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STRONTIUM-90

Accumulation of Strontium in Bovine Bones

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The strontium, strontium-90, and calcium content of bovine bone ash from Nevada range cattle at three locations was studied from 1958 to 1962, inclusive. The level of strontium-90 was influenced more by world nuclear testing than by location of the animals within the state. Peak concentrations occurred in 1959 (1 year after initiation of the moratorium) and in 1962 (1 year after testing was resumed). Total strontium was characteristic of the location of the herd. When a herd was moved from an area of high concentration to a correspondingly low area, the total strontium in the bovine bone ash gradually became similar to that in the new environment. The strontium-90 content of bovine bone ash was unrelated to either total strontium or calcium. Calcium level was related to total strontium, but the correlation was not high ($r = 0.5$).

Physiologically and chemically strontium is similar to calcium, and, thus, both are concentrated in the osseous tissues of animals. The turnover rate of mineral elements from the skeleton is usually low; hence, the content of somewhat unusual elements in the bones of animals represents a long-time effect.

Since the advent of nuclear devices, much interest has been expressed in the accumulation of fission products in the tissues of both men and animals. Of the major fallout products of biological importance, only strontium-90 is retained in animal tissues for a long time (7.4 years) (*7*). Iodine-131 has a short physical and biological half life. While the physical half life of cesium-137 is long, its biological half life is short (17 days) (*7, 9*). Many other fission products are not readily absorbed and, thus, disappear from the animal in a short time (*12*).

The purpose of this study was to measure the stable strontium and strontium-90 in the bones of range cattle grazing on different range areas in Nevada and to determine the relation between the stable and radioactive elements under these conditions.

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Methods

During the 5 years from 1958 to 1962, grade and purebred Hereford cattle from three locations in Nevada were slaughtered twice each year: the Nevada Test Site of the Atomic Energy Commission (NTS) and Delamar Valley (DV), located 80 km. (50 miles) east of the NTS herd in southern Nevada, and the Knoll Creek Field Laboratory (KC) of the University of Nevada, located 90 km. (70 miles) south of Twin Falls, Idaho, and 480 km. (300 miles) north of the DV herd. The experimental areas and sampling procedures have been described in detail (*1, 2*).

At each sampling, one third of the shaft and entire femur head and the distal third of the eighth rib, including

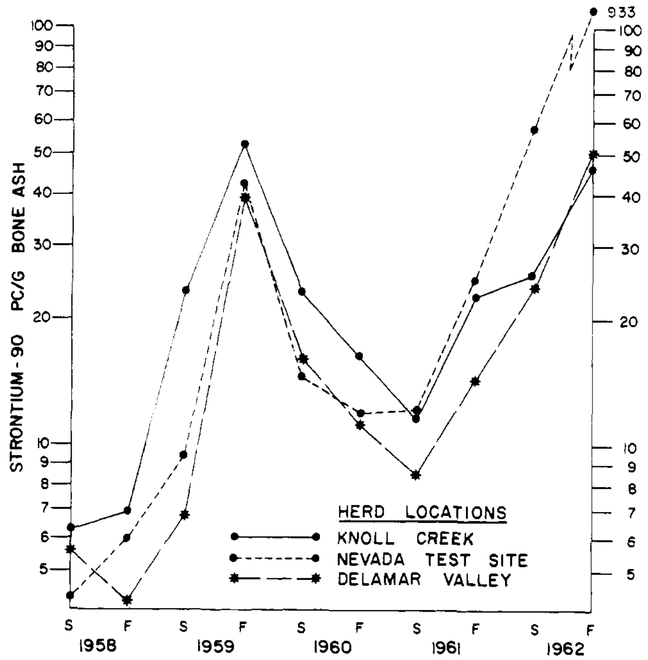

Figure 1. Strontium-90 content of bovine bone ash at three locations from 1958 to 1962, inclusive

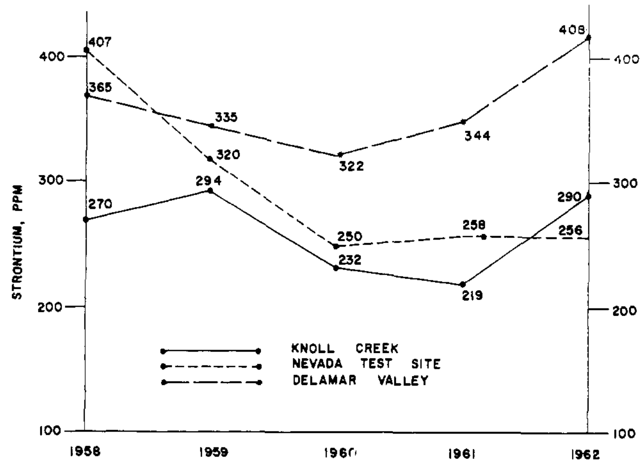

Figure 2. Strontium content of bovine bone ash at three locations from 1958 to 1962, inclusive

the costochondral junction, were removed from each animal and ashed in a porcelain crucible in a muffle furnace at 600° C. Total strontium, strontium-90, and calcium were determined. Calcium and strontium were separated as described by Wade and Seim (*13*) and determined on a flame photometer. Another aliquot of the strontium fraction was used for strontium-90 determination. Strontium-90 was determined as described by Martell (*8*) with the substitution of the ion exchange separation of Wade and Seim (*13*) for the conventional nitrate precipitation for isolation of the strontium. At slaughter, a complete autopsy was conducted on each animal and the following tissues were examined for histopathology: thyroid, adrenal, costochondral junction of the eighth rib, kidney, colon, rumino-reticulo fold, eye, spinal cord, and other abnormal or unusual tissues. Reproductive performance was also noted during this period.

