ture zone is well developed for a length of 850 km west of the Sierra Leone shelf.

The Guinea fracture zone has the same trend as the Vema fracture zone, has the same sense of displacement (*4*), and is the eastern analog of the Vema fracture zone and its associated fractures. The lack of evidence for continuity between the two fracture zones is due partly to the fact that more detailed surveys are required, and partly to a probable difference in response of the oceanic crust to the deforming stresses. The Barracuda Fault (*5*) (Fig. 1), east of Guadeloupe in the Antilles, is also analogous to the Guinea fracture zone. Our survey of the eastern extension of the fault (December 1963) showed that it extends eastward to at least 53° West longitude as a low, east-west, nonmagnetic range of abyssal hills which has apparently dammed the northward flow of turbidity currents, the abyssal plain to the south being shallower than the sea floor to the north of the range. The amount of horizontal displacement is unknown. The fault seems to be part of the same pattern exhibited by the Vema fracture zone with its associated troughs, and by the Guinea fracture zone, thereby indicating that a zone of deformation exists across the whole of the Atlantic Ocean. The Guinea fracture zone shows that the shear zone intersects the African continent and marks the northern limit on the African coast of a wide zone of left lateral shear whose southern limit is roughly the Equator (*3*).

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25 May 1964

## Meteorological Evaluation of the Sources of Iodine-131 in Pasteurized Milk

Abstract. *An examination of possible sources of radioiodine found in samples of milk in the midwestern states during May and early June 1962 shows that atmospheric testing at Christmas Island was the principal contributor to incidents of significant concentrations of iodine-131 in milk (exceeding 300 picocuries per liter). Underground testing at Nevada played at most only a minor role during this period. There is a cause-and-effect relationship between the penetration of thunderstorms into high concentrations of nuclear debris in the lower stratosphere and the subsequent amount of iodine-131 in milk. Analyses of samples of rainwater confirm the importance of this "scavenging" mechanism. The relative contributions of atmospheric and underground testing to the iodine-131 found in milk samples from September 1961 to December 1963 has been reviewed and only one incident in which the amount of iodine-131 exceeded 300 picocuries per liter could be attributed to an underground test.*

Several attempts have been made recently (*1–3*) to explain the increased amounts of iodine-131 that were found at certain times during 1961 and 1962 in samples of milk analyzed in laboratories of the U.S. Public Health Service Pasteurized Milk Network (*4*, pp. 82–83) and to attribute the source of the radioiodine to specific nuclear tests. A review of the radiologic and the meteorologic evidence, together with the available data concerning nuclear tests (*5*), shows that a reasonable and consistent explanation can be made for each of the observed instances of greatly increased radioiodine content in pasteurized milk (that is, more than 300 pc of $I^{131}$ per liter of milk) (*3*).

It has been postulated (*2*) that underground nuclear tests in Nevada, which were contained to the extent that no visible cloud of debris was formed at the test site, could have been the major contributors of $I^{131}$ to the milk in the Midwest in May 1962. We now report that the principal contribution to the amount of radioiodine found in midwestern milk samples was made by the atmospheric tests conducted by the United States near Christmas Island, rather than the underground tests conducted in Nevada.

Atmospheric testing of nuclear devices was halted with the end of the U.S.S.R. series in early November 1961, and was not resumed until the United States began testing in the vicinity of Christmas Island on 25 April 1962. During this hiatus in atmospheric testing, 25 underground tests and 1 cratering event were announced in Nevada. (The term "underground test," as used in this report, refers to those tests designed to have their radioactivity contained underground. Although also detonated underground, cratering detonations are not intended to completely contain the radioactivity produced.)

It is estimated that each kiloton equivalent of fission energy produces about 125,000 curies of $I^{131}$ (*6*). This radioactive isotope has a half-life of 8.1 days and, if it is deposited on pastures, feed, or in water supplies, it can be expected to reach maximum concentrations in milk after a lag of 2 to 4 days (*6*). During the winter months, dairy cattle are not on pasture and would be expected to experience little exposure to fresh deposits of $I^{131}$. After about 1 March, on the average, dairy cattle south of about 37°N derive 75 percent or more of their roughage from grazing or fresh chopped green feed (*7*). Farther north, cattle go on pasture somewhat later depending on local weather conditions.

In view of these farming practices, the most significant portion of the interval between atmospheric tests is March and April. During this period, 11 underground tests and 1 cratering event were announced. Of the 11 underground tests, 3 were announced as being not fully contained, yet during this period, the concentrations of radioiodine were near or below the levels of detectability in the samples analyzed. Of 490 samples taken in the continental United States during March and April 1962, 441 showed $I^{131}$ concentrations below the threshold of detectability (10 pc/liter), 38 had values between 10 and 25 pc/liter, and none was above 45 pc/liter. Of 104 milk samples in areas south of 37°N, only four were above the level of detectability.

