Table IV. Multilevel Assay Expressing Relative Estimation of Available Calcium in Micro-Cel as Related to $CaCO_3$ Calcium

Criteria[a]	Sex	3 Weeks Estimated available Ca, %	3 Weeks Lower[b] limits, %	3 Weeks Upper[b] limits, %	8 Weeks Estimated available Ca, %	8 Weeks Lower[b] limits, %	8 Weeks Upper[b] limits, %
Plasma alkaline phosphatase	M	N.s.[c]	N.s.[c]	N.s.[c]	77	57	104
	F	60	32	113	59	28	122
Tibia ash	M	80	56	114	95	81	112
	F	59	44	79	75	54	104
Tibia calcium	M	79	54	116	85	69	105
	F	54	41	73	72	55	96
Body growth	M	53	31	91	62	46	83
	F	N.s.[c]	N.s.[c]	N.s.[c]	70	46	109

[a] Log transformation of all data used in analyses.
[b] Upper and lower 95% confidence limits.
[c] N.s. = not significant, since slopes did not approach significance.

Cel, as measured by alkaline phosphatase, was similar to that of tibia ash at 3 weeks and below it at 8 weeks. Several of the analyses indicate low precision because of their wide confidence limits. The results suggest that a tibia ash analysis is satisfactory in evaluating calcium availability in 3- and 8-week-old pullets, whereas body growth comparisons are adequate for cockerels of comparable age. This conclusion was reached because a satisfactory dose response curve is obtained with each of these two analyses, and their confidence limits are least variable in the sex of selected use. Plasma alkaline phosphatase data may not give as precise results as body growth and tibia ash. Calcium analysis of the tibia ash is not suggested, since it is more cumbersome than a tibia ash determination.

In the present experiment the calcium present in Micro-Cel was 53 and 59% utilized by 3-week-old Arbor Acre White Rock cockerels and pullets, respectively, when compared to $CaCO_3$ containing an equivalent amount of calcium. At 8 weeks, the value increased to 62% for cockerels and 75% for pullets. The sex difference in utilization of calcium is believed to be due to the different growth patterns; in the pullet the apparent utilization of calcium from Micro-Cel may be accentuated because of slower growth. The difference between cockerels and pullets in early growth is not great, but by 8 weeks it is appreciable.

It is possible that these interpretations of the data may apply only to Arbor Acre White Rock chicks and that other strains of chickens have different growth patterns, and may therefore have different calcium requirements.

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CATTLE AS FALLOUT MONITORS

Cesium-137 Concentrations in Desert Range Cattle

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Cesium-137 concentrations in desert range cattle showed a declining trend from 1959 through 1961, probably due to decreasing amounts of Cs^{137} available in the biosphere. In 1962 the concentrations increased in response to renewed nuclear weapons testing. Correlation between liver and muscle Cs^{137} concentrations was highly significant. The slope of the equation relating liver and muscle Cs^{137} concentrations was 0.42, indicating the possibility of different mechanisms of Cs^{137} uptake in these two tissues.

Cesium-137 is the only fission product of appreciable half life found in the edible tissues of meat animals. Other fission products are either poorly absorbed from feed or are highly localized in portions of the animal not normally used for human food—for example, zirconium-95 and ruthenium-106 are not physiologically absorbed by the animal (*16*), strontium-90 is localized in osseous tissues, and iodine-131 is confined largely to the thyroid gland. The iodine-131 concentrations in the thyroid glands of the cattle used in this study have been reported (*3*).

This study was undertaken to monitor the concentration of cesium-137 in livestock grazing two divergent desert range areas.

Methods

Three herds of cattle were studied, all grade or purebred Herefords. The cattle in the two southern locations, DV (Delemar Valley) and NTS (Nevada Test Site), subsisted on range alone except for occasional concentrate feed-

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ings during the winter. The KC (Knoll Creek) herd was on range during the summer and fed locally produced native grass hay during the winter.

In the spring and fall, after the first two years, five animals were sacrificed from each herd—a calf, a yearling, a two-year-old, a three-year-old, and a mature cow (Table I).

Table II gives all published releases of fission products to the atmosphere during this study.

Samples of liver and skeletal muscle from the round were taken from each animal and 150-gram subsamples of each were analyzed for Cs^{137} by the method previously described (*2*) after wet digestion with nitric acid (*1*). Previous studies (*2*, *6*) indicated that this procedure gave good decontamination from fission products of similar γ-ray energies and quantitative recovery of Cs^{137}. Samples that were not subsampled immediately were frozen until analysis.

