Deposition of Fallout Cesium 137 on Forage and Transfer to Milk

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CESIUM 137 is one of the most important contaminants from fallout nuclear debris because of its long physical half-life and affinity for biological systems. Body burdens of this radionuclide in man result principally from the food-chain sequence: air and precipitation to plants, plants to milk and meat, with dairy and beef cattle as the principal vectors between plants and man's diet. This apparently simple relation describes the food-chain pattern for cesium 137 quite adequately since uptake of cesium 137 by plants from soil is negligible (*1*) and dairy products and beef contribute most of the cesium 137 in the average U.S. diet (*2*).

Mathematical models describing the transport of radioactive fallout to milk, emphasizing strontium 90, have been presented (*3–7*). In these models, certain common assumptions were made regarding forage contamination and feeding practices, but actual data were unavailable. The relation between radionuclide levels of forage and milk has been reported by several workers for strontium 90 (*8–12*) and cesium 137 (*13, 14*). The general relation between fallout, feeding practices, and milk levels has been discussed (*15–18*). A common deficiency of these models and discussions has been the absence of concomitant data for all three: fallout, feed, and milk.

As pointed out in a recent panel discussion of approaches to studying radiological hazards in the environment, the large-scale monitoring network method and the investigation of specific ecosystems are complementary in understanding the behavior of fission products in the biosphere (*19*).

Observations on the transport of cesium 137 in a controlled dairy ecosystem at Colorado State University were initiated in 1962, and data have been collected for the various steps in the food chain. The ecosystem consisted of one herd of 112 cows and an irrigated farm in a geographic region that would be classified as a dry area (*20*). From the study of this ecosystem, we believe that estimates of cesium 137 body burdens of the general population can be significantly improved.

Methods

The cows in the herd at Colorado State University were studied in two groups: 12 cows that were fed on pasture and 100 cows fed on drylot (harvested) feed. Milk samples from the herd on pasture were collected two or three times

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a week, and samples from the herd fed on dry lot, once a week. For comparisons of feed, milk samples were collected daily from each cow. The total intake and production were recorded. Feed samples were composited daily.

Forage samples were collected by cutting measured areas of randomly selected sites in the pasture about 2 inches above the ground. Hay samples were taken from bales of hay with a core sampler. The forage and hay samples were dried to a constant weight and ground to a constant density before counting. Cesium 137 content of grain, fed in addition to hay and forage, was measured in pelleted grain.

Samples of each rainfall were collected by a fiber-glass funnel from a 47-square-foot catchment. A cation exchange column was connected to the funnel. The analysis of precipitation samples has been described by Johnson and associates (*21*).

All samples were analyzed for cesium 137 by gamma-ray spectrometry. The detector was a 4- by 8-inch sodium iodide (thallium-activated) crystal, shielded from background by an 8-inch-thick steel-walled chamber and connected to a 400-channel pulse-height analyzer. Hay and forage samples were standardized for height and density to a constant geometry and counted in a 2½-gallon cardboard container. Milk samples were counted in a 5.47-liter Marinelli-type beaker. A "spectrum stripping" computer program was used to determine the absolute activity of each radionuclide present in the sample (*22*).

Results and Discussion

Entry of cesium 137 to the cow by routes other than the diet are negligible. Cesium 137 has not been detected by gamma-ray spectrometry in drinking water for the herd. Inhalation levels must also be negligible, as air concentrations in 1962, 1963, and 1964 ranged from 0 to 0.5 picocurie per cubic meter of air. On the assumption that a 600-kg. cow uses 150 cubic meters of air per day, the cow's intake of cesium 137 during the highest air concentrations would be 75 picocuries per day, or less than one-tenth of 1 percent of its daily intake from feed during this period (*23*).

Since the nondietary sources of cesium 137 are minimal and uptake by plants from soil was negligible in our system, we focused attention on the deposition of cesium 137 on feed crops. A soil-plant relation exists, however. Hansen and associates (*12*) have shown that soil fertility, by influencing growth rate, is a factor in determining the contamination of plants by radionuclides.

