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Selected Radioisotopes In Animal Tissues In Nevada:

^{90}Sr and ^{137}Cs Measurements From 1956 to 1977

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SELECTED RADIOISOTOPES IN ANIMAL TISSUES IN NEVADA: ^{90}Sr and ^{137}Cs Measurements from 1956 to 1977

by

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ENVIRONMENTAL MONITORING SYSTEMS LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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INTRODUCTION

Since 1956 the Animal Investigation Program (AIP) has been conducting surveillance of domestic and wild animals on and around the Nevada Test Site (NTS) and assessing the radionuclide burdens present in their tissues and any resulting pathological effects. Other AIP objectives were to investigate alleged dosage to animals, to maintain public information contacts with the off-site population, and to conduct special ad hoc investigations. Most of the radionuclide burden data and the AIP's history and evolution have been published in the annual reports of this program (Farmer 1959; Fountain 1961; Smith and Giles 1970, 1974, and 1975; Smith et al., 1976a, 1977a, 1977b, 1978a, 1978b, and 1979). Additional unpublished data were gleaned from the AIP historical files. This rather substantial body of radiological data has been reviewed and analyzed for trends with time and source of exposure. Because of the volume of data, only a summary has been included in the appendices of this report. The complete data are available in the AIP file for further study.

A sufficient data base existed for trend analyses for the longer-lived and biologically-active radionuclides such as strontium-90 in bones, cesium-137 in soft tissues, iodine-129 in thyroids, and plutonium-238 and -239 in bones and soft tissues. The presence of shorter-lived radionuclides such as iodine-131, zirconium-95, cerium-144, ruthenium-106, etc., were usually relatable to specific events, (e.g., the Peoples' Republic of China's atmospheric tests) or specific locations, (e.g., tritium in tissues collected from animals near Sedan Crater or drinking from waters draining the tunnels of Ranier Mesa) and these findings have been described adequately in the previously mentioned annual reports. Plutonium-238 and -239 trends and levels in the NTS beef herd were discussed in detail in previous reports (Smith et al., 1976b and 1979) as were iodine-129 levels in thyroids (Smith 1977). Only the strontium-90 and cesium-137 data and trends are reported herein.

SUMMARY AND CONCLUSIONS

A 1974 study of cesium-137 in soil in the NTS environs (Andrews and Vandervort, 1978) resulted in the finding that concentrations in soil from the northern arc extending from northwest to northeast within approximately 200 km from the NTS center had a geometric mean of 0.89 pCi/g. This is nearly three times the geometric mean of 0.33 pCi/g for the remainder of the locations north of an east-west line through the NTS center and 16 times the 0.05 pCi/g found at locations south of the east-west line. These findings follow a general pattern similar to the cumulative close-in fallout patterns from atmospheric testing at the NTS. Cesium-137 and strontium-90 have similar half-lives and should be distributed in similar fashion. The conclusion, then, would be that strontium-90 was deposited in a similar pattern from close-in fallout from the atmospheric tests.

The correlation of strontium-90 in the bones of young ruminants on and near the NTS with annual global fallout rates indicates that close-in fallout was not a significant long term source of strontium-90. Desert bighorn sheep from the northern portions of the hunt areas, particularly from 1972 on, exhibit higher concentrations of strontium-90 in bone than those from the southern areas. While this observed difference may be due to a higher uptake by plants of strontium-90 deposited in the northern portion from close-in fallout, it may also be due to higher annual rainfall with its associated higher annual deposition of worldwide fallout.

Analysis of strontium-90 data for desert bighorn sheep as a function of age showed that the controlling factor in bone concentration was the exposure which occurred during the period of maximum bone growth, up to one year of age. Subsequent intake has some effect, but much less. The same analysis showed an effective half-life for strontium-90 in desert bighorn sheep of about 4.8 years. Comparable data for humans yielded effective half-lives of 2.7 and 4.3 years for two population groups.

The enhanced strontium-90 uptake by young animals was also demonstrated by the data from the NTS beef herd. During, or immediately following, periods of higher deposition rates the younger animals exhibited higher concentration in bone. During low fallout periods the older animals, which had been young during heavier fallout periods, had higher concentrations of strontium-90 in bone than the young animals.

Variations in tissue concentrations of cesium-137 confirm earlier reports of a short effective half-life, on the order of 2 to 3 weeks. The conclusion is that the concentration of cesium-137 in edible tissue can be expected to reach ambient levels within 6 months after exposure to a contaminating event

if the animals are provided uncontaminated feed. Even in the absence of positive action to provide clean feed, natural weathering reduces vegetation contamination levels so rapidly that animal tissue concentrations will still return to normal in nearly the same period of time.

The maximum hypothetical annual dose to a standard man, consuming edible tissue from an animal exposed to fallout on the NTS, was 32 mrem from cesium-137. Under normal circumstances, tissue contaminated to that level would not be available for consumption for a full year due to the short effective half-life. Therefore, the maximum dose would be considerably less. Worldwide fallout appears to have been the predominant source of strontium-90 in the animal diets. The comparisons between annual deposition rate and human diet intake of strontium-90 and between strontium-90 concentration in animal and human bones tends to confirm this. A possible reason for this stronger correlation with annual fallout rates than with close-in deposition is the length of exposure. Most of the close-in fallout at the NTS occurred for relatively short periods of time. The majority of the worldwide fallout has occurred throughout the year. Although short-term incidences of high contamination of vegetation followed each of the atmospheric test series, as evidenced by higher levels found in the tissues of Lincoln County deer and desert bighorn sheep from the northern portion of the hunt area, the majority of the exposure must have come from the more steady-state contamination resulting from worldwide fallout.

A similar conclusion regarding the role of continuously deposited worldwide fallout in tissue concentrations is reached for cesium-137. The concentrations measured in the various organs sampled reflect the recent fallout history, within the past few months. The fluctuations noted, correlated with deposition rates, indicates that animal uptake of these two radionuclides results primarily from surface contamination on vegetation rather than from plant uptake from the soil.

As part of the 1974 study in the NTS environs by Andrews and Vandervort, strontium-90 was measured in selected vegetable samples collected from home gardens. Six of 16 samples analyzed had low levels of strontium-90. One of these was from south of the NTS and five were from north of the NTS. The higher levels of contamination were from three leafy vegetables and could have resulted from either worldwide fallout (two of the samples also contained high levels of cosmic-generated beryllium-7), from contamination by resuspension of soil contaminated by earlier fallout, or from uptake from the soil. The inference was that the concentrations observed may have been related to the higher fallout which had occurred in the areas sampled. Even if this is the case, the degree of contamination of vegetation due to resuspension or uptake, even in plants from an irrigated garden, appears to be low. With the low rainfall in the area, it is unlikely that the residual strontium-90 or cesium-137 in soil plays any important part in the natural vegetation food chain, with the exception of that soil ingested directly with plant roots, etc., during grazing or that deposited on the plants by resuspension.

Histopathological examinations of tissue and lesion samples, and analysis of blood samples from the animals used in this long-term study have revealed no effects which could be attributed to exposure to radioactive materials.

One objective of the program from the beginning was "to provide further information as to the status of the offsite animals in their environment, with special emphasis on the radioactive isotopes uptake from fallout in ruminants". The results of this study of the data collected indicate that proximity to the NTS has had very little long-term impact on animals from the standpoint of uptake of either strontium-90 or cesium-137.

STRONTIUM-90 IN BONES OF CATTLE, DEER, AND BIGHORN SHEEP ON AND NEAR THE NEVADA TEST SITE 1956 TO 1977

BACKGROUND

Measurements of strontium-90 in the bones of animals on and near the NTS have been made since 1956. The groups of animals studied and the periods for which data are available are:

NTS Beef Herd	1957-1977
Delamar Valley Beef Herd	1957-1961 1964-1967
Knoll Creek Beef Herd	1957-1961 1964-1967
NTS Deer	1964-1977
Lincoln County Deer	1958-1961
Off-NTS Deer other than Lincoln County	1956-1972
Bighorn Sheep - Desert Game Range	1956-1977
Bighorn Sheep other than Desert Game Range	1960-1963

Bighorn sheep and deer were selected as representative of off-NTS ruminants, and were widely available through annual sports hunting. The areas represented were the ones most commonly downwind from the NTS nuclear testing activities. As shown in Figure 1, Lincoln County occupies roughly the northeast quadrant from the NTS. The Desert Game Range lies mostly east and southeast of the NTS. The NTS beef herd generally grazed the northeast portions of the NTS prior to 1964 and the west central portion thereafter, and the NTS deer were generally collected from the northwest area. Off-NTS deer from other than Lincoln County were usually collected from Clark, Elko, and Nye Counties, although the 1961 collection included Humboldt and Esmeralda Counties.

STRONTIUM-90 IN BIGHORN SHEEP

AIP personnel, with the cooperation of the Nevada Department of Fish and Game, collected hock bones from bighorn sheep at Fish and Game checkpoints during the hunting season. Fish and Game personnel estimated the age of each animal sampled. During the years 1956 to 1977 AIP sampled 382 sheep. The number sampled each year ranged from 7 to 34, depending on hunter success.