During the first three sampling periods (1.5 years), four cattle (a calf, a yearling, a 2-year-old, and a mature cow) were slaughtered at each location. Thereafter, animals of these age groups, plus a 3-year-old animal, were slaughtered each period.

Results and Discussion

The type of range area and animal management procedures differed markedly between herds in the northern (KC) and southern locations (NTS and DV) in Nevada. The Knoll Creek herd was maintained at a higher elevation (1650 *vs.* 1070 meters; 5400 *vs.* 3500 feet), grazed on a sagebrush-grass range for 6 to 8 months each year, and fed harvested feeds for the remainder of the year. The southern Nevada herds were maintained on salt-desert shrub range for the entire year with occasional concentrate supplementation. The annual precipitation is usually less in the southern Nevada location (18 to 36 *vs.* 7 to 20 cm.; 7 to 14 *vs.* 3 to 9 inches, as reported by the Weather Bureau, 1958–62).

The strontium-90 content of bovine bone ash followed a similar pattern irrespective of herd location (Figure 1). From levels of 4 to 6 picocuries (pc.) or micromicrocuries per gram of bone ash initially, the content of strontium-90 increased about 10-fold during the 1958 and 1959 periods. These levels were directly related to world nuclear testing activity. Known nuclear tests during this period have been reported (*2*). The testing moratorium began in late 1958. The peak concentration of strontium-90 in bovine bone ash was reached approximately 1 year later. During the moratorium the levels of strontium-90 decreased but still did not attain the levels noted in 1958. When the moratorium ended in the fall of 1961, the levels immediately increased in all locations. Differences between years are statistically significant ($P < 0.01$), but not consistent for the different locations (Figure 1). During the early part of the study (1958–59), the strontium-90 content of bovine bone ash was higher for the KC herd; during the terminal years (1961–62), especially during the last year, the NTS herd was much higher. Since the prevailing winds from the Nevada Test Site travel northeast and normally miss the KC location, strontium-90 in the tissues of these cattle reflected fallout common to the northern hemisphere rather than fallout originating at the Nevada Test Site during 1958–59. The level of strontium-90 uptake was higher at the KC location, probably because of the greater amount of rainfall in northern Nevada. However, after the termination of the testing moratorium (September 1961), the uptake of strontium-90 by cattle on the Nevada Test Site was appreciably greater and reflects the very rapid acceleration of testing in this area. Since the levels were similar between the KC and DV areas, it appears that most of the fallout was contained on the NTS or else bypassed the DV area as it traveled east. Only minimal sporadic amounts of rain would be expected in southeastern Nevada.

The accumulation of strontium-90 in the tissues of grazing beef cattle was also influenced by age of the animal. When levels of strontium-90 were elevated (Table I), younger animals had higher levels than mature cattle (1959, 1962). Data obtained with man are similar (*6*). Schultz and Longhurst (*10*) found that the strontium-90 content of the mandible of deer collected in northern California followed a similar pattern in 1958–1960, but at lower levels. Russian data for pig and sheep bones collected in 1958 were higher, although the type of bone from these species was not specified (*11*). Strontium-90 levels in human bones in North America follows a similar trend, but the levels are lower by a factor of approximately 100 (*6*). Data presented in the literature (*7*) indicate that these values are lower than the maximum permissible concentration for human bone except for younger animals on the NTS in the fall of 1962. Since human bones have a lower concentration than cattle bones by a factor of 100 in North America (*6*), and since this occurred only on restricted areas of the NTS, it does not appear to represent hazards to man. When bone levels of strontium-90 were low in this study, all cattle showed a similar trend. Calves may even have had slightly lower levels during periods of low uptake (1960–61). At these times this interaction was statistically significant ($P < 0.05$). This phenomenon

Table I. Effect of Age of Animal and Sampling Time on Strontium-90 Content of Bovine Bone[a]