The transfer of cesium 137 from air and rainfall to plants is affected by many variables, which together yield an apparent deposition coefficient for a single deposition occurrence. The deposition coefficient is defined as the change in cesium 137 per square meter on forage, divided by the deposition on an arbitrary surface. For rainfall deposition, the denominator is the deposition measured by rain collectors. Air-to-plant deposition is expressed by the deposition velocity; that is, the change in plant cesium 137 (picocuries per square meter) divided by the air concentration (picocuries per cubic meter) averaged over a day.

Considered individually because of the many variables involved, rainstorms can either result in increases or decreases in forage concentrations of cesium 137. This is because rain, by washing, may remove a considerable amount of superficial cesium 137 from leaves. Similarly, the deposition of cesium 137 from the air is not separable from the losses occurring simultaneously due to weathering. The levels of cesium 137 associated with forage are complexly related to rainfall and air concentrations. A discussion of the deposition mechanisms is not within the scope of this article.

We found, however, that the fallout pattern, either as rainfall deposition over the growing period or as integrated air concentration, can be used to predict the cesium 137 on alfalfa hay at harvest. This is significant because the diet of dairy cows is composed to a large extent of harvested hay.

The parameters of this generalization are derived as the apparent rainfall deposition coefficients for harvested hays and the apparent air deposition velocities calculated for the hay crops from 1962 through 1965 (see table). The rainfall deposition coefficients were approximately one-fourth, one-fifth, and one-tenth of those for the successive crops of hay called first-, second-, and third-cutting hay. The hay concentration

Cesium 137 deposition coefficients and deposition velocities for harvested hay

Year	Rainfall deposition, picocuries per square meter	Forage activity, picocuries per square meter	Deposition coefficient	Average air concentration, picocuries per cubic meter	Deposition velocity, meters per day [1]
First-cutting hay: [2]					
1962	4, 230	870	0. 21	0. 11	100
1963	7, 000	1, 640	. 23	. 21	100
1964	3, 720	1, 380	. 37	. 16	110
1965	1, 480	420	. 28	. 05	110
Second-cutting hay: [3]					
1963	2, 730	530	. 19	. 15	80
1964	730	150	. 21	. 06	70
1965	340	60	. 18	. 03	60
Third-cutting hay: [4]					
1962	1, 460	120	. 08	. 04	70
1963	2, 220	230	. 10	. 08	70
1964	1, 250	80	. 06	. 04	50
1965	300	70	. 23	. 02	90

[1] Deposition velocity was calculated by using a value of 30 days for the exposure period of first-cutting hay, 35 days for second-cutting hay, and 40 days for third-cutting hay.
[2] April to June; average yield 0.340 kg./m.^{2}.
[3] June 15 to July 30; average yield 0.225 kg./m.^{2}.
[4] July 20 to August 30; average yield 0.210 kg./m.^{2}.

of cesium 137 for each cutting divided by the integrated air concentrations yielded an average deposition velocity of 80 meters per day.

Thus while the deposition effects of cesium 137 on the alfalfa or pasture from separate rainfalls, as well as the deposition from air, are highly variable, these factors can be averaged over a considerable period of time. When the time interval is the growing period of a hay crop, the net result is that the hay can be expected to contain the amount (picocuries per square meter) of cesium 137 predicted by an apparent deposition coefficient.

There are two rather distinct feeding situations: (*a*) pasture feeding and (*b*) stored feeding on drylot. These must be considered when relating deposition to milk levels. The content of cesium 137 in the forage and in the milk of cows on pasture is shown for 1962, 1963, and 1964 (fig. 1). The bar graph along the horizontal scale shows the cesium 137 deposition by precipitation on the pasture. It is apparent that a general but not a precise relation exists between cesium 137 deposition by rainfall and its content in forage and milk.

A controlled feeding trial in which the cows were fed a known amount of cesium 137-contaminated feed showed that the transfer of cesium 137 from feed to milk can be quantitated quite accurately at equilibrium. The transfer coefficient, defined as the percentage of dietary cesium 137 secreted per liter of milk, ranged from 0.24 to 0.72 and decreased as the content of crude fiber increased in the diet (*24*).

