Reports

Radioiodine Fallout over the Midwest in May

Abstract. *High concentrations of radioiodine in milk, found preferentially over the midwestern United States after atmospheric nuclear tests in May 1962, 1965, and 1966, can best be explained by high-reaching intense thunderstorms that scavenge passing radioactivity from the upper troposphere and lower stratosphere.*

Fallout after nuclear tests, including 8-day radioiodine, I^{131}, has been documented (*1*). Radioiodine enters man by passage from the nuclear cloud and through atmosphere, pasture, cow, and milk. I now illustrate the manner in which one atmospheric phenomenon increases the likelihood of contamination of milk in the Midwest in May or thereabouts, in contrast to other parts of the country and other months.

Nuclear clouds passed over the United States during May of 3 years between 1961 and 1967. The highest concentrations of radioiodine in milk occurred in the Midwest during each episode (Fig. 1, Table 1). The air concentrations (Table 1) are the highest readings, preceding the peak milk concentrations, from the closest station to each milkshed. All the highest concentrations in milk, apart from Charleston, South Carolina, occurred in the Midwest. The highest values during episodes in January and in September through December 1961–67 were not preferentially in the Midwest (*1, 2*).

Crops may be contaminated by deposition of radioiodine with precipitation or directly by ground-level radioiodine, or by both. It is argued that during the three May episodes almost all radioiodine was deposited with rainwater.

Three other episodes with little or no rain but with much I^{131} in milk were examined for their ratios of I^{131} in milk to gross beta activity in ground-level air; such ratios roughly indicate the contributions of dry fallout to contamination of milk. During dry weather the ratios are less than 3 on all but three of 17 sites; the highest is only 15, while equivalent ratios (Table 1) run to scores. These higher ratios suggest that a mechanism other than dry fallout enhanced the contamination of milk in May.

Nor is there correlation between milk contamination and gross beta radioactivity during the three May episodes. For example, in May 1966 the highest Midwest concentrations were 9 pc/m^3 in air and more than 100 pc/liter in milk, while Denver, Colorado, and Phoenix, Arizona, reported 14 pc/m^3 and only 20 and 30 pc/liter, respectively. Since the latter stations had little rain, the air : milk ratios agree with the previous dry-weather ratios.

Unfortunately a direct link between concentrations of radioiodine in the upper atmosphere, in rainwater falling on a milkshed, and subsequently in milk is unavailable because of the lack of appropriate measurements. The ability of rain to scavenge fission products from the atmosphere and of contaminated rainwater to enhance concentrations in milk is universally acknowledged. There are a few reports of radioiodine in rainwater in the Midwest in May 1962 (*3*), and many observations of gross beta radioactivity in rainwater during all three episodes (*1*). But, because of the isolated nature of thundershowers and other difficulties, it has not always been possible to document adequately even gross beta contaminations in rainwater in all milksheds. In some instances the evidence of significant gross beta concentration in rainwater over the Midwest is clear: on 17 May 1966 Jefferson City, Missouri, reported a concentration about 30 times greater than did any non-Midwest station after the nuclear test of 9 May 1966 (*1*).

The Midwest suffers severe weather in the spring. It is the severe thunderstorms from which some tornadoes spawn that concern us rather than the high incidence of tornadoes. Florida and the Southwest have the most thunderstorms in summer (*4*). Two characteristics set the Midwest in May apart from the rest of the United States: there is high incidence of nocturnal storms, and the cloud tops reach to great heights. While the nocturnal frequency is of unknown significance, one may argue that high-reaching rainclouds by day and by night account for the greater fallout of I^{131} in the Midwest during May.

Clouds from atmospheric nuclear detonations equivalent to more than about 10 kilotons rise initially into the upper troposphere or lower stratosphere or the upper atmosphere—above about 10 km. These higher altitudes contain a