*Wichita incident, 13 May 1962.* An abrupt change in the $I^{131}$ concentrations became evident when a sample of pasteurized milk taken on 13 May at Wichita, Kansas, contained 670 pc of $I^{131}$ per liter of milk. Several subsequent samples at Wichita and at other midwestern locations in late May and early June also showed concentrations well in excess of 100 pc/liter.

Table 1. Concentrations of fission products in samples obtained during May 1962 by the Defense Atomic Support Agency, Project Star Dust. Half-lives: $Sr^{90}$, 28 years; $Sr^{89}$, 50 days; $Ba^{140}$, 12.8 days; $I^{131}$, 8.1 days; $Mo^{99}$, 2.8 days.

| Altitude (thousands of feet) | Latitude (°N) | Disintegrations per minute per standard cubic foot of air* | | | | | |
|---|---|---|---|---|---|---|---|
| | | Total beta concentration | $Sr^{90}$ | $Sr^{89}$ | $Ba^{140}$ | $I^{131}$ | $Mo^{99}$ |
| | | | *1 May 1962* | | | | |
| 45.1 | 31–49 | 73 | 0.23 | 3.63 | | | |
| 55.9 | 31–49 | 124 | 0.61 | 5.24 | | | |
| | | | *3 May 1962* | | | | |
| 55.0 | 19–30 | 113 | 0.45 | 4.63 | | | |
| 59.8 | 19–30 | 90 | | | | | |
| | | | *8 May 1962* | | | | |
| 41.0 | 31–49 | 36 | 0.17 | 1.68 | | | |
| 50.0 | 43–49 | 65 | 0.24 | 2.61 | | | |
| 50.0 | 38–43 | 56,100 | 7.71 | 877 | 3,100 | 5,300 | 8,350 |
| 50.8 | 31–37 | 26,900 | 2.46 | 408 | 1,320 | | 4,260 |
| 59.6 | 43–49 | 113 | 0.50 | 5.18 | | | |
| 59.7 | 37–43 | 3,200 | 0.72 | 68.0 | 156 | | |
| 59.8 | 31–37 | 4,970 | (3.75)† | (458) | (6,030) | 218 | 261 |
| | | | *10 May 1962* | | | | |
| 40.0 | 30 | 23 | 0.06 | 0.56 | 0.10 | | |
| 44.8 | 30 | 91 | 0.08 | 1.15 | 1.02 | | |
| 49.7 | 30 | 33,200 | 4.69 | 572 | 6,920 | | 2,670 |
| 54.6 | 30 | 7,770 | 1.68 | 211 | 2,000 | 278 | 245 |
| 55.9 | 30 | 9,210 | 2.19 | 244 | 2,560 | | 309 |
| 60.0 | 30 | 6,860 | 1.46 | 149 | 1,510 | 170 | |
| | | | *15 May 1962* | | | | |
| 44.8 | 31–49 | 41 | (0.04) | (0.19) | | | |
| 55.0 | 24–29 | 4,540 | 1.06 | 115 | 1,740 | 350 | 60.9 |
| 59.7 | 19–30 | 1,380 | 0.57 | 40.6 | 76.3 | | |
| | | | *18 May 1962* | | | | |
| 55.2 | 31–35 | 10,800 | 2.43 | 50.3 | 720 | | 216 |
| 55.4 | 31–40 | 4,780 | 0.63 | 51.5 | 665 | 95.2 | 145 |
| 55.4 | 35–40 | 1,670 | 0.56 | 31.7 | 357 | | |
| 55.5 | 45–49 | 206 | 0.54 | 13.6 | 19.9 | | 2.21 |
| 55.6 | 40–44 | 963 | 0.63 | 20.5 | 198 | | 28.0 |
| 55.6 | 40–49 | 675 | 0.54 | 11.2 | 94.6 | 16.5 | 10.0 |
| | | | *22 May 1962* | | | | |
| 40.0 | 31–37 | 14 | 0.05 | 0.51 | | | |
| 40.1 | 37–49 | 69 | 0.38 | 2.46 | | | |
| 50.8 | 30–49 | 110 | 0.37 | 3.53 | 0.35 | | |
| 59.9 | 43–49 | 110 | 0.40 | 4.35 | | | |
| 60.1 | 31–43 | 808 | 0.69 | 34.1 | 180 | | |
| | | | *24 May 1962* | | | | |
| 39.0 | 30 | 4 | | | | | |
| 44.8 | 30 | 27 | 0.05 | 0.71 | 1.91 | | |
| 48.8 | 30 | 878 | 0.09 | 11.4 | 130 | | 25.6 |
| 54.6 | 30 | 1,430 | 0.37 | 33.7 | 275 | 32.1 | 9.96 |
| 56.0 | 30 | 2,180 | 0.40 | 32.6 | 75.1 | | 22.3 |
| | | | *29 May 1962* | | | | |
| 45.8 | 31–49 | 78 | 0.30 | 3.17 | | | |
| | | | *30 May 1962* | | | | |
| 54.9 | 31–49 | 172 | 0.61 | 5.82 | | | |
| | | | *31 May 1962* | | | | |
| 55.3 | 15–30 | 209 | 0.19 | | 28.4 | | |
| 60.7 | 19–24 | 2,340 | 1.16 | 90.8 | 514 | 64.9 | 3.08 |
| 61.0 | 24–30 | 2,040 | 0.93 | (6.98) | 92.5 | | |