For predominantly hay diets, the milk transfer coefficient was 0.24, with a variation coefficient of 27.2 percent for 71 observations. For predominantly grain diets, the transfer coefficient was 0.58, with a variation coefficient of 34.0 percent for 71 observations. These values are considerably less than those derived from tracer experiments, which indicated that the transfer coefficient was about 1 percent of the daily intake of cesium 137 (*15*). The reason for this decreased availability of fallout cesium 137 has been attributed largely to fixation at the plant surface by clay-mineral residues (*24*).

The values of the transfer coefficient for pasture conditions in our study averaged 0.33 for 1962–64, approximating the values derived from the predominantly hay ration. Predicting the cesium 137 levels in milk is complicated chiefly by uncertainties about the intake of forage and, consequently, cesium 137.

Figure 2 shows the cesium 137 levels found in the milk of the drylot herd from May 1, 1962, to December 15, 1964. The first few analyses in May 1962 indicated barely detectable levels

of cesium 137, resulting from the use of feed that had been stored since harvesting in 1961, a period of low environmental contamination by fission products. Rapidly rising and more variable levels occurred after mid-June 1962 due to feeding green alfalfa cut that summer. The maximum concentration of cesium 137 in milk (98 picocuries per liter) was reached July 19. From October 1, 1962, to June 15, 1963, during the winter feeding period, the levels were essentially constant at 30 to 40 picocuries per liter.

In the summer of 1963, the content of cesium 137 in milk rose in June and again reached levels of nearly 100 picocuries per liter. Hay harvested in mid-June 1963 was fed to the cows in August and September, and the concentration of cesium 137 in milk rose to 170 picocuries per liter. During the winter of 1963–64, the concentration declined to a fairly constant level of a little less than 100 picocuries per liter. The level increased only slightly during the summer of 1964, owing to hay harvested in mid-June. No green-cut alfalfa was fed to the cows during the summer of 1964.

The winter levels of cesium 137 in milk were lower than summer peak levels because the university herd was fed mostly third-cutting hay during the winter months. The concentration of cesium 137 in first-cutting hay was several times that found in second- or third-cutting hay (see table). First-cutting hay usually was harvested about June 15 and therefore was exposed

Figure 1. Cesium 137 in rainfall, pasture forage, and milk from cows grazing the pasture during the summers of 1962, 1963, and 1964

