cow secretes 1% of the daily ingested I-131 in each liter of milk, a liter of milk contains the I-131 from the forage covering 4.8 $ft^2$ of ground. Thus, a child might be expected to obtain a thyroid dosage by direct ingestion of contaminated leafy vegetables that is less than 20% of the dosage estimates in this report.

## References

A1. Loutit, J. F., W. G. Marley, and R. S. Russell. The nuclear reactor accident at Windscale — October, 1957: Environmental aspects. Appendix H of The Hazards to Man of Nuclear and Allied Radiations. A Second Report to the Medical Research Council. London, Her Majesty's Stationery Office, 1960, pp. 129-139.

# APPENDIX B

## RELATIONSHIP BETWEEN RETENTION OF FALLOUT PARTICLES ON PLANTS AND THE HALF-RESIDENCE TIME OF PARTICLES ON PLANTS

In terms of the physical processes involved, the observed sharp cutoff in the apparent retention of particles above and below 50 μ in diameter on plants probably results from a drastic change in the half-residence time of the particles on plants. The density of plant growth in an average pasture is such that it represents essentially complete ground cover. Thus, all particles must originally fall out on the plants. Following this, the larger particles are rapidly lost from plants while the smaller particles are removed at a much slower rate. Recent measurements on plants contaminated with volcanic ash would suggest that the half-residence time of the larger particles is 1-2 hr[B1] while the earlier measurements suggest that the half-residence time for the smaller radioactive fallout particles is 14 days.[B2] The measurements of the particle sizes retained on plants, together with these measured half-residence times, indicate that the half-residence time is a rapidly changing function of particle diameter as the diameter falls below 50 μ. The data, however, are not sufficient to indicate whether the average half-residence time for 20 μ particles is 14 days, or some lower value.

Furthermore, it is also possible that even for the particles in the smaller size range, a certain fraction of those initially deposited are rapidly lost from plants with half-residence times corresponding to hours rather than 14 days. In other words, it is reasonable to assume that there is not a single half-residence time for a particular particle size class, but rather the half-residence time of the remaining particles is a continuously varying function of time. This assumption is also supported by the field data.

Therefore, as Miller suggests,[B1] the range in measured plant retention of fallout particles of from 1-25% could be the result of differences in the time between deposition of the particles and sampling of the plants. The higher values could have been obtained by sampling a few hours after deposition while the lower values could have been obtained by sampling much later.

The assumption used in this report was that all particles below 5 μ (primarily below 30 μ) that are initially deposited on forage are lost from the forage with a 14-day half-residence time. The above considerations suggest that this is a maximum estimate, that the 30-μ particles may have a shorter half-residence time, and/or that a fraction of the initially deposited particles of any size may be lost at a more rapid rate. However, the evidence presently available to us is not sufficient to justify altering the dosage estimates.

References

B1. Miller, C. F. The retention by foliage of silicate particles ejected from the volcano Irazu in Costa Rica. (Research done at Stanford Research Institute, Menlo Park, Calif.) Paper presented at the Symposium on Radioecological Concentration Processes, held April 25-29, 1966, in Stockholm, Sweden.

B2. Thompson, S. E. Effective half-life of fallout radionuclides on plants with special emphasis on iodine-131. University of California Lawrence Radiation Laboratory (Livermore), UCRL-12388, 1965.

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