All measurements of Cs^{137} were made with a well-type scintillation counter [5.1-cm. diameter and height NaI(Tl) crystal], single-channel pulse height analyzer, and scaler; the pulse-height analyzer was set to accept γ-ray energies of 0.662 ± 0.025 m.e.v. Unknowns were compared with standards previously calibrated against known quantities of Cs^{137}. Two counting systems of different manufacture were used for each sample. They were virtually identical in background (4 counts per minute) and efficiency (10 pc. of Cs^{137} per count per minute) at the narrow band width used. Samples were generally counted for 2 hours with a 1-hour background between samples. Background data were averaged daily and weekly. For a representative low activity sample of 0.25 pc. per gram the 43 pc. measured gave a total count rate of slightly more than twice background. For samples below 0.2 pc. of Cs^{137} per gram, duplicate analyses indicated a standard deviation of analysis of ±0.032 pc. of Cs^{137} per gram.

Although Cs^{137} is the principal isotope of cesium remaining for an appreciable time in fallout, the gaseous precursors of Cs^{135} were observed in the effluent from the Kiwi reactor series (*14*). Since the NTS herd was located in the fallout pattern from the Kiwi reactor test of October 19, 1960 (*3*), and was sampled 12 days after the test, cesium-135 was searched for in these samples. Subsequent to γ-ray measurement of Cs^{137} the cesium coprecipitated with cobalt cobalticyanide was dissolved, the cesium reprecipitated as the chloroplatinate, and the precipitate transferred to a flat planchet and counted with a low-background anticoincidence Geiger counter to determine total beta emission. Comparison of the γ-ray and β-particle measurements revealed no beta radioactivity that could not be accounted for by Cs^{137}. It was concluded that beta-emitter Cs^{135} was not present in these samples in detectable quantities.

Table I. Experiment Design of Biannual Sampling Procedures for Each Herd

Period	Calves	Yearlings	2-Yr.-Old	3-Yr.-Old	Adult	Total: From each herd	Total: Per sample period
Fall 1957[a]	2	2			1(2)[b]	5(6)[b]	11
Spring 1958	1	1	1[c]		1	3(4)[c]	10
Fall 1958	1	1	1		1	4	12
Spring 1959	1	1	1		1	4	12
Fall 1959 to fall 1962[d]	1	1	1	1	1	5	15

[a] NTS and DV herds only.
[b] Two adults slaughtered from DV herd only.
[c] 2-yr. old from NTS herd only.
[d] Biannually.

Table II. Relation of Known Nuclear Tests to Herd Sampling Dates in Nevada[a]

Time Sampled	I^{131} Releases
Fall 1957	Plumbob series (5/21 to 10/7/57) Nevada Test Site. British series (to 12/57), Pacific ocean. U.S.S.R. series (to 12/57). Safety tests (12/57) Nevada Test Site. NTS herd assembled 12/57
Spring 1958	No local nuclear tests. Hardtack, Phase I (4/58 to 8/58), Pacific. British series (4/58 to 9/58), Pacific
Fall 1958	Hardtack, Phase II, (9/12 to 10/30/58), Nevada Test Site. Sampling immediately post testing
Spring 1959	Testing moratorium
Fall 1959	Testing moratorium
Spring 1960	Testing moratorium. French tests (2/60 to 4/60). Sahara desert
Fall 1960	Testing moratorium. "Kiwi" reactor tests (7/8/60, 10/19/60), Nevada Test Site
Spring 1961	Testing moratorium. French tests (12/60), Sahara desert
Fall 1961	U.S.S.R. tests from 9/61
Spring 1962	U.S.S.R. and U.S. tests
Fall 1962	U.S.S.R. and U.S. tests

[a] Compiled from several sources by the Reference Department, University of Nevada Library. Checked by the Division of Operational Safety, U. S. Atomic Energy Commission.

Results and Discussion

Considerable differences exist between the range types. The KC location is a representative sagebrush-grass range, whereas the DV and NTS locations are salt desert-shrub ranges. The NTS and DV cattle averaged about 460 to 610 meters (1500 to 2000 feet) less elevation than the KC cattle (1650 meters or 5400 feet), and were approximately 500 km. (300 miles) south of the KC herd. The KC area is typical of northern and the DV and NTS areas of southwestern great basin range conditions.