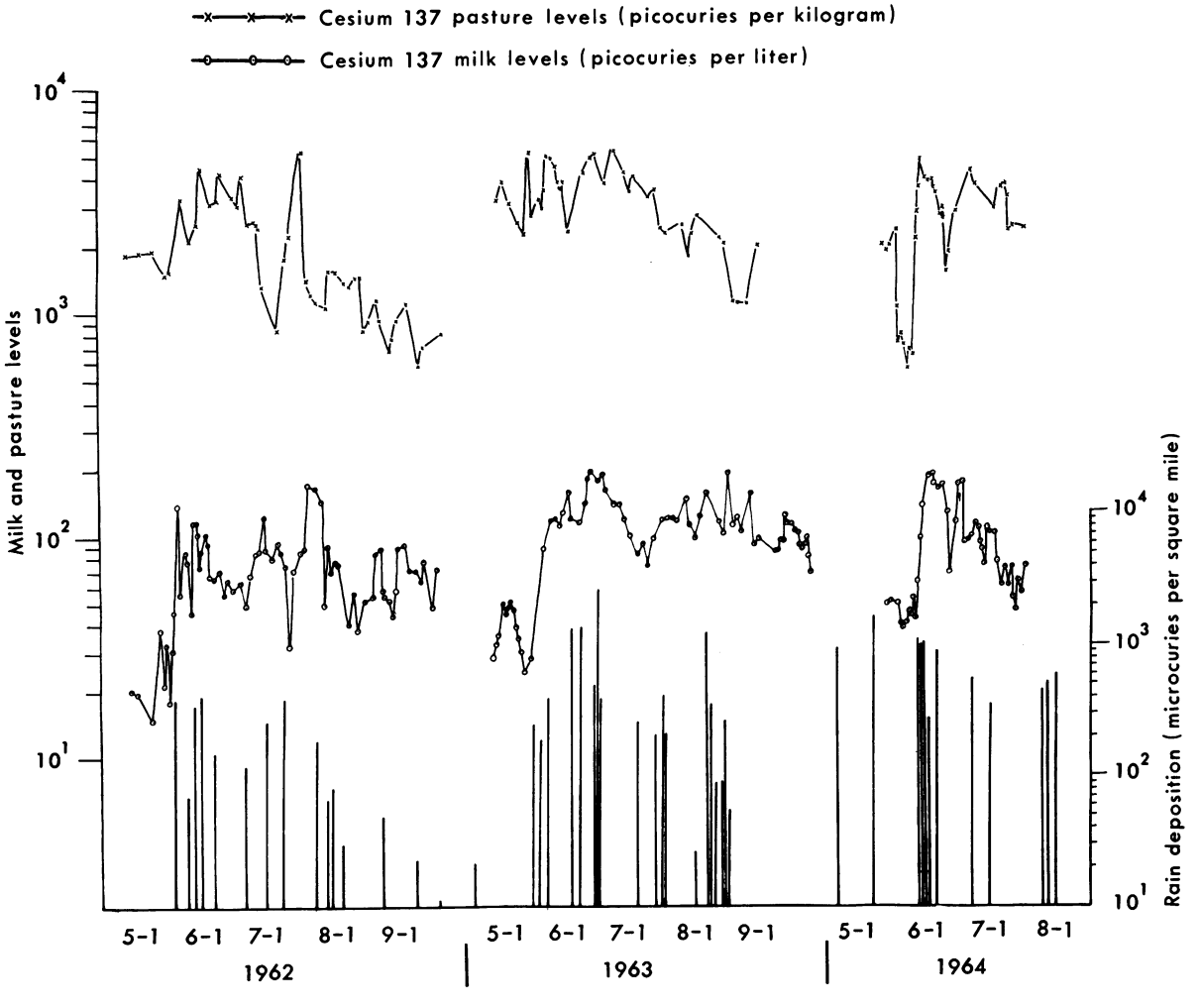
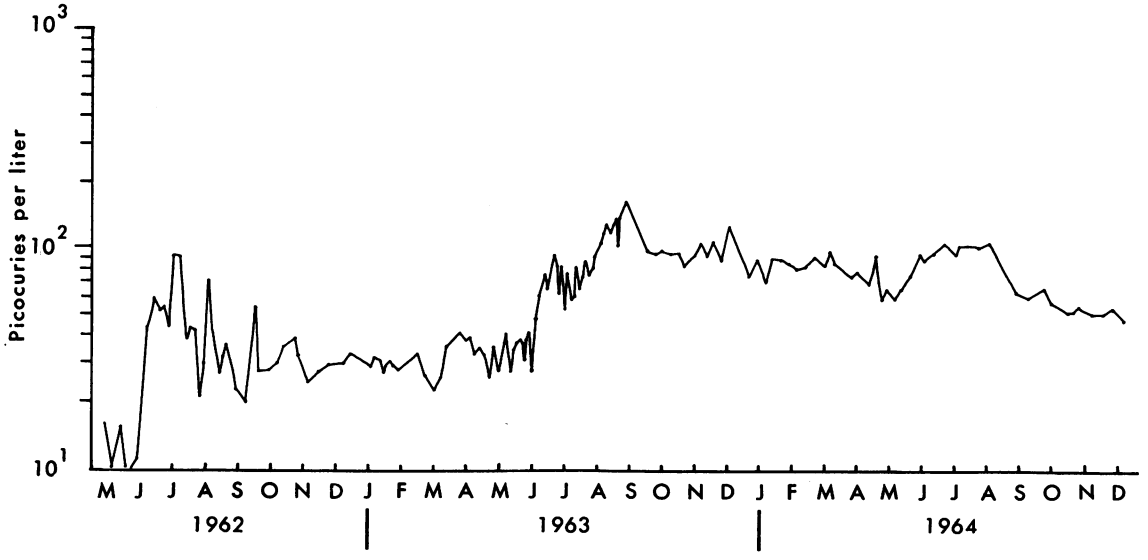


Figure 2. Cesium 137 in milk from cows fed on drylot (harvested) feed from May 1962 to December 1964



during its growth period to the usual spring peak of fallout. The second cutting of alfalfa hay was harvested in mid-July, and the third in late August. The cesium 137 content in first-cutting hay was lower than the maximum values found for pasture forage in the same year.