The results of bone analyses for strontium-90 are summarized by year of collection in Appendix Table 1 and in Figure 2. A gradual increase in average concentrations occurred through 1961 with a sharp increase then continuing through 1964. After holding steady for 4 years, through 1968, a rapid

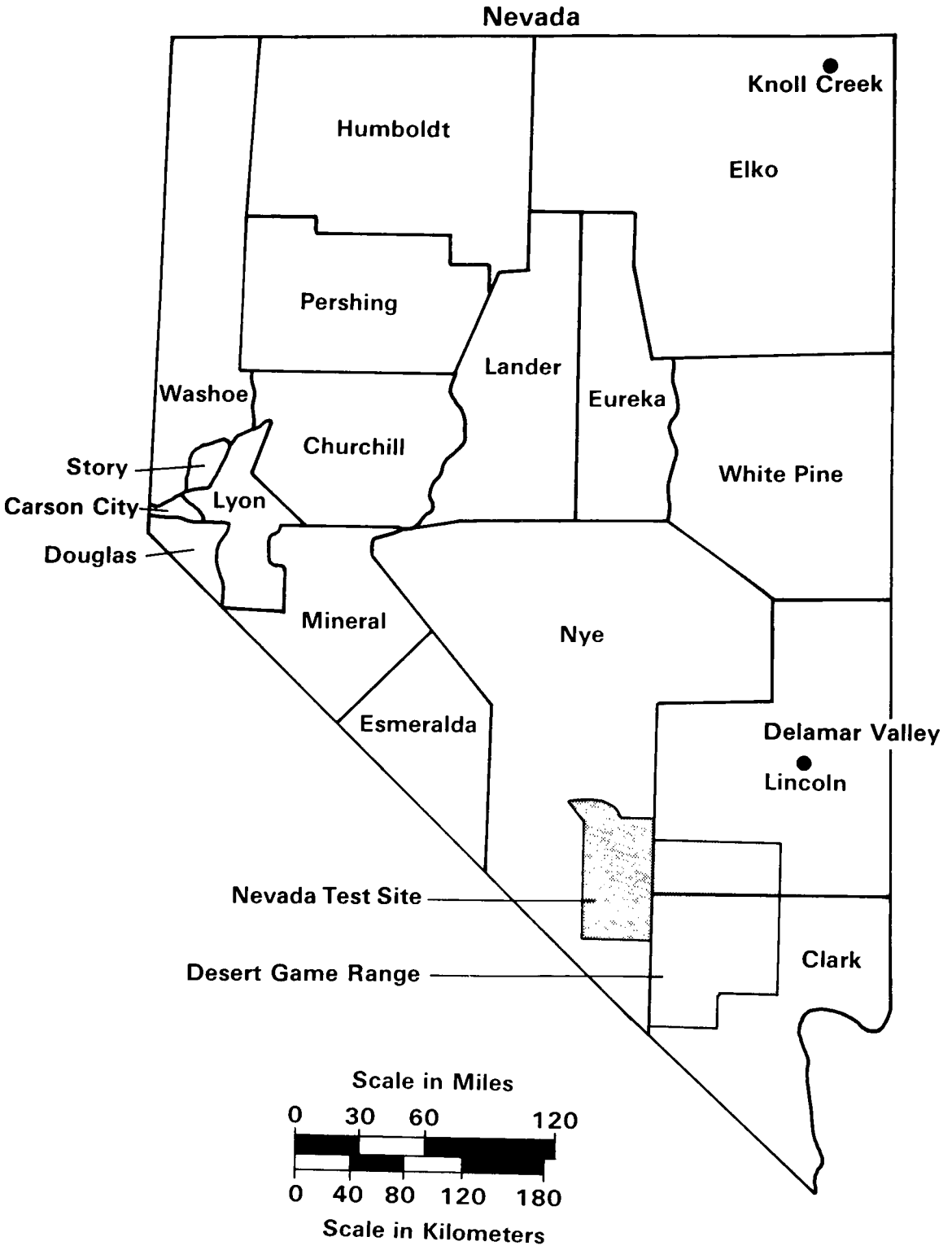

Figure 1. Map of Nevada showing the Counties, the Nevada Test Site, and Desert Game Range.

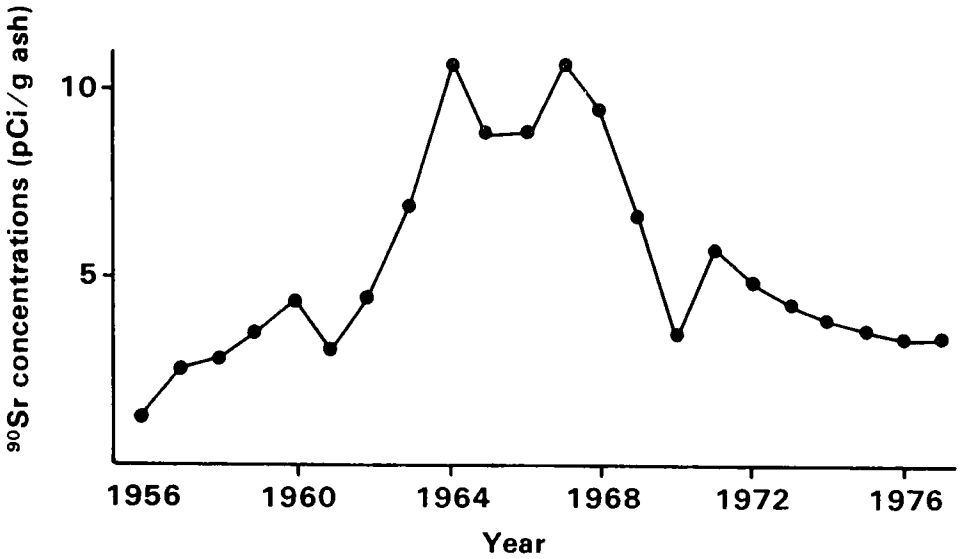

Figure 2. ^{90}Sr concentrations in bighorn sheep hock bones.

decrease occurred which began tailing off in about 1971 reaching a relatively steady level by 1976. It is obvious that this pattern does not match that of atmospheric testing at the NTS. Therefore, the role of worldwide fallout in relation to the observed concentrations was investigated.

The Health and Safety Laboratory of the Atomic Energy Commission (now the Environmental Measurements Laboratory of the Department of Energy) in New York began measuring strontium-90 deposition at various stations worldwide as early as 1954 (HASL-329, 1977). The station most typifying the type of rainfall and area as that of the Desert Game Range was Salt Lake City. Figure 4 is a plot of the annual strontium-90 deposition at Salt Lake City from 1957 to 1975. During the period following 1956, the annual deposition in New York was nearly identical to that at Salt Lake City, so the plot includes deposition data from New York for 1954 to 1956. Also shown in Figure 4 is the cumulative strontium-90 in the soil as determined from the deposition data. Again, it is seen that the strontium-90 concentration curve in Figure 3 for bighorn sheep does not correlate well with either the annual or cumulative deposition curves. The plot of annual and cumulative fallout demonstrates that most of the worldwide fallout is delayed several years after the associated atmospheric nuclear tests.

No model has been available to describe the rate of accumulation of strontium-90 in the bones of bighorn sheep. However, some information was available on deer and cattle. Farris (1967) showed annual strontium turnover rates in deer bone of 0.35 for 7- to 18-month-old animals, 0.094 for 19- to 30-month-old animals, and 0.070 for plus 55-month-old animals. Fountain

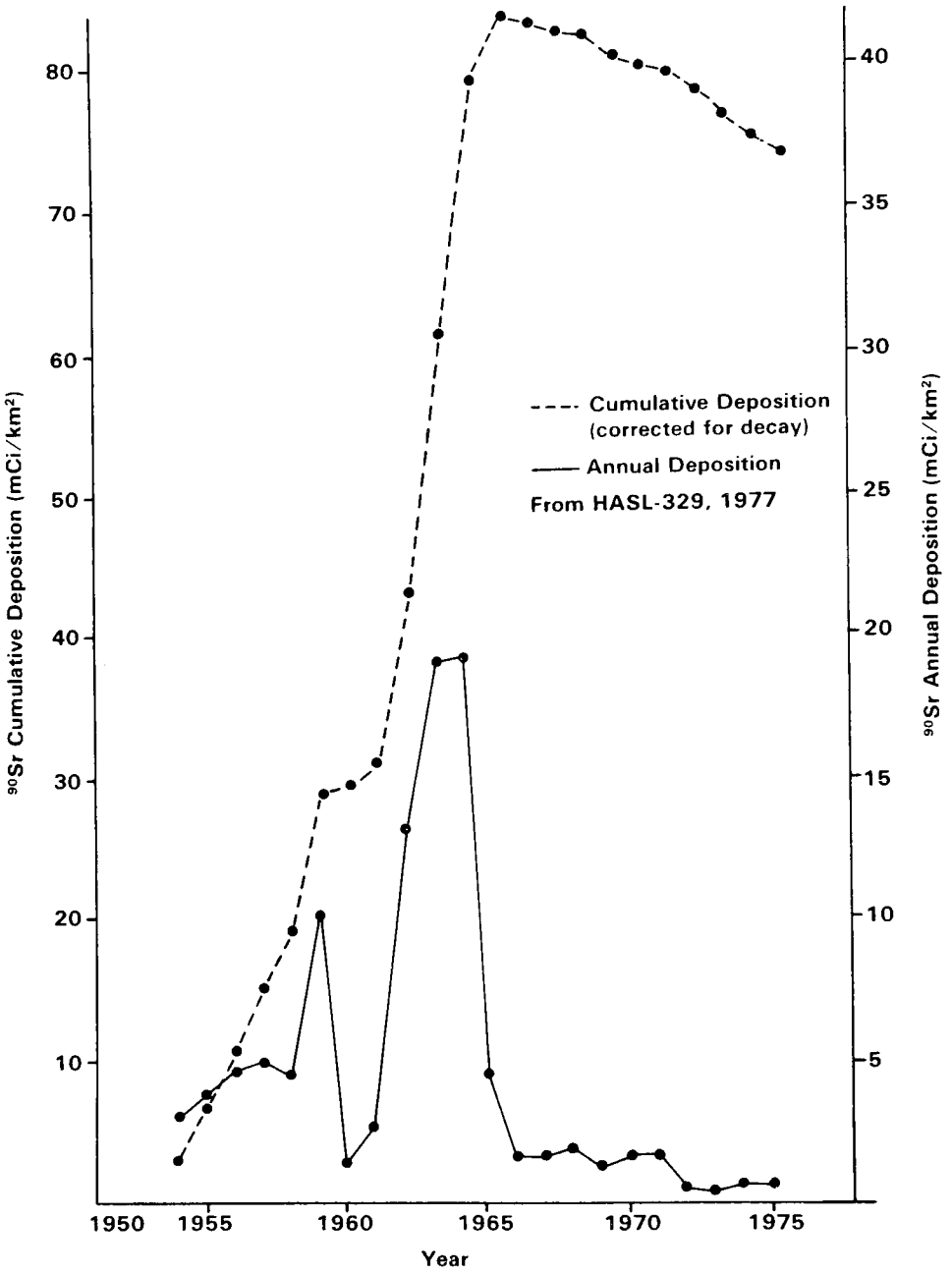

Figure 3. Annual and cumulative ^{90}Sr deposition in soil at Salt Lake City, Utah and New York, New York.