Considering the data as a whole, a highly significant correlation ($P = 0.001$, $r = 0.987$) was found between liver and muscle Cs^{137} concentrations (Figure 1). A subset composed of only the low concentration 1959–1961 data gave a regression equation insignificantly different from that for all of the data ($P = 0.001, r = 0.85, L = 0.0193 + 0.497M$). A correlation between the Cs^{137} concentrations of liver and muscle was not surprising; however, the high significance would not be expected *a priori*. The slope of the regression equation (0.42) relating liver and muscle Cs^{137} concentrations indicated that the entry of cesium into tissues was not a passive contamination process. If it was strictly a diffusion process, one would predict a slope of 1 (1 to 1 relation), modified by the difference in water content of the two tissues. The difference in water content of beef liver (70%) and muscle (74 to 77%) (*8*) is not sufficient to account for the observed slope. On this assumption the predicted slope would be about 0.9. Similarly, the differences in Cs^{137} concentration in liver and muscle are not proportional to the differences in potassium concentration. Assuming a constant ratio within an animal of Cs^{137} to potassium, one would expect the Cs^{137} concentration in liver to be greater than in muscle (*8*)—the opposite of the findings reported here. One must therefore conclude that the Cs^{137} content of tissues is governed by considerations other than water content (simple concentration equilibrium) or potassium content. Cesium-137 is apparently subject to some process(es) aiding its entry into muscle and/or excluding it from liver. Although not explicitly indicated, a relation of the type described is implicit in published data for several species (*5*, *13*, *16*, *17*).

Because of the method used for sampling the range cattle populations, it was impossible to arrive at a statistical

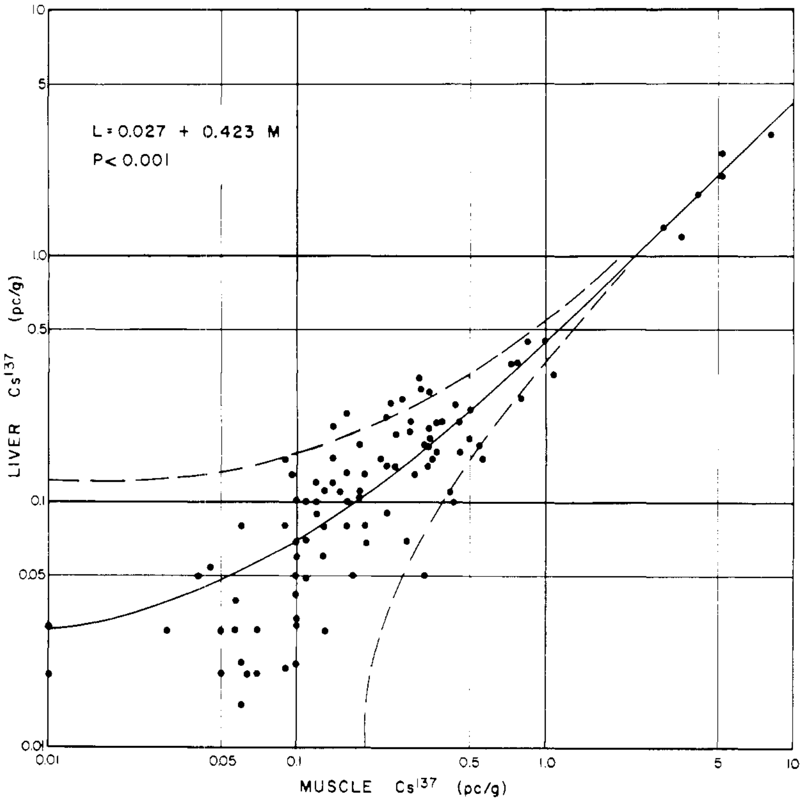

Figure 1. Correlation of liver and muscle Cs^{137}

Data presented in logarithmic graph because of wide range. Linear regression equation and envelope of standard deviation thus appear as curved lines