Year		Calf	Yearling	2-year-old	3-year-old	Mature
				Age of Animal Pc./G. Bone Ash		
1958	Spring	5.7 ± 2.4[b]	6.2 ± 5.3	4.8 ± 3.1	...	3.9 ± 2.4
	Fall	6.7 ± 4.8	6.2 ± 3.9	5.7 ± 2.8	...	4.3 ± 1.5
1959	Spring	13.2 ± 12	15.2 ± 8.2	18.3 ± 17	...	12.3 ± 10
	Fall	58.6 ± 9.6	61.5 ± 9.6	39.2 ± 16	32.3 ± 8.8	34.2 ± 21
1960	Spring	13.8 ± 4.6	20.6 ± 6.2	19.6 ± 2.6	20.3 ± 5.7	16.1 ± 11
	Fall	11.9 ± 2.5	14.1 ± 3.7	13.7 ± 3.5	14.7 ± 5.6	11.8 ± 4.2
1961	Spring	6.7 ± 4.4	7.8 ± 2.7	14.7 ± 4.0	13.5 ± 3.1	9.0 ± 3.1
	Fall	12.8 ± 3.2	21.1 ± 5.1	19.3 ± 5.2	23.4 ± 6.8	26.3 ± 9.8
1962	Spring	59.1 ± 42	36.5 ± 35.0	16.8 ± 3.2	36.1 ± 12	30.1 ± 8.8
	Fall	1140 ± 1660	141 ± 150	210 ± 260	130 ± 140	93.3 ± 94.0

[a] Statistically significant age of animal × sampling time interaction, $P < 0.05$.
[b] Mean plus standard deviation.

Table II. Correlations of Constituents of Bovine Bone Ash

Constituent[a]	Correlation Coefficient
Strontium and strontium-90	0.09
Strontium and calcium	0.54[b]
Strontium-90 and calcium	−0.04
Rib Sr and femur Sr	0.89[b]
Rib Sr-90 and femur Sr-90	0.93[b]
Rib Ca and femur Ca	0.35[b]

[a] 139 animals.
[b] Statistically significant at $P < 0.01$.

appears to measure, to a certain extent, the rate of bone formation in the younger animal. Since strontium is related to calcium, both biologically and chemically, it is a pattern that one might expect. It would also suggest that strontium-90 occurs mostly as a surface contaminant of western range plants rather than entering the water-soil-plant-animal cycle. If not, one would expect the variation in strontium uptake by calves to be more constant, irrespective of testing period. The strontium-90 content of the bone ash of calves is exceedingly variable between sampling dates and directly coincides with nuclear testing.

The patterns of iodine-131 (*7*), cesium-137 (*2*), and strontium-90 accumulation and dissipation from animal tissues differ greatly as expected and reflect the varying physical and biological half lives of these elements. Monitoring studies with cattle have facilitated the simultaneous measurements of these elements at levels currently available in the biosphere with an animal species that maximizes the uptake of these elements and concentrates them in its tissues at levels that are much higher than expected with man. The average strontium-90 content of the bone ash of rib and femur was 67.2 *vs.* 59.5 pc. per gram of bone ash. These results are similar to earlier studies (*3, 5*).

The effect of location by years on the stable strontium content of the bone ash of cattle from these locations is shown in Figure 2. The NTS herd was assembled from the DV herd in late 1957. Animals in the DV and KC herds had spent their entire lives in their current locations. Apparently these three herds represented two different environments in regard to total strontium uptake. The animals in the DV herd contained 322 to 408 p.p.m. of strontium in their bone ash, while the KC herd bone strontium ranged from 219 to 294. The NTS herd gradually changed from a high strontium level to a level similar to the KC herd during the period measured. Types of range plants and other environmental features are similar in the Nevada Test Site and Delamar Valley. These data suggest that soil and vegetation in Delamar Valley probably contain higher levels of stable strontium than other areas in Nevada and, consequently, cattle tissues contain higher levels of this element. The strontium content of range plants has not been measured at this time.

In contrast to the strontium-90 levels, the femur consistently had higher levels of stable strontium than the rib (338 *vs.* 304 μg. Sr per gram of bone ash, statistically significant at $P < 0.05$). The age of the animal had no consistent effect on the amount of stable strontium in bovine bone ash. Bohman *et al.* (*3*) found that the total strontium content of the rib was less than the femur, but the level of stable strontium increased with age of the experimental animal. The animals in the earlier study had been maintained under similar conditions, while in the current study animals were obtained from three rather diverse environments. The calcium content of bone ash was relatively constant among years, bones, and locations. Younger animals had slightly less than older animals (34.6, 35.5, 36.3, and 36.3% Ca for calves, yearlings, 2-year-old, 3-year-old, and mature animals, respectively).

The relation among the strontium, strontium-90, and calcium content of bovine ash was studied (Table II). The strontium-90 content was unrelated to either strontium or calcium. Total strontium was significantly correlated with total calcium ($r = 0.54$). The relation between rib and femur calcium was 0.35, between rib and femur strontium, 0.89, and between rib and femur strontium-90, 0.93.

Apparently, the intermittent exposure to strontium-90 and the continuous exposure to stable strontium created metabolic conditions that resulted in tissue deposition patterns that are unrelated. This study was primarily concerned with the accumulation of strontium in the tissues of grazing animals, and does not provide information on the effect of total strontium on strontium-90 uptake. Several environmental conditions differed between locations in addition to the level of stable strontium. Comar (*4*) has stated that strontium-90 will not resemble stable strontium until steady-state conditions are obtained, leading to similar physical distribution of these two forms of this element. If testing completely stopped or became constant, this steady state could, in time, be realized. Conditions leading to a steady state have not been obtained at this time. No pathology or histopathology observed in these animals during this study appears to be related to radiation damage. Reproductive patterns appear to be normal.

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