* Where no result is given no data were available. † Parentheses indicate data which appear to be anomalous on the basis of absolute concentrations or of nuclide ratios.

The first ten atmospheric tests at Christmas Island, all with yields in the intermediate (20 to 1000 kilotons) to low megaton range, were detonated between 25 April and 14 May. Routine stratospheric air-filtering operations were conducted over western North America (approximately 105°W) by the Defense Atomic Support Agency, Project Star Dust. The data for May 1962 are given in Table 1. All relevant available data in the vicinity of the United States are shown.

On 8 and 10 May very high concentrations of fresh fission products appeared on filters exposed in several flights over the southwestern states at about 50,000 feet (15,000 meters) (*8*). Substantial concentrations of fresh fission products were evident in the lower stratosphere on the next missions conducted on 17 and 18 May, again on 22 and 24 May, and some fresh debris was still present on 31 May. It seems reasonable to assume that at least a portion of the lower stratosphere over North America contained debris from the Christmas Island tests during most of the month of May.

The lack of any meteorological data in the vast region of the Pacific between Christmas Island and the North American continent makes it impossible to reconstruct meteorologically the precise path followed by the several fragments of nuclear clouds from Christmas Island that were intercepted. However, the high concentration of particulate debris in the atmosphere and the radiochemical dating of this debris (*8*) identifies its origin.

The most detailed evidence linking stratospheric debris from a test on Christmas Island to the appearance of $I^{131}$ in pasteurized milk was found in mid-May in Wichita, Kansas (Table 2). The $I^{131}$ concentrations on 13 and 15 May were the highest measured during May 1962. Since about 2 days or more are required for deposited iodine to appear in a milk sample, the deposition over the Wichita milkshed probably occurred on or before 11 May.

As shown in Table 1, on 8 May fresh debris was collected at 50,000 and 60,000 feet, with the highest concentrations occurring at 50,000 feet (the high $I^{131}$ and $Mo^{99}$ concentrations should be noted). Radiochemical analysis indicated the most probable date of origin to be 4 May (*8, 9*). A sample obtained at 41,000 feet did not appear to contain fresh debris. (The detonation on

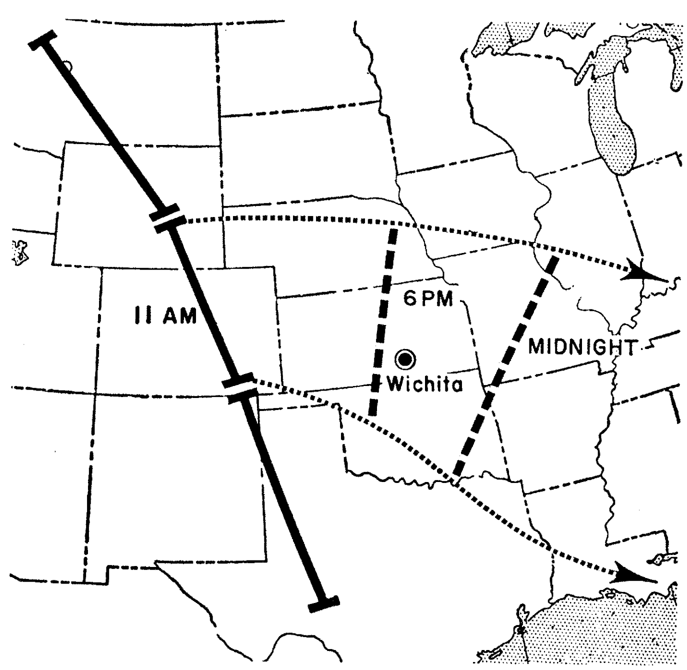
4 May was of intermediate yield and the debris cloud stabilized with its base at about 40,000 feet and its top at about 62,000 feet. An average west-southwest wind of 20 meters per second near the 50,000-foot level would be required to carry the debris to the United States.)