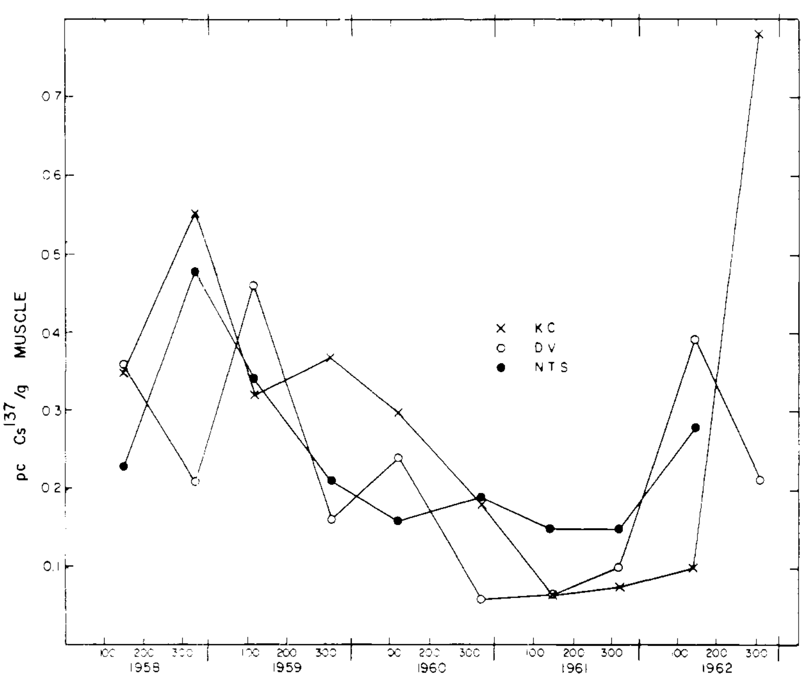

Figure 2. Muscle Cs^{137} concentrations in range cattle

Each point represents average of three to five animals (see Table I). Numbers on abscissa refer to serial number of day of year

measure of the effect of age on Cs^{137} concentration in liver and muscle. Only one animal per age group was slaughtered at any location at any time. During the period without nuclear weapons tests, the Cs^{137} concentration in animals changed only slowly. If one considers spring and fall data as replicates, one can apply analysis of variance techniques to these data. This was done with the 1960 muscle data and the 1961 liver data (Table III).

Factorial analysis showed that location was highly significant ($P = 0.01$) except on the liver data when the calf group was included ($P = 0.10$). Age was insignificant ($P = 0.25$). In view of the foregoing, all data, irrespective of age, from a given location at a given time were averaged. For samples collected prior to the fall of 1962, the average standard deviation of these means was 0.043 pc. of Cs^{137} per gram (Figures 2 and 3).

Data on Cs^{137} analyses from the NTS and KC locations for 1957–59 were reported by Van Dilla, Farmer, and Bohman (*15, 16*), who found a response of the NTS group to nuclear weapons test on the Nevada Test Site during this period, but reported no increase of Cs^{137} at the KC location. These samples for 1958–1959 were reanalyzed by the present method, averaged with those previously reported, and plotted in Figures 2 and 3.

Only two sets of samples were taken before the cessation of nuclear weapons tests in 1958. Another set was taken within 3 weeks after testing ceased at the Nevada Test Site and shortly before the conclusion of a test series in Siberia. No gradient in Cs^{137} concentration was observed with distance from the Nevada Test Site. Published data (*3*) for I^{131} concentrations in the thyroid glands of the same cattle indicated a marked gradient with distance from the Nevada Test Site. Iodine-131, having a half life of 8 days, indicated fallout produced only shortly before the measurement. Cesium-137 now in the biosphere could have been produced at any time since the development of nuclear weapons. Thus I^{131} could be expected to respond more markedly to a release of fission products than Cs^{137}. Fission products resulting from detonation of high yield nuclear devices are carried through the tropopause into the stratosphere, from where they fall to earth slowly and essentially uniformly around the northern hemisphere. The half life of I^{131} is too short to permit appreciable transport by this mechanism (*3, 9*). At areas remote from nuclear weapons testing this stratospheric route is the principal source of fallout cesium-137. Thus one would expect less gradient in Cs^{137} with distance from the Nevada Test Site and less dramatic fluctuations than were observed with I^{131}. This is in accord with the data presented in Figures 2 and 3.

During 1959, 1960, and 1961 the cesium-137 concentration in liver and muscle of range cattle decreased slowly. The values in 1962 were about one fourth of the 1958 values, reflecting the decreasing amounts of Cs^{137} available in the biosphere, in agreement with data on humans (*10*). Little difference was observed in cesium-137 concentration, although the data from the NTS herd

Table III. Analysis of Variance Summary

Source of Variance	Calf Group Included: Degrees of Freedom	Calf Group Included: Mean Square, Muscle	Calf Group Included: Mean Square, Liver	Calf Group Excluded: Degrees of Freedom	Calf Group Excluded: Mean Square, Muscle	Calf Group Excluded: Mean Square, Liver
Age	4	0.0297	0.0161	3	0.0081	0.00017
Location	2	0.117[a]	0.0175	2	0.0887[a]	0.00445[a]
Age × location	5	0.0115	0.0245	4	0.0166	0.00181[b]
Error	18	0.0195	0.0109	14	0.00633	0.0044

[a] $P = 0.010$ or less.
[b] $P = 0.025$.