(1961) reported that cattle appeared to accumulate strontium into the skeleton on a definite age gradient until reaching 2 years of age after which time the levels remained fairly constant. Both reports indicate that young animals are accumulating strontium into their bones at the most rapid rate. Therefore, a decision was made to list the concentration of strontium-90 at the time of collection versus the year during which the animal was 1 year old. The data were then averaged for each year and plotted as in Figure 4. For comparative purposes the annual strontium-90 deposition rate in Salt Lake City is overlaid on the plot. It can be seen that the two curves are now quite similar. Sheep which were 1 year old during the period 1956 to 1958 had higher concentrations of strontium-90 in bone than might have been expected from the comparison of the rest of the data. Part of this difference might be ascribed to the effect of close-in fallout during those years; however, it is more likely that they accumulated additional strontium-90 during the higher worldwide fallout in 1959 and during the peak fallout years of 1962 to 1964. Sheep which were 1 year old during 1960 and 1961 would also have received an additional body burden during the years 1962 to 1964, although not as much as animals which were in their first year or two of age during those years.

Figure 5 is a graphical representation of the correlation between strontium-90 bone concentrations and annual strontium-90 deposition rate during the year in which the sheep were 1 year old. As explained above, the low annual depositions in 1956, 1960, and 1961 were, to a large extent, countered by the heavier fallout of succeeding years. Those data points, therefore, would not be expected to demonstrate as high a correlation as other years. Analysis of the data in Figure 5 shows a good correlation of bone concentration to fallout deposition, even when data for the three years is included. When all data are considered, the regression line relating bone concentration to annual deposition is:

$$C = 2.25 + 3.81 \ln D$$

If data for the years 1960 and 1961 are excluded, the equation becomes:

$$C = 2.24 + 3.37 \ln D,$$

where C = strontium-90 bone concentration (pCi/g ash)
D = annual strontium-90 deposition (mCi/km^2)

The correlation coefficient for all data excluding 1960 and 1961 was 0.84 and for all data the correlation coefficient was 0.76.

Results for four bighorn sheep collected in 1975 were not included in the graphical presentation. Those results, ranging from 19 to 40 picocuries per gram (pCi/g) ash, were considered to be analytical anomalies not representative of the population.

Other studies of radioactivity concentrations around the NTS have shown some residual of close-in fallout from the atmospheric tests with a

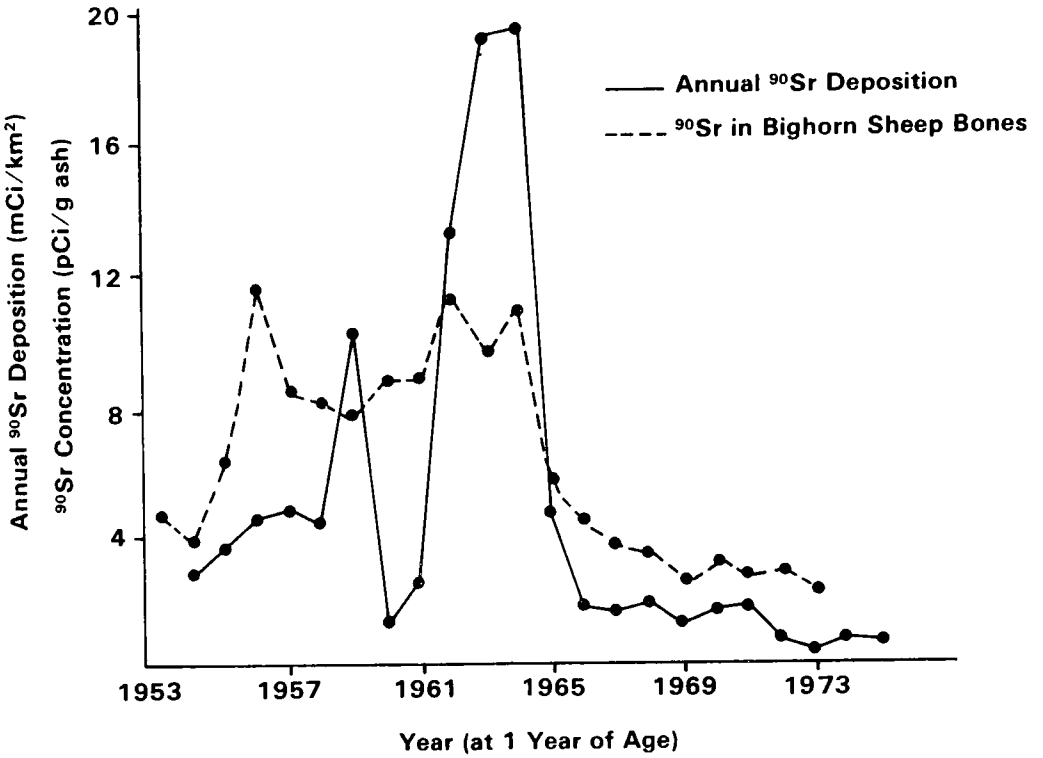

Figure 4. Bighorn sheep hock bone ^{90}Sr concentration vs. year at 1 year of age compared to annual ^{90}Sr deposition for Salt Lake City.

correlation between azimuth from the NTS and concentration (Andrews and Vandervort 1978). In a simple test of this observation, the sheep results were divided into two groups from north and south of Las Vegas. Because of testing restrictions close-in fallout seldom fell south of Las Vegas. During the period 1965 to 1977, 13 years of data are available. For 3 of these years, all animals came from north of the line. During 8 of the remaining 10 years mean concentrations measured north of the line were higher than those measured south of the line. A sign test of the data plotted in Figure 7 shows that the difference is significant at the 25 percent level. While not conclusive, the data indicate that the sheep from the northern area, primarily the Sheep Range, are exposed either to a higher degree of residual close-in fallout or to a higher annual rainfall with its associated higher annual strontium-90 deposition than those from the southern area. Data from 1965 and 1966 may also include animals from the northern area exposed during their early years to close-in fallout. The most likely explanation, considering the low and relatively uniform worldwide fallout from 1965 on, is that the higher concentrations observed from the northern animals result from residual close-in fallout. The results are shown graphically in Figure 6.

In order to estimate the effective half-life of strontium-90 in bone, concentrations were compared to age for desert bighorn sheep born during the same year (cohort). Since animals from each cohort were collected over a range of years, an effective half-life could be estimated from the decrease in

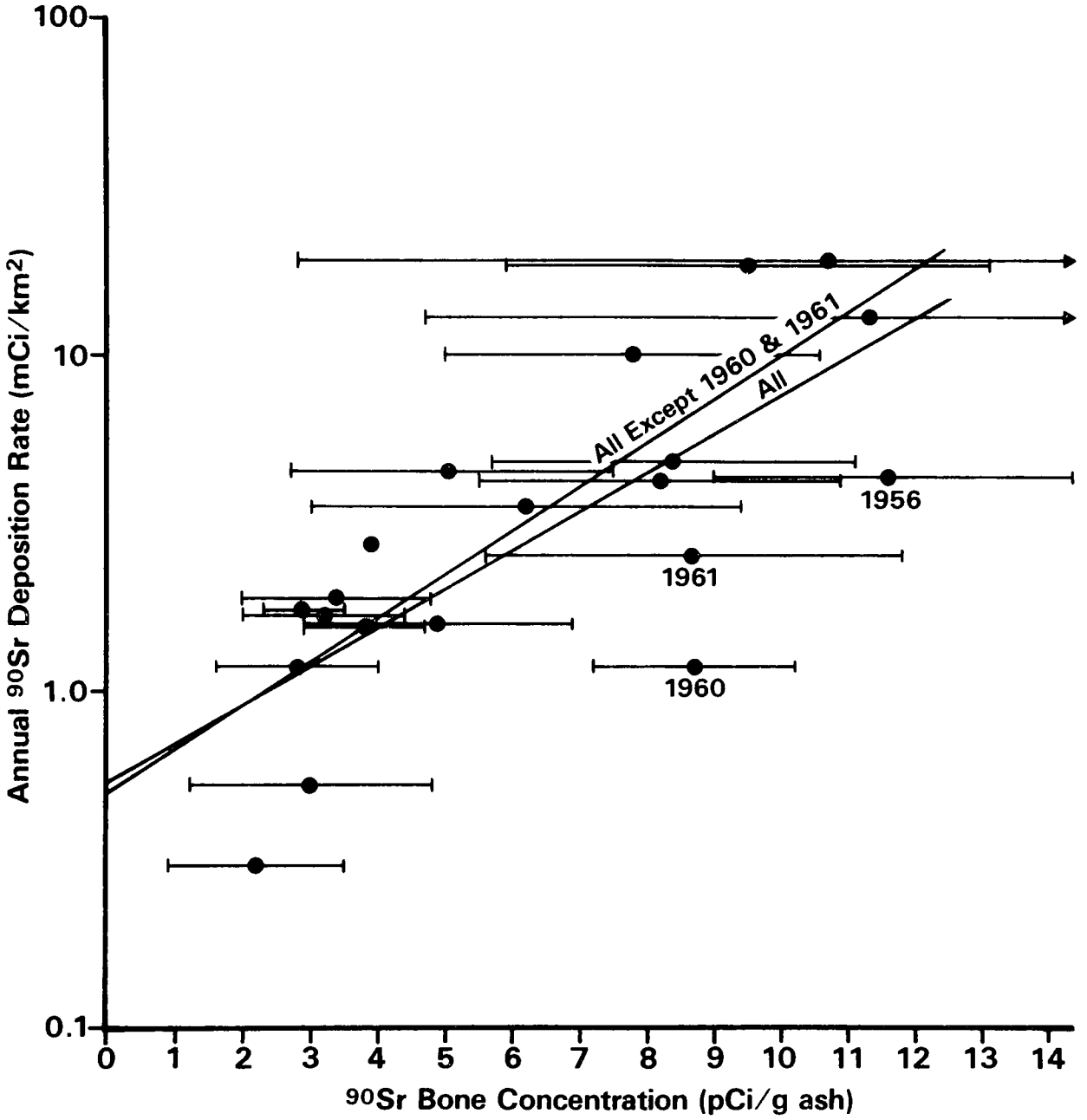

Figure 5. Comparison of mean ^{90}Sr bone concentration to annual deposition rate during year in which sheep were 1 year old.