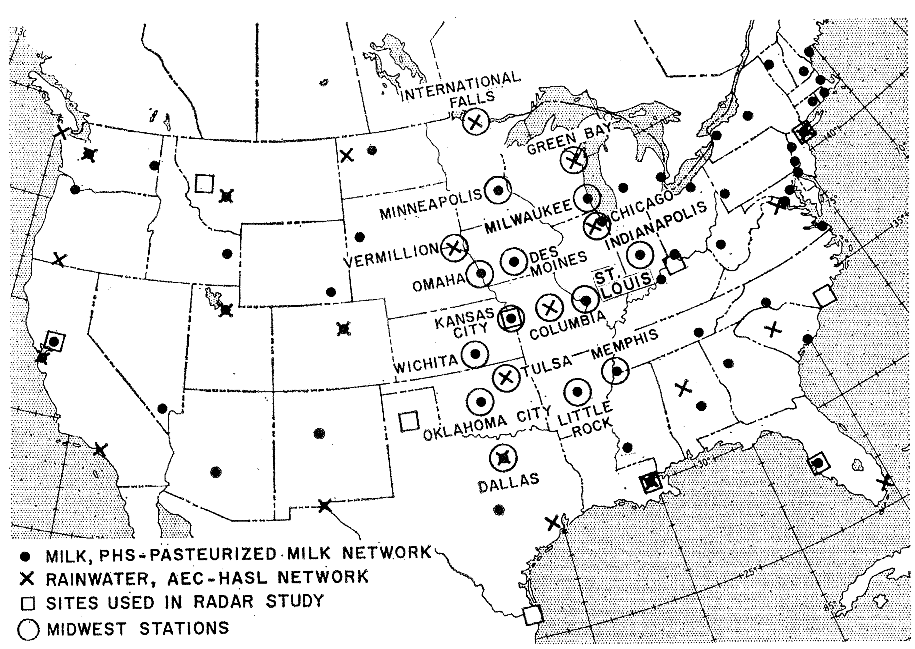

Fig. 1. The three networks used; Dallas, Texas, may not be midwestern.

larger fraction of the radioactivity and stronger winds than does the lower troposphere. The stronger winds normally effect faster transit to the United States, with less decay and dilution. The three nuclear tests of Table 1 and most of those used for comparison had forces greater than 10 kilotons. Meteorological processes such as high-reaching thunderstorms, which preferentially bring radioactivity to the ground with the least decay and dilution, contribute most to contamination of crops by radioiodine.

An analysis by station and month of penetrations of the stratosphere by thunderstorms has been reported (*5*); such statistics reflect the distribution of high-reaching thunderstorms. Unfortunately only ten Weather Bureau radar sites were studied, of which only one, Kansas City, Missouri, is midwestern. For the months April–June 1961–64 Kansas City reported 90 penetrations of the tropopause; New Orleans, 65; no other station, more than 30. In fact during no other 3-month period did any station other than Kansas City and New Orleans have more than 40 penetrations during these 4 years. Both Kansas City and New Orleans reported maxima in May. Kansas City was unique in having a nocturnal as well as an afternoon maximum of penetrations of the tropopause.

The most convincing evidence for the hypothesis of the high-reaching thunderstorm follows from a detailed study of the May 1962 episode (*6*). For example, the coincidence of thunderstorm and a cloud of fresh fission products, at 15.2 km over the Wichita, Kansas, milkshed during the night of 8 May, accounts for the first subsequent milk sample having a concentration of 670 pc/liter (Table 1). From their study of this episode List *et al.* (*6*) concluded that

> All the incidents of high I^{131} concentration 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 phenomena of the nocturnal thunderstorm.

In all three May episodes heavy rain ($\geq$2 cm/day) fell over every milkshed in Table 1 between the time of arrival of the nuclear cloud and the reported highest concentration of I^{131} in milk. Whenever radar echoes of thunderstorm tops were examined during periods of the heavy rain, the tops reached well above 10 km. The first arrivals of the nuclear clouds over the Midwest are based on aircraft measurements in 1962 (*6*) and on meteorological trajectories; they are partly verified by aircraft measurements of radioactivity in 1965 and 1966. Heavy thundershowers are always potentially available to deposit radioiodine on the milkshed 2 to 6 days before the high concentrations in milk.

Table 1. Radioiodine episodes following announced atmospheric nuclear tests during May between 1961 and 1967 (*1*). Milk from milksheds appearing in Fig. 1 but not in Table 1 contained less than 70 pc of I^{131} per liter. Nuclear clouds from the three tests reached the Midwest by 9 May 1962, 19 May 1965, and 15 May 1966, respectively.