The three paths along which samples were taken at about 50,000 feet on 8 May are shown in Fig. 1. The subsequent movement of the air containing the highest concentration of debris, reconstructed from the 50,000-foot wind charts, is also shown. This debris should have been over the Wichita milkshed about 9 P.M. C.S.T. on the evening of 8 May. The horizontal extent of the debris cloud must have been several hundred miles since it had been diffusing for about 4 days and must have been over the milkshed for a period of at least several hours. There is strong evidence that the debris was scavenged and deposited by heavy thunderstorms occurring over a portion of the milkshed on the evening of 8 May and early morning hours of 9 May.

The precipitation amounts reported by Weather Bureau stations and cooperative observers in Kansas on 9 May (generally for the 24-hour period ending about 7 A.M. C.S.T.) are shown in Fig. 2. The approximate outline of the Wichita milkshed is also indicated (*4*, pp. 137–158). Precipitation occurred over the eastern portion of the milkshed and was particularly heavy between Hillsboro and Cassoday and at Chapman. The Weather Bureau *Storm Data* for May 1962 (*10*) records that heavy hail, an indication of severe thunderstorms, occurred over an area covering eight counties from the vicinity of Longford (just north of the milkshed) to Cassoday. The hail occurred from 6 to 11 P.M. C.S.T. on 8 May in the vicinity of Chapman and from about midnight to 2 A.M. on 9 May in the Hillsboro-Cassoday area. In Cassoday, where data were available hourly, it was reported that 1.5 inches (3.7 cm) of precipitation fell between midnight and 3 A.M.

The observations reported once each hour by the weather radar at the Wichita airport provide additional information on these storms. The WSR-57 radar set in use at Wichita can "see" precipitation-size drops in the atmosphere to a distance of about 450 km. The tops of precipitation echoes can be reliably determined for storm cells within 185 km of the radar (*11*). The radar record shows considerable thunderstorm activity occurring within the range of the radar throughout 8 and 9 May. However, echo tops of 50,000 feet or higher were reported only from about 7 P.M. C.S.T. on 8 May to 2 A.M. C.S.T. on 9 May. It is during this period that the high concentrations of radioactive debris at 50,000 feet were most probably brought to earth. Figure 3 shows the area over which thunderstorm echoes were reported during this time interval. Crosses indicate the locations at which echo tops of 50,000 feet or higher were reported and the time (to the nearest hour) of each such report is shown. In a situation of widespread, intense thunderstorm activity, such as this one, storm cells are continually forming, building, and dissipating. Fluctuations in the heights of the cloud tops occur on a time-scale much shorter than an hour (*12*). Since the observations were reported only once an hour, it is probable that additional storm cells penetrated the 50,000-foot level during this period.

Thus there is convincing evidence that high concentrations of debris at 50,000 feet were scavenged and deposited by severe thunderstorms over the Wichita milkshed, and that this mechanism accounts for the highest concentration of radioiodine recorded in May 1962. The radar echo reports indicate that at least some of these storms extended to 50,000 feet or higher and the occurrence of hail indicates extreme turbulence and vertical



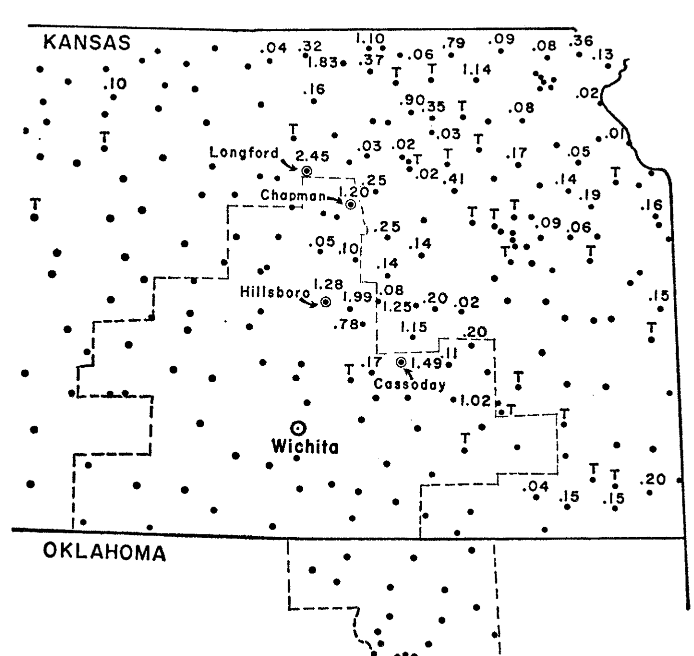




Fig. 1 (left). Location of the three paths along which samples were taken from aircraft flying at about 50,000 feet (15,000 meters) on 8 May (solid lines). Successive positions of the air containing the highest concentration of nuclear debris determined from meteorological trajectories are shown by dashed lines. All times are Central Standard. Fig. 2 (right). Precipitation (in inches) during 24-hour period ending on the morning of 9 May 1962 over eastern Kansas and the Wichita milkshed (dashed outline). Dots indicate location of reporting stations; where no value is given, no rain occurred. *T* denotes trace of precipitation.