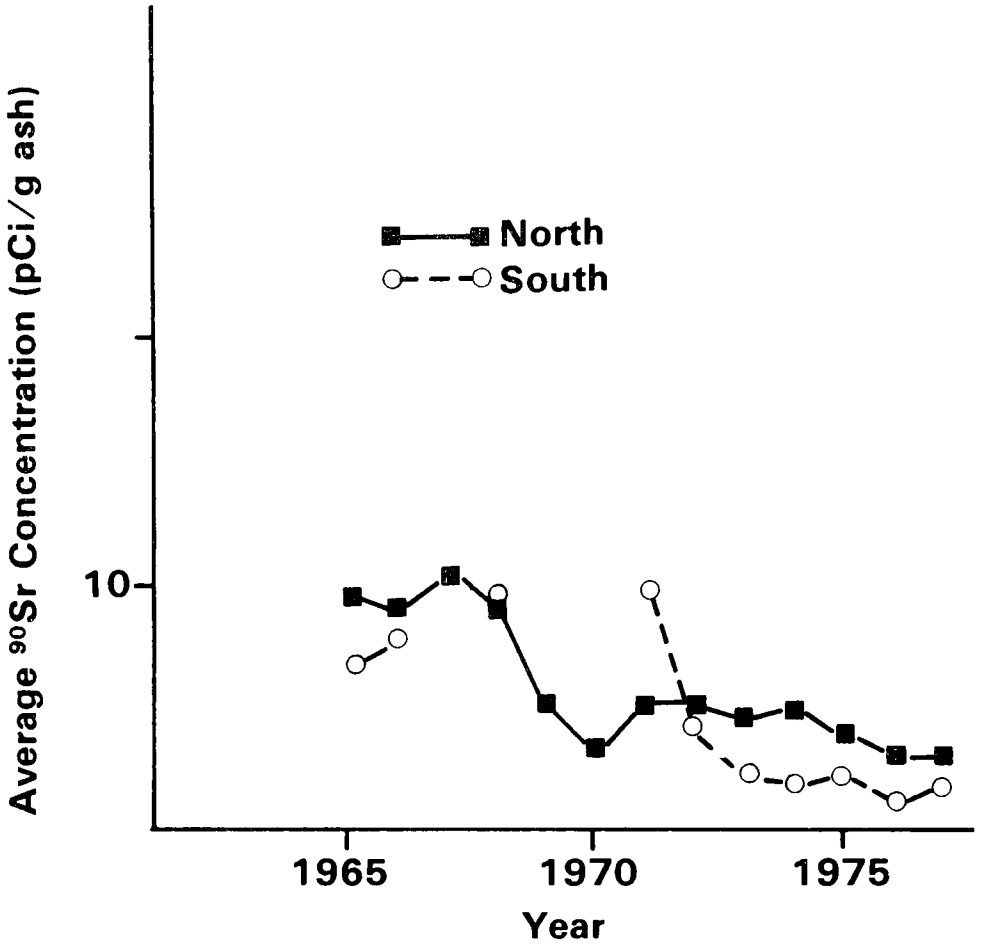

Figure 6. Comparison of ^{90}Sr concentrations in bones of bighorn sheep from north of an east-west line through Las Vegas to sheep from south of the line (minus 4 high anomalies in 1975 data).

concentration with time. The strontium-90 concentration in bone in animals collected from 1964 to 1977 were compared to age at collection for each cohort. These sheep had all reached one year of age during the years 1956 to 1964. Thus, this selection of cohorts permitted a comparison of strontium-90 concentration versus age for sheep that had been exposed during the peak fallout years and harvested after the peak fallout years. The harvest of animals which had been 1 year old in 1956 was too small for meaningful results. The groups which were 1 year old in 1960 showed no appreciable change with age. Groups which were 1 year old in the years 1965 on showed no change, but as shown in Figure 5 all those animals had relatively low concentrations. The mean effective half-life determined from this analysis was 4.8 ± 2 years.

In humans, the observed ratio -- defined as the ratio of Sr/Ca in bone to Sr/Ca in the diet -- decreases from 1 at birth to 0.25 after 1 year of age.

In adult humans the mineral turnover in the shaft of long bones is about 1 percent per year (FRC 1965). The sheep from which data were used to estimate the biological half-life of strontium in bone received their major exposure to strontium as lambs during the period of heavy fallout prior to 1964. Assuming that mineral metabolism in sheep as a function of maturity is similar to that of humans, the exposure to the lower levels of fallout after 1964 are not believed to have a major effect on the observed effective half-life.

In the 1961 to 1965 study of deer in Colorado, Farris determined an approximate biological half-life for strontium-90 of 9.7 years (Farris 1967). It is possible that there is a basic difference between deer and sheep, but it would appear that his data were influenced by the heavy worldwide fallout occurring during that period of time. That the 4.8 year effective half-life is probably a better estimate, at least for mature bighorn sheep, was verified through a formula for estimating biological half-lives that is based on body size (Reichle, et al. 1970). If an average weight of 68 kg is applied to this formula, the calculated biological half-life is 5.4 years and the effective half-life is 4.5 years.

STRONTIUM-90 IN DEER

Strontium-90 bone concentrations for deer and desert bighorn sheep are compared in Figure 7 and summarized in Appendix Tables 1, 2, and 3. It is immediately obvious that the results, when plotted versus year sampled, are quite similar. Some small, but probably significant differences are: (1) strontium-90 concentrations in deer from Lincoln County during the years 1956 to 1958 are about twice as high as in other deer, and (2) deer reached a

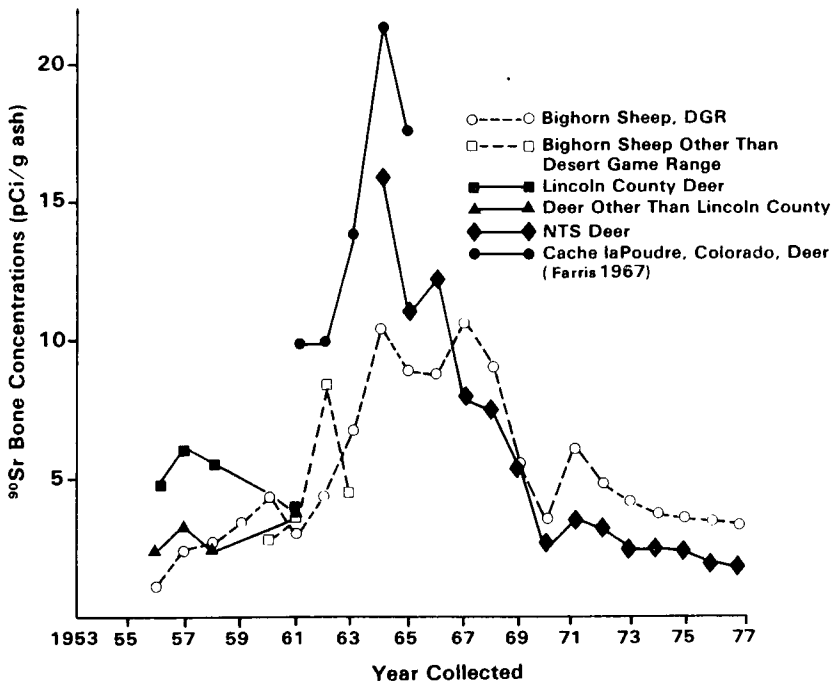

Figure 7. Average ^{90}Sr bone concentrations in deer and bighorn sheep.

higher peak in 1964 than did sheep and dropped off more rapidly thereafter. Bighorn sheep from areas other than the Desert Game Range do not differ significantly from sheep from the Desert Game Range. Deer and desert bighorn sheep results are very close for the years 1968 to 1977.

The fact that the concentrations in Lincoln County deer during the late 1950's were higher than in deer from the rest of the State most likely reflects the immediate effects of close-in fallout from the NTS. The difference in peak response and decline in concentrations between deer and sheep is believed to be due primarily to the age of the animals collected. The higher concentrations observed in the sheep bones during the years from 1967 on are probably related to the older age at harvest and hence exposure to greater fallout levels during the period of rapid growth.

According to information from the Nevada Wildlife Department, the average age of the deer herd in the area of concern is about 30 months. The average age of bucks harvested by hunters is 36 months. During one recent year 58 percent of bucks collected were 30 months or younger and 89 percent were 54 months or younger. Due to the young age of the deer sampled compared to sheep, the deer tend to reflect conditions during the previous year or two. Bighorn sheep must either meet a minimum Boone and Crockett score based on horn size and curl or must be 7 years old to be legal game animals. They are generally 5 years of age or more, with many as old as 12 years. This tends to flatten the response to the effect of exposure during individual years.

STRONTIUM-90 IN CATTLE

Strontium-90 concentrations in femurs of cattle from the NTS beef herd are available from 1957 to 1977 (Appendix Table 4). The results, plotted versus year of collection, are shown in Figure 8. Also plotted are the results for strontium-90 in NTS deer hock-joints. For the period 1966 to 1977, the two are essentially indistinguishable.

Approximately one-half of the beef cattle sacrificed each year are under 2 years of age. Therefore, the results for each year tend to reflect recent changes in strontium-90 deposition, as do the deer. It would be expected, then, that the results would follow the trend of fallout shown in Figure 3. This is found to be the case, with a broadening of the peak caused by lag in response by the cattle. Of particular note is the reponse of younger animals as compared to mature cows. During the period 1958 to 1960, the mature cows had strontium-90 concentrations ranging from half to three-fourths of the averages of the younger animals. In 1961, after a year of low deposition, the mature cows had a concentration 10 percent greater than the average of the young animals.

Two other beef herds were maintained by the University of Nevada, Reno, at Delamar Valley, 75 miles northeast of the NTS, and at the Knoll Creek Experimental Station 330 miles north of the NTS (Figure 9). These herds were sampled during the years 1957 to 1961 and 1964 through 1967 (Appendix Tables 5 and 6). The results were similar to the results for the NTS herd, as seen in Figure 8, indicating that worldwide fallout was the main factor in strontium-90 uptake in the desert environment. The consistently higher concentrations for Knoll Creek herd may be due to factors such as higher rainfall or higher accumulative close-in fallout.