In addition to the transfer coefficients of feed to milk, it is necessary to consider the biological half-time of cesium 137 in the cow. During periods of rapidly fluctuating intakes of cesium 137 by the cows, as during pasture feeding, the milk levels of cesium 137 responded rapidly to the changes in pasture forage activity. This implied that the effective biological half-time of cesium 137 in the lactating cow was no greater than a few days.

Subsequent tracer experiments were performed to determine the biological half-time of radio-cesium in lactating cows by administering cesium 134 orally and following the milk secretion rate. These experiments showed that the excretion function was a sum of three exponential decay terms with half-times of 1, 3, and 35 days (*24*). In the lactating cows, the intercepts of the two short components at equilibrium were large relative to the long component and are interpreted as the reason for the rapid response observed in milk to changes in pasture fallout deposition.

The observed milk secretion functions are similar to those recently published by the U.S. Federal Radiation Council (*20*). Our studies, however, have shown that the milk transfer coefficients for fallout cesium 137 were considerably lower than predicted in the council's report. This is due to the decreased availability of fallout cesium 137 as compared with completely soluble tracer doses of the isotope.

These observations on the effective biological half-time of cesium 137 in the cow and the observed response in milk levels to fluctuating pasture deposition allow the prediction that peak concentration of cesium 137 in milk would appear quite rapidly after peak fallout depositions. The average lag between the production of milk and its consumption may be as much as 7 days but probably is on the order of 5 days. Therefore, peak concentrations of cesium 137 in milk would probably appear to the consumer in 1 to 2 weeks after the peak deposition.

The choice of feeding practices selected by dairymen can make any relation between milk contamination and fallout rate almost meaningless (*25*). One can easily postulate a feeding system in which the levels of cesium 137 in milk would decline while the fallout rate was increasing. As pointed out previously, due to the much higher cesium 137 concentration in first-cutting hay, harvested during the peak fallout periods, supplemental feeding of this hay can result in

higher milk concentrations from drylot-fed cows than from those fed on pasture. In the summer of 1963, the peak fallout occurred in June, before first-cutting hay was harvested (fig. 1), while the peak milk concentrations occurred in August and September, owing to the feeding of this first-cutting hay (fig. 2).

The availability of cesium 137 and its biological half-time in cattle would apply also to an evaluation of cesium 137 levels in beef in relation to the fallout rate. The long component of the biological half-time apparently governs equilibrium levels in meat. Comparisons of this type have been published (*26*).

Conclusions

Our investigations were made to determine a prediction model for the transfer of fallout to milk. While some of these conclusions may tend to be specific for one location, the limitations usually are apparent and over-generalizations can be avoided. For instance, the transfer coefficient of cesium 137 from hay to milk will vary somewhat depending on the importance of fixation of the cesium 137 by the clay minerals of the local soil. Feeding practices, such as drylot or pasture, must always be the first consideration, along with the fallout rate during the growing period of the feed. The deposition coefficients for fallout to hay crops need to be tested for other locations, especially where transfer of cesium 137 from soil to plant may be more important.

Within these defined limits then, our conclusions about the transfer of cesium 137 from fallout to milk should be applicable to all dairy systems in the United States. Further refinement for predictive purposes will depend largely on elucidating the deposition mechanisms of cesium 137 on plants and correlating such mechanisms with the agricultural practices in various milksheds.

The controlled dairy ecosystem used in these studies has provided data and concepts probably not available from data obtained by the nationwide sampling networks and thus will provide more reliable estimates of human body burdens caused by the dairy food chain through environmental contamination with cesium 137.

Summary

Milk samples were collected from 12 cows on pasture and 100 fed on drylot in 1962, 1963, and 1964 at Colorado State University. Concurrent samples of feed intake and milk production from each cow, daily air samples, and samples of each rainfall were collected. All samples were analyzed for cesium 137 content. Deposition of cesium 137 in rainfall ranged from 300 to 7,000 picocuries per square meter and on alfalfa hay from 60 to 1,640 picocuries per square meter. Deposition coefficients ranged from 0.06 to 0.37.