mixing. Continued elevated concentrations of $I^{131}$ were indicated by the next Wichita milk sample (660 pc/liter) taken 2 days later on 15 May. The concentration decreased to 165 pc/liter by 22 May. Each milk sample analyzed by the Pasteurized Milk Network is a composite representative of all pasteurized milk sold in Wichita, whereas the rainfall occurred over only a small portion of the milkshed on 8–9 May. This implies that milk from some individual farms may have contained concentrations of $I^{131}$ considerably above the milkshed average.

On 29 May, an increase to 340 pc/liter was observed in Wichita milk. The available evidence suggests a similar explanation. Numerous thunderstorms extending to 50,000 feet or more were observed over the Wichita milkshed during the night of 24–25 May and six stations within the milkshed reported rains of 1 inch or more. This was the first violent convective activity observed over the milkshed in more than a week. The continued presence of fresh fission products in the lower stratosphere supports this interpretation.

*Other incidents in May and early June 1962.* Although the milk samples from Wichita contained the highest concentrations of $I^{131}$ reported during May 1962, several other milksheds experienced similar concentrations and on 1 June a higher reading was obtained in Kansas City, Missouri (see Table 2).

The initial large rise in the $I^{131}$ concentration in milk from Kansas City on 18 May is apparently associated with the thunderstorm activity of the night of 8–9 May, the same situation responsible for the first increase in Wichita. Precipitation was widespread over the Kansas City milkshed during the night of 8–9 May, with the heaviest showers in the southern portion of the milkshed. Although several thunderstorms were reported, the highest radar-observed cloud top over the milkshed was at 47,000 feet. The milk sample taken on 11 May may reflect the first appearance of $I^{131}$ from this source. The time interval between assumed deposition and the milk sample taken on 18 May makes the association less certain than in the other cases investigated here.

Evidence concerning the observed increase in $I^{131}$ concentration in Kansas City near the end of May is more conclusive. The most vigorous convective activity reported in the continental United States in May 1962, based on

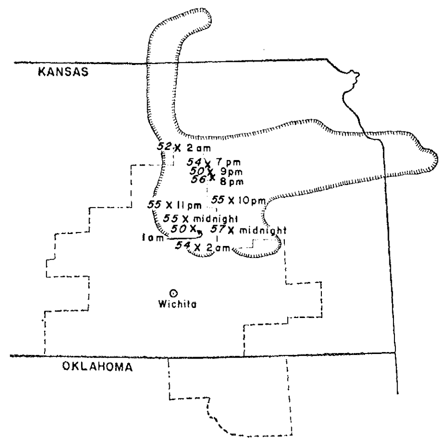



Fig. 3. Area of thunderstorm echoes reported by Wichita radar, 7 P.M. 8 May to 2 A.M. 9 May 1962. Location of each echo extending to 50,000 feet or higher is shown by an *X*, altitude (in thousands of feet) and time (C.S.T.) are indicated.

radar-detected cloud tops and on precipitation, occurred over the Kansas City milkshed on the night of 25–26 May. Several cloud tops in excess of 60,000 feet were reported and more than a dozen stations in the milkshed reported rains in excess of 1 inch. Three stations collected more than 2 inches of rain during the storm. Again, the thunderstorm mechanism, reaching well into the lower stratosphere, appears to be the most logical explanation of the elevated concentrations of $I^{131}$ in milk.

Similar association between thunderstorm cloud tops of 50,000 feet or more, heavy rainfall over the milkshed, and increased $I^{131}$ concentrations is found for the four additional incidents of $I^{131}$ concentrations of about 300 pc/liter or more reported by the network during May and early June 1962: Des Moines, Iowa (300 pc/liter on 17 May); Minneapolis, Minnesota (290 pc/liter on 18 May); Oklahoma City, Oklahoma (460 pc/liter on 29 May); and Omaha, Nebraska (340 pc/liter on 1 June).

All the incidents of high $I^{131}$ concentrations in May and early June occurred in the Midwest and must be viewed as a result of the intense convective activity associated with the meteorologically well-known spring phenomenon of the nocturnal Midwest thunderstorm (*13*).