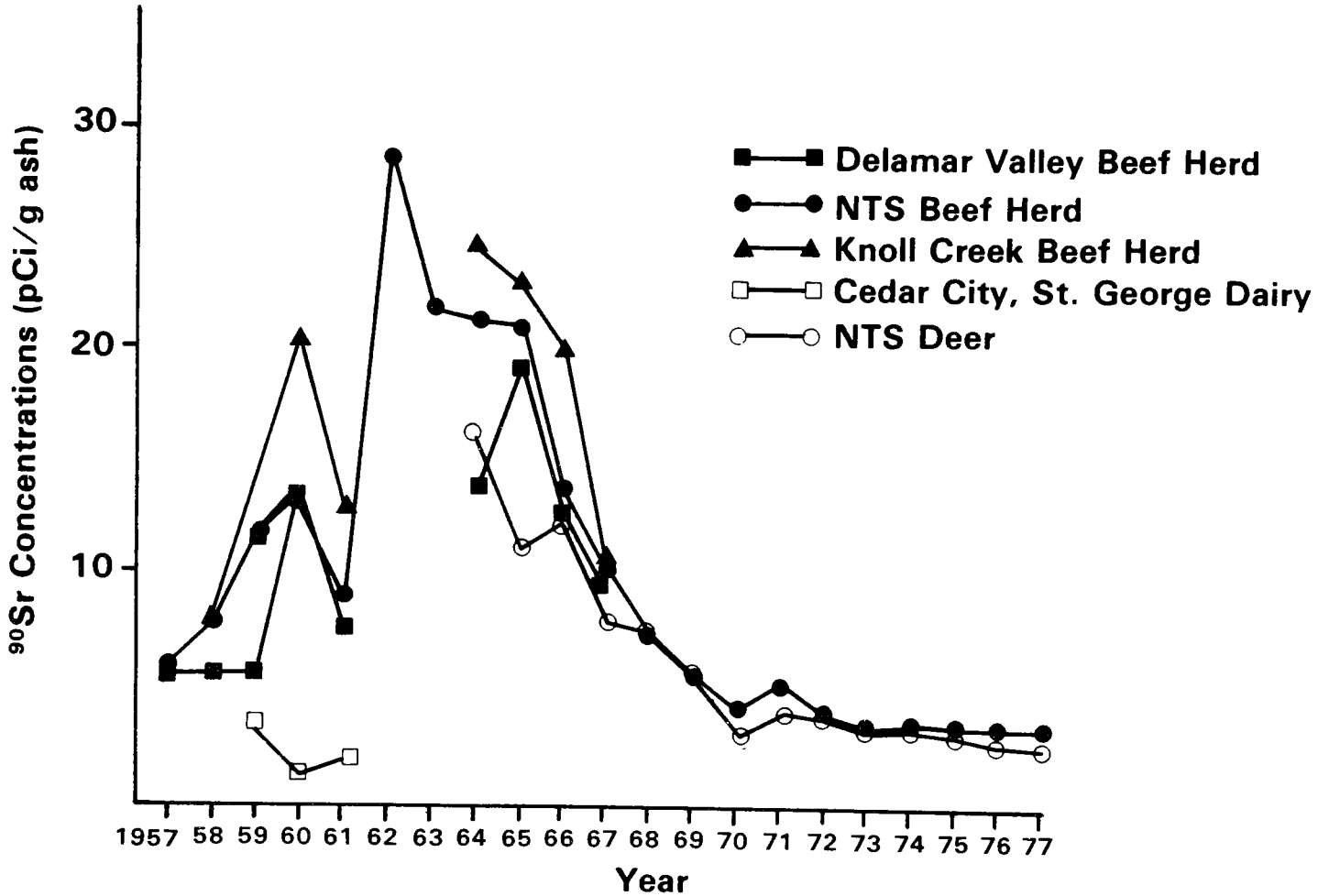

Figure 8. Average ^{90}Sr bone concentrations in cattle and Nevada Test Site deer.

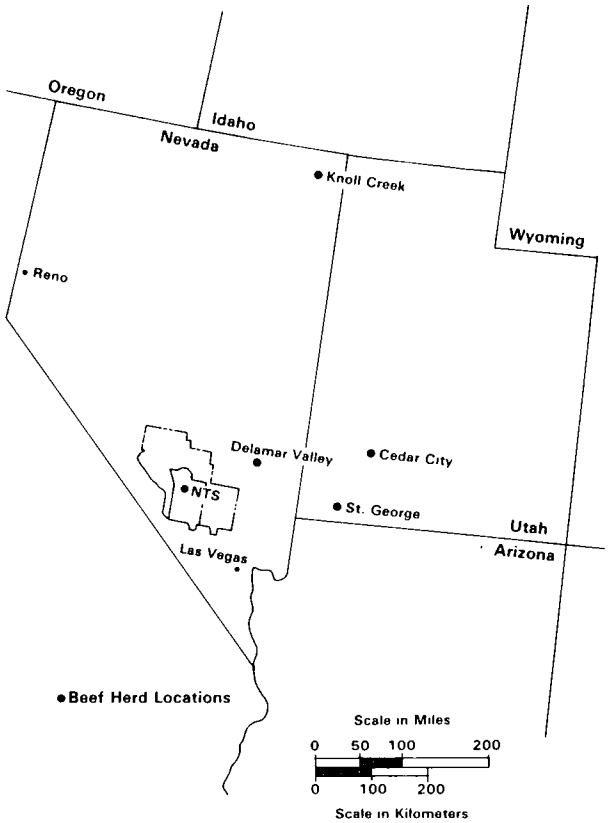

Figure 9. Locations of cattle herds routinely sampled.

Bone samples collected from dairy cattle in Cedar City and St. George, Utah, from 1959 to 1961 (Appendix Table 3) showed much less strontium-90 than the beef cattle in Nevada. As these cattle were maintained on irrigated pasture or fed crops from irrigated fields, they consumed the fallout from a much smaller area than did the wider ranging beef cattle grazing on native vegetation.

Through 1966, bones from the NTS beef cattle contained strontium-90 concentrations about twice those reported from the bones of desert bighorn sheep. This probably reflected the fact that half the cattle sampled were less than 2 years of age and hence were undergoing rapid bone development during the period of high fallout. After 1966, the strontium-90 concentrations in bones from the two species were approximately equal with slightly higher levels reported in the bighorn sheep. This again can be explained by the higher age at sampling (average of 7+ years) of the bighorn sheep; i.e., the bighorn sheep which were immature during the period of high fallout were being harvested concurrently with younger cattle which were immature during periods of lower fallout.

COMPARISON TO STRONTIUM-90 IN HUMANS

The Environmental Measurements Laboratory of the Department of Energy - formerly the Health and Safety Laboratory (HASL) of the Atomic Energy Commission and the Energy Research and Development Administration - has measured strontium-90 in adult human vertebrae in New York City since 1954 and

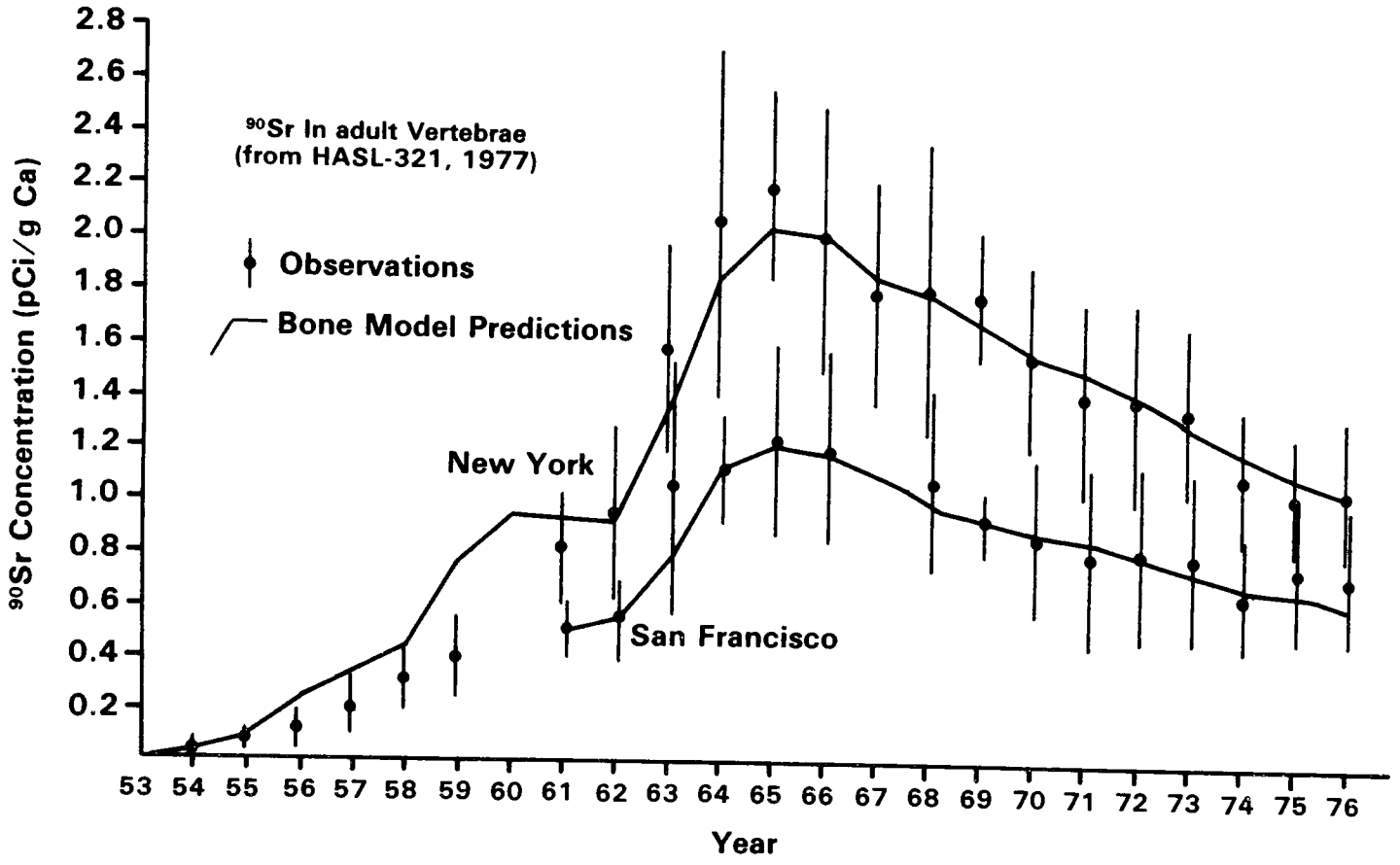

Figure 10. ^{90}Sr in adult human vertebrae -- observations and bone model predictions.