The maximum levels of cesium 137 in milk from cows fed on pasture were about 200 picocuries per liter in 1962 and 1963, while the maximum levels in milk from cows fed on drylot were about 170 picocuries per liter. Levels of cesium 137 in milk were lower during the winter months because third-cutting hay, with low cesium 137 activity, usually was fed to all the cows. Transfer coefficients, the percentage of ingested cesium 137 found per liter of milk, were higher for high-grain diets (0.58) than for predominantly hay diets (0.24).

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Health Education Abstracts

The Society of Public Health Educators has announced publication of *Health Education Abstracts*, a quarterly journal of articles abstracted from over 50 professional journals in the fields of education, public health, and social sciences. Volume I will be issued in the fall of 1966 at the time of the Society of Public Health Educators' annual meeting.

Subscriptions are $5 per year for Fellows of the Society of Public Health Educators, Inc., and $7.50 for the general public. Single copies are $1.50. Orders for the journal may be addressed to Dr. Marian E. Leach, editor, Society of Public Health Educators, Inc., 140 East 25th Street, New York City 10010.

Program Notes

Syphilis Decline in New York

Practicing physicians in upstate New York granted local health departments permission in 1965 to interview a record 99 percent of the persons with reported cases of syphilis. The interviews yielded names of 5,500 persons who had been exposed to syphilis; 4,700 were referred for medical examinations.

Total cases of syphilis reported upstate declined from 3,368 in 1964 to 2,665 in 1965. Reported gonorrhea cases, however, rose from 5,852 to 7,122.

High Intensity Microwaves

The Pennsylvania Department of Health has issued a warning about the dangers of serious burns from high-intensity microwaves leaking from superquick food-heating units.

High-intensity microwaves escaping from open or slightly ajar doors can burn deeply under a person's skin and even damage his eyes without his being immediately aware of the injuries, explained Edward J. Baier, chief of the department's industrial hygiene section.

Microwaves are used in food automats and cafeterias and even in some modern homes to heat and cook food quickly. In industry, they are used in fusing of glue, welding of wood, and in rolling machines and electronic equipment.

Preventative Dentistry for Children

About 3,000 military dependent children in the Beaufort, S.C., area participated in a program of preventative dentistry introduced by the U.S. Navy during Children's Dental Health Week—February 6–12, 1966.

At wooden water troughs in tents, the children cleaned their teeth with fluoride and pumice after Red Cross dental clinic volunteers had instructed them in proper brushing techniques (see photo). In the final step at the tent site, the children sat in chairs at a half-dozen completely portable field dental units to receive applications of topical fluoride by teams of dentists and technicians.

The third phase of the program calls for continued use of a dentifrice containing stannous flouride.

Naval stations at Fallon, Nev., and Kodiak, Alaska, also initiated such programs for children of military personnel.

Averting a Measles Epidemic

What could have been the worst measles epidemic in Illinois in 10 years was averted this past measles season, Dr. Franklin D. Yoder, director of the Illinois Department of Health, announced. An epidemic of major proportions had been predicted for the spring of 1966, and cases reported in the early part of the measles season corresponded to the disease pattern of the 1956 epidemic.

Wholehearted cooperation of local health departments, private physicians, and parents in using the measles vaccine, Yoder said, resulted in abortion of about 30,000 cases of measles compared with reported cases in the last epidemic year, 1956.

American Ambulances too Frilly?

The Pennsylvania Department of Health is conducting a survey of ambulances used in north central Pennsylvania communities to find the most practical and economical means of providing adequate ambulance service.

"Eventually we would like to arrive at a suggested set of standards which could be incorporated into the design of new ambulances," said Dr. C. L. Wilbar, State health secretary. "These standards," he pointed out, "should be strictly for the benefit of the patient, who is usually not in any condition to appreciate unnecessary frills."

A survey of community ambulances is needed because most ambulances are modified after purchase.

Items for this page: Health departments, health agencies, and others are invited to share their program successes with others by contributing items for brief mention on this page. Flag them for "Program Notes" and address as indicated in masthead.