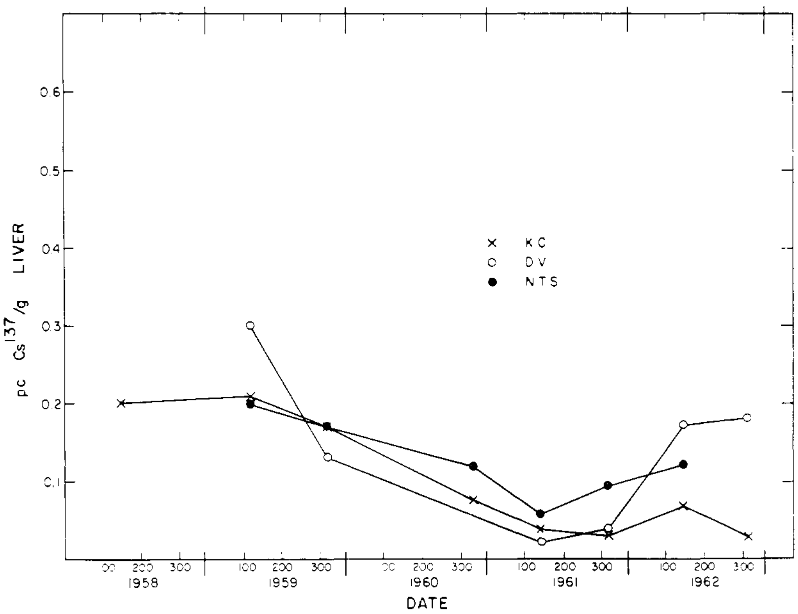

Figure 3. Liver Cs^{137} concentration in range cattle

Each point represents average of three to five animals (see Table I). Numbers on abscissa refer to serial number of day of year

generally were slighly higher than from the other two locations. For example, the NTS muscle Cs^{137} concentration in the fall of 1958 was 0.42 pc. per gram (range 0.39 to 0.71) and in the fall of 1961 was 0.15 pc. per gram (range 0.10 to 0.23), but the DV muscle Cs^{137} concentration in the fall of 1958 was 0.21 pc. per gram (range 0.12 to 0.37) and in the fall of 1961 was 0.10 pc. per gram (range 0.05 to 0.18). Analysis of variance (Table III) indicated this effect was significant. This may represent an increased deposition before 1959 of short-range fallout containing Cs^{137} from tests conducted on the Nevada Test Site.

During 1962 the Cs^{137} concentration in range cattle increased in response to the resumption of nuclear weapons testing (Figures 2 and 3). At the DV and KC locations the increase was relatively moderate. At the NTS location, the cattle were moved after the spring 1962 sampling, so as to be exposed to the maximum possible fallout resulting from testing on the Nevada Test Site. Cesium-137 concentrations in muscle and liver averaged 5.5 pc. per gram (range 3.5 to 8.9) and 2.3 pc. per gram (range 1.2 to 3.9), respectively, on five animals. These values are considerably greater than Cs^{137} concentrations reported in this and other studies, but the cattle were exposed to the maximum fallout possible under the test circumstances.

Precipitation at the KC location is about twice that of the other two locations, averaging 10 inches per year contrasted to an estimated 6.4 inches at the NTS and DV locations. This difference did not result in any obvious differences in Cs^{137} concentrations in liver and muscle. Possibly the increased deposition at the dryer southern locations (DV and NTS) due to their proximity to the Nevada Test Site offset the expected increased deposition due to precipitation at the KC location.

The muscle cesium-137 concentration was greater than that in liver, as would be expected from the previously discussed relation between liver and muscle cesium, and also more erratic. The reason for this greater fluctuation of muscle cesium is not readily apparent.

The levels of cesium-137 found in this study are in general agreement with those previously reported for the same herds in the same locations by Van Dilla, Farmer, and Bohman (*15*, *16*). Our 1961 measurements are only slightly higher than the Cs^{137} concentrations in New Mexico cattle before and after the Project Gnome explosion in December 1961 (*17*). Data from human samples taken in Japan in 1958 (*18*) and in Germany in 1959 (*12*) are approximately the same as from cattle samples taken in the same years.

In all animals studied the concentration of Cs^{137} was less than the maximum permissible concentration (*4*, *7*) and hence the animals were considered fit for human consumption.

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