San Francisco since 1961. The results of these measurements are compared in Figure 10 to predicted values based on concentrations in food from those areas (HASL-321, 1977). A comparison of these data with those collected from bighorn sheep bones shows similar trends. As a basis for comparison of strontium-90 in New York City to Nevada the annual deposition of strontium-90 in New York City is compared to the annual deposition in Salt Lake City. As explained earlier, Salt Lake City is similar in geographical location and rainfall to the mountainous areas on and near the NTS. As shown in Figure 11, within the limits of accuracy of sample collection and analysis, there is essentially no difference in the annual strontium-90 depositions between New York City and Salt Lake City.

The daily intakes of strontium-90 in terms of pCi strontium-90 per gram of calcium (HASL-328, 1977) for three U.S. cities are shown in Figure 12. These data, based on market-basket sampling, are similar to the strontium-90 fallout data presented in Figure 11. More closely related to the data of Figure 11 are the strontium-90 concentrations measured in milk in New York (Figure 13, HASL-321, 1977). The human vertebrae data reflect the fallout and consumption patterns with a delay of about 2 years in peak concentrations and a longer decay period following the peak. Very much the same pattern is seen for bighorn sheep in Figure 1, with a shorter response time. The major difference in the shape of the curves is the difference in average ages of the populations sampled as all human data are from persons over 21 years of age. The concentrations of strontium-90 in vertebrae when normalized to pCi/g ash (divided by 2.6) are about one-tenth those measured in bighorn sheep. This

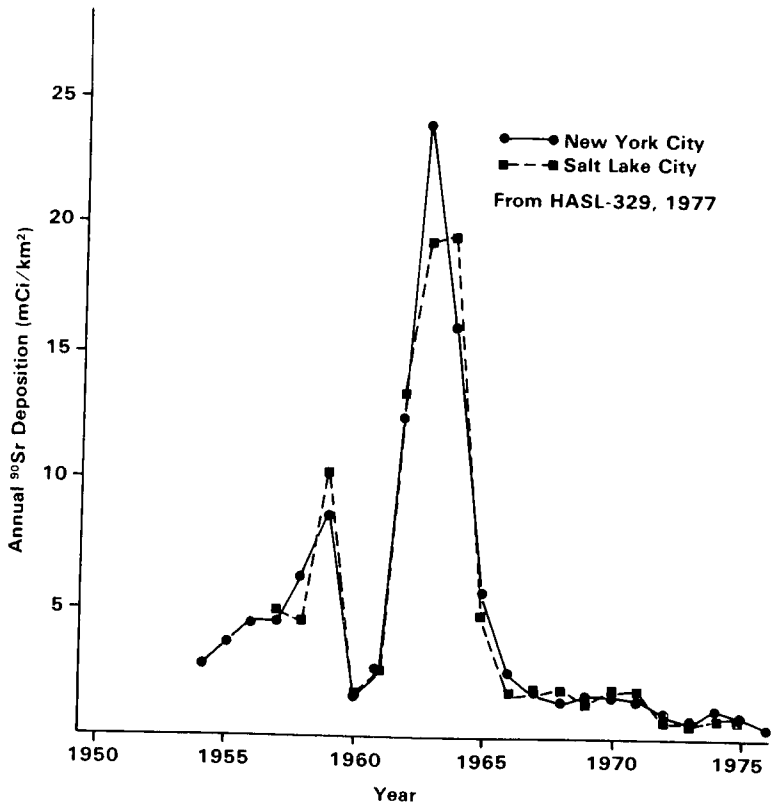

Figure 11. Annual ^{90}Sr deposition in New York City and Salt Lake City.

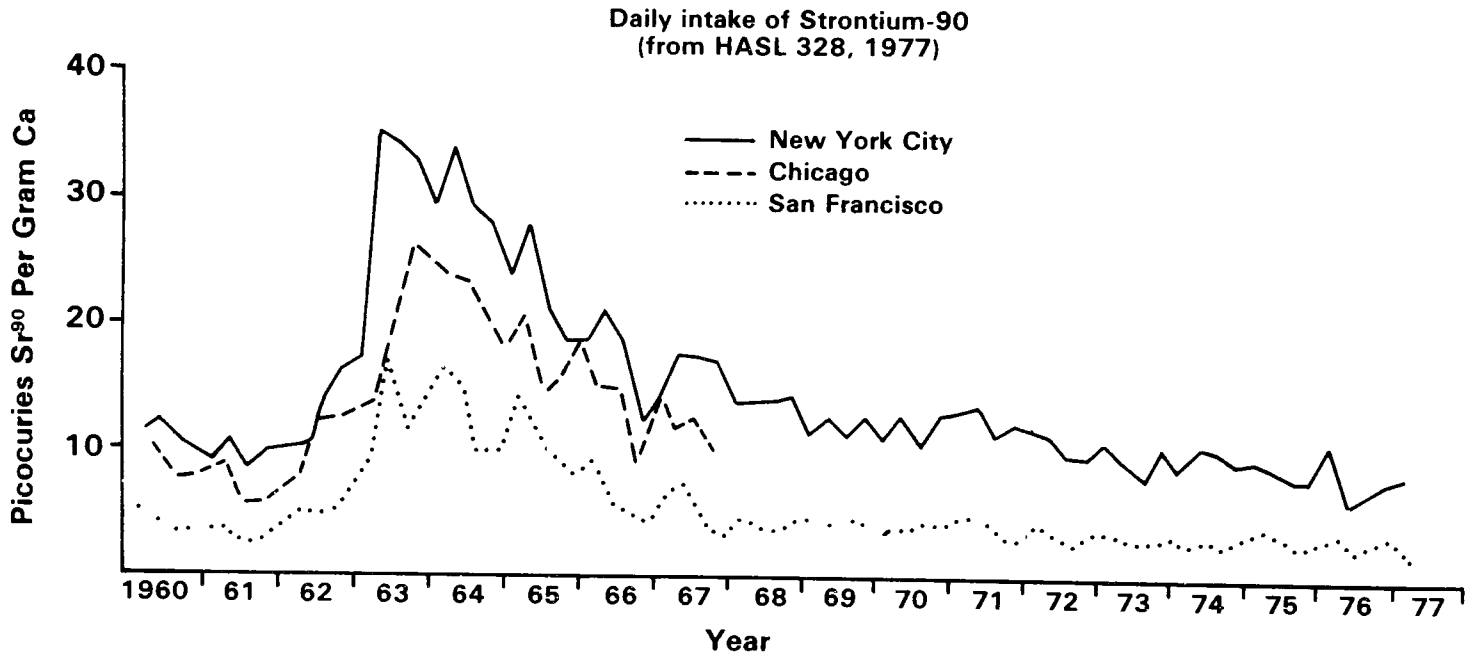

Figure 12. Daily human dietary intake of ^{90}Sr.

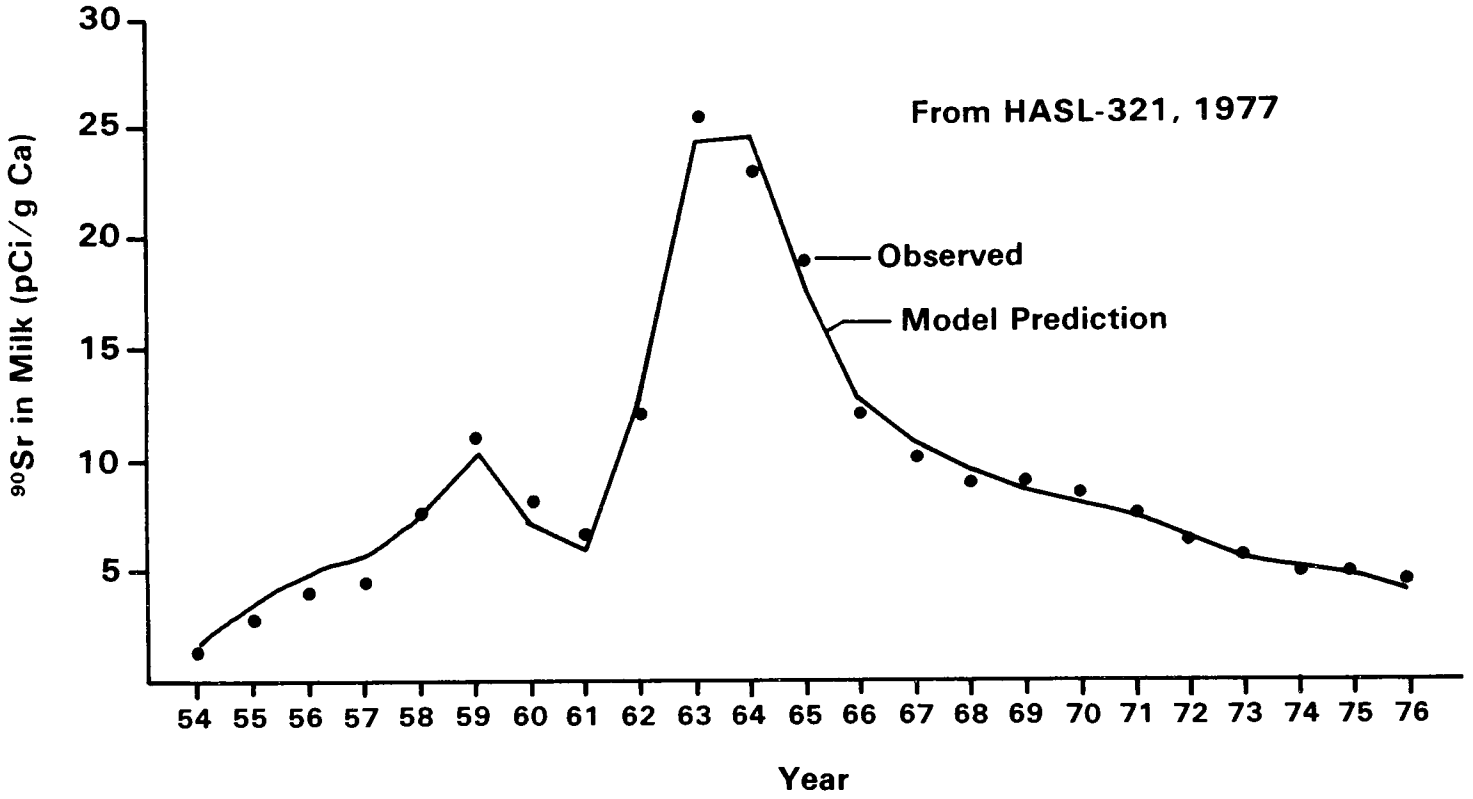

Figure 13. Average annual ^{90}Sr concentration in milk in New York City.

results from the differences in diet (sheep grazing directly on contaminated vegetation) and the age difference. Except for these factors, similar mechanisms appear to exist for humans and bighorn sheep relative to strontium-90 metabolism and retention.