Milkshed	Date	Concentration of I^{131}	
		Highest in milk (pc/liter)	Milk:air (pc/liter:pc/m^3)
Test at Christmas Island (2°N), 4 May 1962			
Kansas City, Mo.	1 June	780	80
Wichita, Kan.	13 May	670	65
Oklahoma City, Okla.	29 May	460	35
Omaha, Neb.	1 June	340	35
Des Moines, Iowa	17 May	300	50
Minneapolis, Minn.	18 May	290	60
Dallas, Tex.	31 May	90	10
Chicago, Ill.	15 May	80	15
Test at Lop Nor (40°N), 14 May 1965			
Kansas City	28 May	220	75
Des Moines	27 May	170	55
Indianapolis, Ind.	1 June	80	80
Minneapolis	1 June	80	80
Omaha	28 May	70	25
Test at Lop Nor (40°N), 9 May 1966			
Little Rock, Ark.	24 May	390	195
St. Louis, Mo.	23 May	280	45
Indianapolis	27 May	190	65
Oklahoma City	24 May	140	25
Kansas City	24 May	140	15
Wichita	24 May	110	110
Memphis, Tenn.	23 May	110	55
Dallas	26 May	100	100
Charleston, S.C.	27 May	100	50

During the three May episodes several Midwest milksheds reported little or no I^{131} in milk within 5 days of thunderstorms after the purported arrivals of the nuclear clouds. Not every intense thunderstorm necessarily scavenges radioiodine. The complex nature of a nuclear cloud, thunderstorm behavior, and the compositing procedure for the milk samples can account for the apparent failures. Rather, the thunderstorm mechanism is proposed as a necessary but insufficient indicator of radioiodine contamination when a nuclear cloud is thought to be passing in the upper atmosphere.

A consequence of deposition of radioiodine by thundershowers is variation in crop contamination between nearby farms. For example, on 21 May 1966, the probable day of contamination of the Wichita milkshed, of 53 rainfall stations in the milkshed three reported rain exceeding 5 cm/day, while 18 stations had no rain. Thus milk from many farms may be entirely free of I^{131} while other milk may be more contaminated than the milkshed composite.

Strontium-90, whose source is the lower stratosphere, can test the hypothesis of the scavenging thunderstorm, which requires preferential deposition in May over the Midwest. The AEC's rainwater-collection network shows that for the years 1960 through 1965 the fallout was 2.3-times as high, and the concentration in rainwater roughly twice as high, in the Midwest as in the rest of the country in May (*7*). Fallout of Sr^{90} is maximum in May at almost all stations in the United States. In April and June the ratio of fallout in the two areas is 1.3; in the remaining 9 months, unity or less. The concentration in rainwater for the 11 months other than May also is about the same in the Midwest as elsewhere in the United States. Thus atmospheric mechanisms effecting more Sr^{90} in rainwater must operate in May over the Midwest than in other parts of the country and seasons.

Other explanations of the Midwest-in-May maximum are possible. Dairying and farming practices vary; for example, cattle on the New Orleans and Tampa, Florida, milksheds are grazed all year, but only from 15 May to 15 September do dairy cattle on the Minot, North Dakota, milkshed derive 75 percent or more of their roughage from fresh, chopped, green feed (*8*). Farming and dairying practices introduce variation in the I^{131} in milk, with the same level of pasture contamination (*9*), but the possibility of their explaining the higher Midwest concentrations of I^{131} in milk, except from St. Louis, Missouri (*9*), is remote. Nor would any nonmeteorological factor explain the pattern of Sr^{90} fallout.

Meteorological phenomena other than high-reaching thunderstorms suggest themselves. Many radioiodine episodes occurred entirely in dry weather (*2*). Another thunderstorm scavenging mechanism has been proposed (*10*). The tropopause can fold and extrude a thin layer of stratospheric air, less than 1 km in thickness, into the troposphere below (*11*); in the course of the extrusion, stratospheric air is brought to the lower troposphere or even to the ground in a matter of 1 day; part of the descending current reascends, and this air is most likely to cause scavenging since it helps to initiate thunderstorms.