*Iodine-131 in rain water.* Additional support of the validity of the thunderstorm mechanism being responsible for bringing $I^{131}$ from the lower stratosphere to the ground is provided by the presence of $I^{131}$ in precipitation from these storms. Fortuitously, during May and June 1962 the Public Health Service Radiation Surveillance Center was conducting an experimental program of analyzing a few precipitation samples for $I^{131}$ content by gamma spectroscopy (*14*). The samples were selected nonsystematically on the basis of sample size and time of receipt at the laboratory. The samples were analyzed with the intent of establishing qualitatively the presence of fresh fission products. The quantitative results represent only an estimate of the $I^{131}$ content and are subject to large errors. The results for May 1962 are given in Table 3.

The $I^{131}$ concentrations were highest in those samples collected in the Kansas-Missouri area during the last week of May, the period of intense convective activity discussed in connection with the data for pasteurized milk from Wichita, Kansas, and Kansas City, Missouri (Table 2).

*Weather Bureau Radar Weather Summary Maps.* These maps are prepared at 3-hour intervals, and each map shows conditions observed during a 5-minute period over the United States east of the Rockies. In May 1962, cloud tops above 50,000 feet were shown on these summaries on 79 occasions; 66 of the echoes occurred in the area between the Rockies and 90°W, and 13 echoes occurred east of 90°W. Of the 13 reports east of 90°W, 9 were definitely not over milksheds supplying the Pasteurized Milk Network, two were near the borders of, but not in, milksheds, and two occurred (on 23 and 24 May) over eastern Pennsylvania, an area that supplies several cities in the network. Whether these storms were associated with the slight increases in $I^{131}$ concentrations in Pittsburgh, Pennsylvania (45 pc/liter on 28 May), or Wilmington, Delaware (40 pc/liter on 1 June), is uncertain. However, these data reinforce the belief that scavenging of the lower stratosphere by penetrating thunderstorms was the chief mechanism influencing the distribution of radioiodine in milk in May 1962. The high $I^{131}$ values occurred in regions of thunderclouds which extended to high altitudes. Farther to the east, where storms extending to such heights were less common, no $I^{131}$ values in milk greater than 100 pc/liter were observed.

*Iodine-131 contributions from Nevada tests.* No analysis of the sources of $I^{131}$ contamination in milk during May

1962 can be complete without a detailed examination for possible contributions from tests conducted in Nevada. Underground detonations were announced at the Nevada test site on 7, 12, 19, and 25 May. An underground test on 27 April should also be considered in connection with the fallout during May. All the detonations were designed to be completely contained within the earth but the containment failed in the event on 19 May. For the 12 May event, radiation above normal background values was detected at the surface above the point of detonation, but at no other place on or off the Nevada test site. For the other events, although the test site was under continuous visual and radiological surveillance, there was no evidence of escaping gases or particulate debris. After the event on 7 May, holes were drilled into the cavity within 24 hours of the detonation and some radioactive debris reached the atmosphere during this operation (*15*).

On 19 May, a low-yield device was detonated at 10 A.M. M.S.T. A visible dust cloud was created which moved north of the test site and was found by aerial monitors to extend to about 11,500 feet above mean sea level at 1½ hours after detonation (*16*). Figure 4 shows the area over which the nuclear debris moved as estimated from meteorological trajectories based on winds from just above the surface (gradient level) to 12,000 feet.

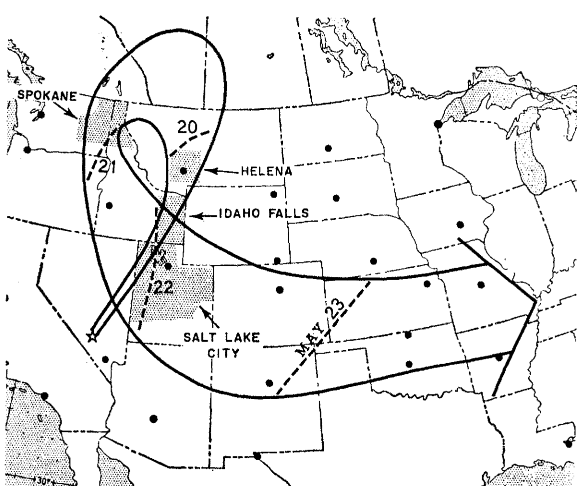
Table 2. Iodine-131 (pc/liter) in samples of pasteurized milk from Wichita, Kansas, and Kansas City, Missouri.