The HASL report (HASL-321, 1977) concluded that a removal rate of strontium-90 from adult human vertebrae of 23 percent per year was inferred from regression analysis of the measured New York diet and vertebrae concentrations. That would infer a biological half-life of 2.7 years. The comparable removal rate inferred for human adults from the San Francisco data was 15 percent per year, or a biological half-life of 4.3 years. Neither value is greatly different from the estimated 4.8 year half-life for bighorn sheep.

CESIUM-137 IN CATTLE AND DEER TISSUES ON AND NEAR THE NEVADA TEST SITE 1957 TO 1977

BACKGROUND

Measurements of cesium-137 in the soft tissues and ingesta collected from animals that resided on and near the NTS have been made for a number of years. Muscle, liver, and lung tissues were selected for analyses because cesium-137 mimics the chemistry of potassium which is an essential element in metabolism within these organs. The ingesta were sampled to reflect the intake at time of sampling. Data sufficient for meaningful discussion exists from the following animal groups and for the indicated time periods:

NTS Beef Herd	1957 - 1977
Delamar Valley Beef Herd	1957 - 1961 and 1964 - 1967
Knoll Creek Beef Herd	1957 - 1961 and 1964 - 1967
NTS Mule Deer	1964 - 1977

CESIUM-137 IN CATTLE

Beginning in December 1957, tissue samples were collected from beef herds on and near the NTS. The intention was to include in each sampling one calf; one each at age one, two, and three years; and one adult (Fountain, 1961). The first sampling in 1957 included herds on the NTS and at Delamar Valley. From 1958 to 1967, herds at the NTS, Delamar Valley, and Knoll Creek were included. For the remainder of the period covered by this report only data from NTS cattle are reported.

Samples were usually collected twice each year during May - June and October - November, referred to herein as the spring and fall samples. During 1958 the samples from the three herds were composited into one sample of each tissue type. Sample analyses for cesium-137 were performed by gamma spectrometry using a 10.2- by 10.2-cm NaI(Tl) crystal detector from 1957 until 1973. Beginning in 1974 gamma spectrometry was performed using lithium-drifted germanium detectors for all samples reported herein except for rumen contents which were still analyzed with the NaI(Tl) detectors.

The results of analysis for cesium-137 in lung, liver, muscle, and rumen contents from cattle from the three herds are summarized in Appendix Tables 7, 8 and 9. Other tissues analyzed have included kidneys and thyroid, but they are not included in this report. In general, the tissue results reported here compare well with results for the other tissues analyzed.

In order to observe the trend in tissue concentrations as a function of time the seasonal samples of muscle were averaged and the results are plotted in Figure 14. Cesium-137 concentrations in the tissue samples did not depend on the age of the animals sampled; therefore, it was considered reasonable to use a simple averaging to demonstrate seasonal variations. The highest concentration was observed in the Fall 1958 sample, following two consecutive years of atmospheric nuclear testing at the NTS. In addition, the 1958 test series was conducted later in the year than usual and was concentrated during the last month of testing (October) shortly before sample collection. Concentrations then decreased steadily during the period of the nuclear testing moratorium which ended in September 1961. Muscle tissue concentrations measured during 1964 and the spring of 1965 were comparable to those observed immediately after the atmospheric test series. By 1966, however, they had returned to the levels observed at the end of the moratorium. From that level they rapidly dropped to the range which has been maintained since (about 25 pCi per kilogram of tissue). All results for samples collected during the

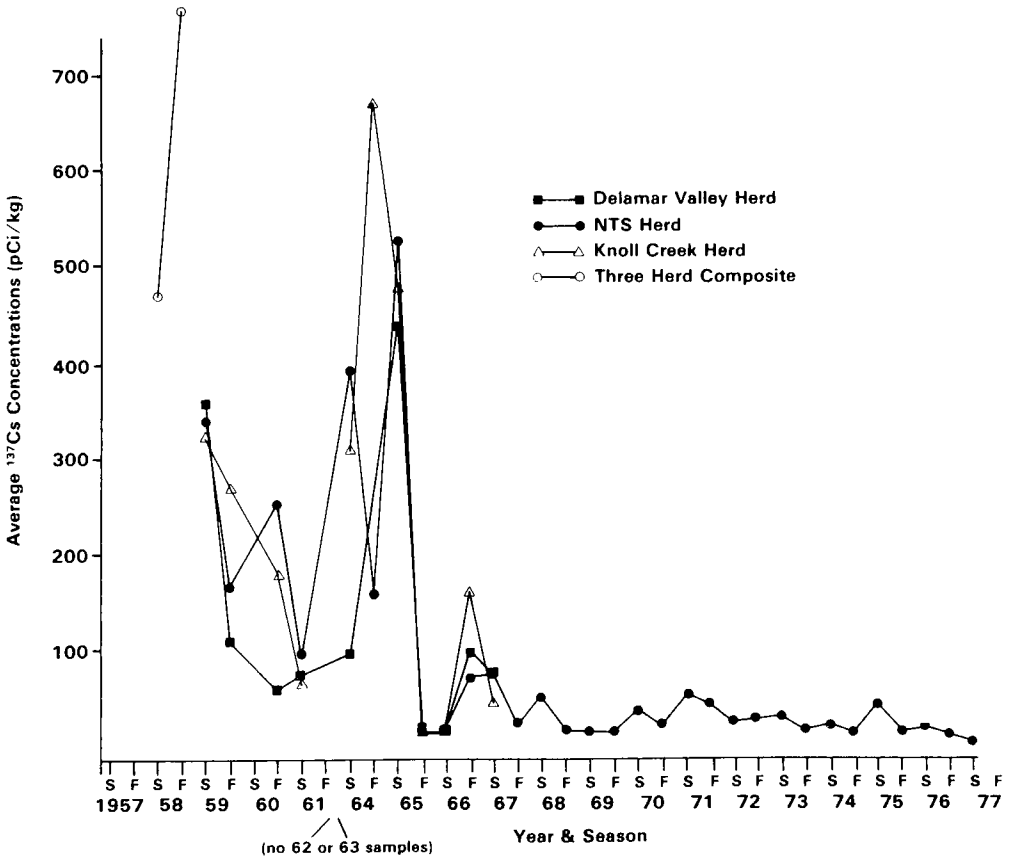

Figure 14. Average ^{137}Cs concentrations in beef cattle muscle tissue.

Fall 1965 and Spring 1966 periods were reported as having less than detectable concentrations of cesium-137. The usual minimum detectable activity (MDA) was about 30 pCi/kg. Compared to the results from before and after that period these results seem exceptionally low. Although there seems to be no basis for discarding these data, they must be considered as suspicious. In all cases where averages included less than detectable concentrations, one-half the MDA or 15 pCi/kg, was used in the averaging.

Cesium-137 concentrations in liver follow the same trends as in muscle, but exhibit overall lower concentrations, especially during peak concentration periods. The differences were as much as a factor of two. Results for lung tissue tend to be very similar to those for muscle. Rumen content cesium-137 results follow the same general trend as for muscle tissue, but there is much less correlation between rumen content concentrations and concentrations in the organs than there is between concentrations in the various organs.

Figure 15 shows the monthly average atmospheric concentrations of cesium-137 at several locations in the continental United States for the years 1963 through 1977. Data are not available for the 2-year period from mid-1966 to mid-1968. The overall pattern is very similar to the annual strontium-90 deposition at Salt Lake City shown in Figure 3. During most of the years the maximum occurred during the spring months. This reflects the increased rate of fallout from the stratospheric reservoir during the spring shift in position of the tropopause gap (Glasstone, 1962). Because strontium-90 and cesium-137 are relatively unfractionated in atmospheric debris from nuclear tests, deposition rates or cumulative amounts of one accurately reflect the same parameters for the other, with suitable factors for production and decay rates (Glasstone, 1962).

Figure 3 shows that the peak years for delayed fallout were 1959 and 1962 - 1964. Figure 15 demonstrates that during those years when cesium-137 was measured in air the peak fallout occurred during the spring. This is reflected in Figure 14 for cesium-137 in muscle tissue. Except for 1966, for which spring data are suspect, and the 1964 Knoll Creek herd, tissue samples collected in the spring show higher concentrations of cesium-137 than the fall samples. The rapid response to recent cesium-137 deposition indicates a short effective half-life. This is borne out by Hood and Comar (1953) who reported a 20-day biological half-life for cesium-137 in a cow and by Goldman, et al., 1965, who reported an average biological half-life of 17 days in sheep and deer. Since the cattle sampled under this program were on pasture contaminated to an unknown degree it is not possible to infer a biological half-life from the data. However, the rapid decrease in tissue concentrations implies both a rapid decrease in vegetation contamination following the peak spring fallout and a short biological half-life. This finding explains the lack of observable difference between cesium-137 concentrations in animals of different ages, as opposed to the strontium-90 results. This also justifies the averaging of data from the animals sampled at one time from a herd.