Unfortunately no climatology of extrusions, and thunderstorms which penetrate them, exists (*12*), although there is reason to think that the Midwest in May may be most vulnerable. In May of 1965 and 1966, cyclones were favorably situated to allow the extrusion process to operate over the Midwest. There are no data on radioactivity to confirm the reality of high concentrations of radioactivity below 10 km. But in May 1962 the extrusion mechanism is not implicated. Thus, although the concentration of I^{131} at Argonne, Illinois (*3*), during 1962 was highest on 10 May in thunderstorm rain, the radiosonde ascents from Peoria, Illinois, on that day show no signs of the temperature inversion or of dry air that are normally indicative of the extruded layer in the troposphere. Although not confirmed, scavenging by thunderstorms of radioactivity from extruded layers cannot be discounted as the explanation of the Midwest-in-May maximum.

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13. Supported by the AEC. Much of the work was done while I was an exchange scientist with the British Meteorological Office, Bracknell, Berkshire. I thank G. Cotton, Environmental Science Services Administration, for assistance in analysis of the Sr^{90} statistics.

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Olivine-Garnet Transformation in a Meteorite

Abstract. *Garnet has been identified for the first time as a meteorite mineral in the Coorara chondrite from Western Australia. It replaces olivine grains in a 1-millimeter veinlet traversing the body of the meteorite. The associated olivine has abnormally low birefringence, which suggests a highly shocked condition. Microprobe analyses do not distinguish the garnet from the associated olivine, which has the composition* $(Mg_{.75}Fe_{.25})_2SiO_4$*; the garnet may have the composition* $Mg_3Fe_2Si_3O_{12}$ *but be unresolvable from the accompanying olivine, or alternatively is nonstoichiometric. Transformation of olivine to garnet under high pressure could have significant implications for the phase composition of the Earth's mantle.*

We received from W. H. Cleverly of the Kalgoorlie School of Mines a small piece of the Coorara meteorite for examination. This meteorite, a much weathered stone, was recently found on the Nullarbor Plain in Western Australia, about 70 miles (112 km) northeast of Rawlinna. While G. Moreland of this institution was making a thin section of the meteorite he noted a purple mineral that was unlike anything he had observed in his long experience in making such sections. X-ray diffraction showed that this purple mineral is a garnet.

The Coorara stone was not seen to fall, but it is certainly a meteorite. Although so weathered that the nickel-iron and almost all the troilite (FeS) originally present are now altered to limonite, it has the typical mineralogy of a chondritic meteorite (olivine, pyroxene, and a little plagioclase), and chondritic structure is present but not prominent.

Examination of three different thin sections has shown that the purple mineral occurs only in a veinlet 1 mm thick. This veinlet is prominent in the body of the meteorite because of its high content of limonite that has a dark brown color in contrast to the pale brown of the rest of the stone. The veinlet contains numerous grains of olivine and pyroxene that have the same composition (determined by electron microprobe) as the olivine and pyroxene in the body of the meteorite. The purple mineral replaces the olivine, but not the pyroxene. Examination of thin sections showed that the purple mineral is isotropic and has a higher refractive index than the enclosing olivine. This olivine has abnormally low birefringence, a feature we have previously observed in olivine in highly shocked meteorites such as Weatherford (*1*).

One grain of the purple mineral, about 0.2 mm across and enclosed in limonite, was carefully cut out from a thin section and mounted in an x-ray powder diffraction camera. The resulting photograph showed a pattern of lines corresponding to that of a garnet with $a = 11.51_5$ Å (calculated from the back-reflections 14.4.0 and 14.4.2). The strongest lines of goethite ($HFeO_2$) and of kamacite (α-Fe,Ni) were also present, but there were no lines of olivine or pyroxene.

Ten different grains containing the purple mineral were analyzed with the electron microprobe and were found to have the following composition: FeO, 23.5 to 25.0 percent; MgO, 36.9 to 39.5 percent; and SiO_2, 37.1 to 39.6 percent (the totals in each analysis were close to 100 percent). Minor constituents detected were Mn ($\sim$ 0.1 percent) and Cr ($<$ 0.1 percent, 0.33 percent in one spot); Al was sought but not found. These analyses correspond to the formula $(Mg_{.75}Fe_{.25})_2SiO_4$, the same composition as the olivine in the body of the meteorite. It is difficult to reconcile this composition with that of a garnet. The general formula of a garnet is $R_3{}^{2+}R_2{}^{3+}Si_3O_{12}$; thus a magnesium-iron garnet should be $Mg_3Fe_2Si_3O_{12}$, with a composition MgO 26.2, Fe_2O_3 34.7, and SiO_2 39.1 percent. To derive this