| Wichita | | Kansas City | |
|---|---|---|---|
| Date | Amount | Date | Amount |
| 6 May | < 10 | 4 May | < 10 |
| 13 May | 670 | 11 May | 40 |
| 15 May | 660 | 18 May | 600 |
| 20 May | 215 | 25 May | 150 |
| 23 May | 160 | 29 May | 590 |
| 27 May | 250 | 1 June | 780 |
| 29 May | 340 | 5 June | 450 |
| 3 June | 160 | | |

For several days prior to this detonation, the Public Health Service Radiation Surveillance Network was reporting the concentrations of gross beta activity in air at ground level. Concentrations of up to 10 pc/m$^3$ occurred daily, and the "apparent age" of the fission products (based on decay characteristics of the debris) was greater than 100 days. The daily concentration of gross beta activity in the surface air was examined in the areas over which the nuclear debris moved and about 300 km on each side. The concentrations did not rise above 11 pc/m$^3$ in the appropriate areas and time periods. At only one location (Helena, Montana) did the debris have an apparent age of less than 50 days; on a filter paper exposed for 24 hours and extracted at 8 A.M. on 20 May 1962, the debris found had an apparent age of 16 days. The debris on a filter paper extracted 24 hours later had an apparent age of 67 days. Although not conclusive, the trajectories and the results for "apparent age" suggest that the 19 May cloud was indeed the same as that sampled at Helena, Montana, during 19 or 20 May, or both, even though the gross beta concentrations were within the background variability.

Also shown in Fig. 4 are the approximate areas of the milksheds of Salt Lake City, Utah; Idaho Falls, Idaho; Helena, Montana; and Spokane, Washington. The debris apparently passed through these areas during the first 72 hours. Considerable precipitation was reported in the first three milksheds during the period the debris passed through; the Spokane milkshed experienced very little rainfall. Two of the 19 pasteurized milk samples collected in May from these four milksheds contained more $I^{131}$ than 20 pc/liter: Idaho Falls, 60 pc/liter on 30 May; and Helena, 60 pc/liter on 29 May. In both cases, the sample was the first taken that would be expected to reflect the test conducted on 19 May. The concentrations at Spokane did not rise, possibly because of the lack of rain.

During the 4th and 5th days after the test conducted on 19 May, the trajectories show that debris from this event must have spread over a wide area of the Midwest as it moved eastward across the United States. As already indicated, $I^{131}$ concentrations in milk in this area rose above 100 pc/m$^3$ toward the end of May. However, to claim a simple cause-and-effect relationship would be naive, since the effect of the 19 May cloud was barely



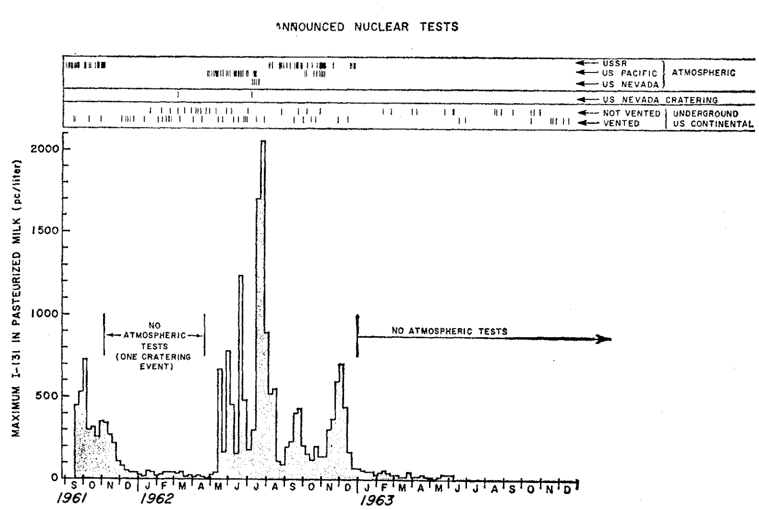




Fig. 4 (left). Meteorological estimate of the path of air up to 12,000 feet mean sea level which may have contained debris from the underground event of 19 May 1962; dates indicate position at 8 A.M. local time. Dots show the stations of the Public Health Service Radiation Surveillance Network and shaded areas denote milksheds traversed during the first three days. Fig. 5 (right). The maximum concentration of $I^{131}$ found in any individual milk sample from the Pasteurized Milk Network in the United States (excluding Alaska and Hawaii) during each week from September 1961 through 1963. The upper part indicates the date and category of every announced nuclear test from September 1961 through December 1963.

Table 3. Estimated $I^{131}$ content of precipitation samples from selected stations, U.S. Public Health Service Radiation Surveillance Network, May 1962.

| Date* | $I^{131}$ (pc/liter)† | Precipitation (in.) |
|---|---|---|
| | *Minneapolis, Minnesota* | |
| 13 May | 390 | 0.64 |
| 29 May | < 170 | 4.8 |
| 30 May | 60 | 0.23 |
| | *Jefferson City, Missouri* | |
| 25 May | 480 | .71 |
| 26 May | 580 | .23 |
| | *Topeka, Kansas* | |
| 25 May | 4000 | .18 |
| 27 May | 440 | .38 |
| | *New Orleans, Louisiana* | |
| 31 May | < 90 | .60 |
| | *Oklahoma City, Oklahoma* | |
| 27 May | 280 | Approx. .25 |
| | *Salt Lake City, Utah* | |
| 26 May | < 90 | .23 |
| 29 May | 40 | .25 |

* End of 24-hour collection. † Corrected for decay to end of collection period.

evident at Idaho Falls and Helena under the very special circumstances when the debris was still relatively concentrated and the precipitation ideally timed for maximum deposition. The much more dilute cloud, the lack of evidence of surface air contamination, and the widespread increase in $I^{131}$ found over large areas of the United States, both near the debris resulting from the event of 19 May and well removed from it, supports the thesis that the scavenging of the Christmas Island debris by the high-level nocturnal thunderstorm was the principal, if not the exclusive, mechanism responsible for elevating the $I^{131}$ concentrations in milk during late May in the Midwest.

Similar analyses of samples of milk and air near possible trajectories of debris from the underground tests conducted on 27 April, 7 May, 12 May, and 25 May, and from the drilling of the cavity on 8 May, show no contamination that could be attributed to these tests. As in the case of the test on 19 May, after the arrival of the meteorological trajectories in the upper Midwest, some milk samples showed an increase in $I^{131}$ concentrations. Again, these increases occurred at many locations irrespective of their proximity to the trajectories. The preponderance of evidence supports the stratospheric scavenging mechanism.

*Sources of $I^{131}$ in pasteurized milk, 1961–1963.* Concern has been expressed over the possibility that underground testing at the Nevada test site has been a frequent source of significant contamination of milk with $I^{131}$ (*2*). The discussion of the 19 May event suggests that, even in the case of the venting described, measured contamination with $I^{131}$ did not exceed 60 pc/liter. A general assessment of the role of underground testing in contaminating milk supplies during periods of no atmospheric testing can be made from the data in Fig. 5. The lower part of the diagram shows the maximum $I^{131}$ concentration found in any individual milk sample from the Pasteurized Milk Network in the United States (excluding Alaska and Hawaii) during each week from the end of the test moratorium in September 1961 through the end of 1963. The upper part of Fig. 5 indicates the date and category of every announced nuclear test from September 1961 through December 1963 (*4, 17*). Underground tests in Nevada were characterized as "vented" if any radioactivity above normal background values was detected after the event either on or off the Nevada test site. As shown, no atmospheric nuclear tests occurred between 4 November 1961 and 25 April 1962 and none occurred after 24 December 1962. It is precisely these periods that begin with a rapid decrease in the maximum concentrations of $I^{131}$ in milk and end with weekly maxima near the lower limit of detection (10 pc/liter). In 1963, all milk samples collected in the United States after the middle of the year had $I^{131}$ concentrations below 10 pc/liter despite the continuation of underground tests.

However, the data in Fig. 5 do not exonerate all underground testing. For example, the value of 1240 pc/liter found in a Spokane, Washington, sample on 21 June 1962 has been shown (*3*) to be the result of an unusual, massive venting of an underground test that occurred on 13 June 1962. All other incidents in the United States of $I^{131}$ concentrations greater than 300 pc/liter in milk samples of the Pasteurized Milk Network have been examined in detail and the sources of debris determined (*3*). The cases are summarized briefly in Table 4. Of the six periods, three are the result of atmospheric testing in the U.S.S.R., two arise from U.S. atmospheric and cratering tests, and one is from a vented underground test in the United States. Only minor contamination occurred from other vented underground tests. There is no evidence of contamination of pasteurized milk with $I^{131}$ from underground tests which were reported to be contained.

Table 4. Sources of $I^{131}$ contamination ≧ 300 pc/liter of milk in PHS Pasteurized Milk Network.

| No. of milksheds | Probable source |
|---|---|
| | *September to December 1961* |
| 13 | U.S.S.R. atmospheric tests |
| | *May to early June 1962* |
| 5 | U.S. Christmas Island atmospheric tests |
| | *Late June 1962* |
| 1 | Vented Nevada underground test |
| | *July to August 1962* |
| 2 | Nevada atmospheric and cratering tests |
| | *September 1962* |
| 6 | U.S.S.R. atmospheric tests |
| | *November to December 1962* |
| 8 | U.S.S.R. atmospheric tests |

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