CESIUM-137 IN DEER

Until 1964 only strontium-90 had been measured in deer from on or near NTS. In December 1964 the program was expanded to include the measurement of

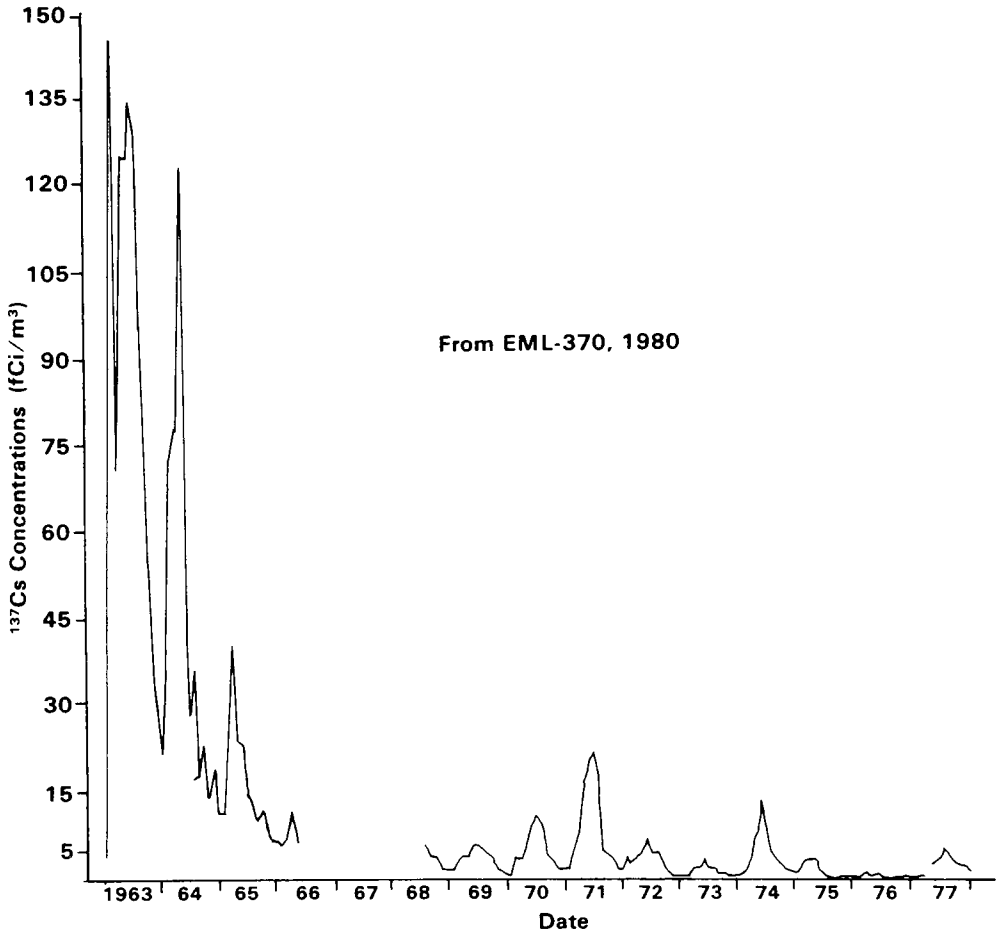

Figure 15. Monthly ^{137}Cs concentrations in air of various Continental U.S. locations (from EML-370, 1980).

gamma-emitting radionuclides in tissue from deer. From December 1964 through 1966, five to twelve deer were collected during each calendar quarter. After 1966 the plan was to collect one deer per quarter. Whenever possible, deer were used which had been killed by vehicles and the needs of the program were supplemented by hunting. Deer were generally collected from the Rainier Mesa-Pahute Mesa area in the northwest portion of the NTS. Deer were occasionally collected from other areas on and off the NTS for special purposes. The same types of samples were collected and were analyzed in the same manner as for cattle.

Cesium-137 concentrations in deer tissues were similar to those observed in cattle from the NTS for the same time period (Appendix Table 10). Monthly average concentrations of cesium-137 in muscle tissue are shown in Figure 16. One major difference noted between cattle and deer results was the series of higher cesium-137 concentrations in deer during 1968. The Cabriolet Event of January 26, 1968 was held in Area 20, in the general vicinity of deer collections. The Buggy Event of March 12, 1968 was held in Area 30, south of the collection area. Both events were cratering tests. Close-in fallout from Cabriolet was primarily to the north of the collection area, but close-in fallout from Buggy was deposited in the deer collection area. The highest concentration of cesium-137 observed in either deer or cattle muscle during the entire period covered by this report was 1,600 pCi/kg in muscle tissue from a mule deer doe collected from Cat Canyon, downwind from Buggy, on the NTS. Muscle tissue from twin fetuses carried by this doe was measured at 4,700 pCi/kg and 2,800 pCi/kg. Close-in fallout from the Buggy Event is believed to account for the increase in cesium-137 concentrations observed in deer muscle during 1968.

In addition to the relatively extensive studies of radionuclides in deer tissue conducted on and near the NTS occasional samples were collected from other areas during the years 1967-1970. All results compared well to those obtained during the same time period on the NTS. In December 1967 three deer were collected from the vicinity of the Gasbuggy Test near Gobernodor, New Mexico (Appendix Table 11). Muscle tissue concentrations of cesium-137 ranged from below MDA to 70 pCi/kg. These results are comparable to those obtained from deer collected on the NTS during September and October of that year which had less than detectable concentrations. Two deer collected from the Central Nevada Supplemental Test Site in January 1968 were measured at less than MDA and 92 pCi/kg, again comparable to those collected near the end of 1967 on the NTS and in New Mexico. Two deer collected from White Pine County, Nevada, during December 1968 were below MDA for cesium-137 in muscle. One deer collected near Pioche, Nevada in Lincoln County, Nevada in October 1970 was below the MDA for cesium-137, compared to one result of 30 pCi/kg in September and one of 61 pCi/kg in November for deer from the NTS. The comparability of these results to those from deer on the NTS is further indication that, except for the period immediately following the deposition of close-in fallout, tissue concentrations of cesium-137 tend to follow the rates at which deposition from worldwide fallout is occurring.

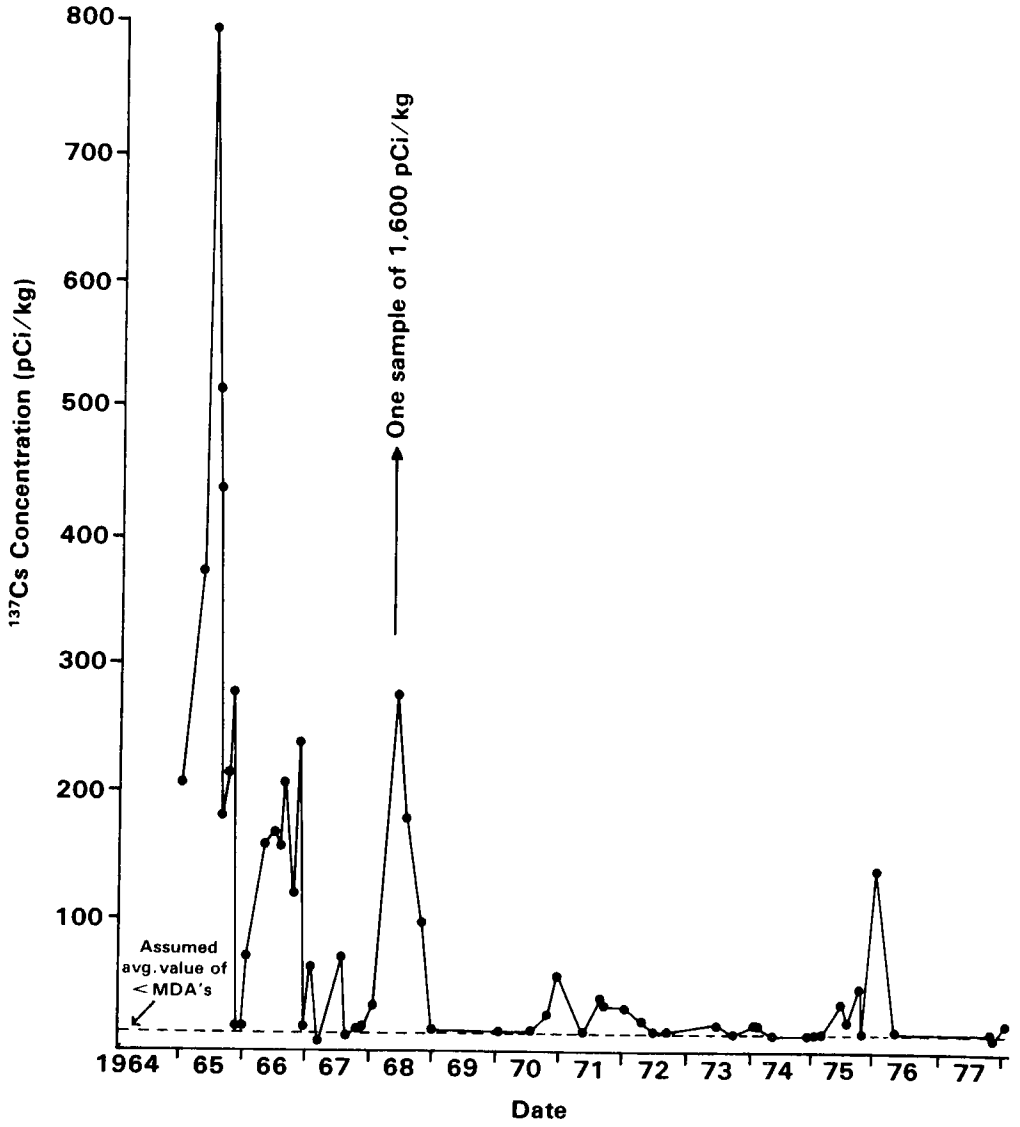

Figure 16. Average ^{137}Cs concentrations in Nevada Test Site deer muscle.

HYPOTHETICAL DOSE CALCULATIONS

Although meat from animals living on the Nevada Test Site is not generally available for consumption by the general public, the dose to a standard man based on a postulated consumption of the meat can be calculated. The dose estimates are not presented as an implication of potential doses, but rather to place the reported radionuclide concentrations in perspective. The dose estimates are based on the techniques and parameters of the International Commission on Radiological Protection (1959,1968) and Dillman (1969). The estimates were from the maximum observed concentrations of the radionuclides in edible tissues of the cattle and deer sampled, and the postulated consumption of 500 grams (about 1 pound) of the meat each day for a year.

The International Commission for Radiological Protection (1959) and the U.S. Department of Energy (1977) present different dose criteria for various parts of the body that are based on estimates of relative radiosensitivity. The National Council on Radiation Protection and Measurements (1971) recognizes this philosophy, but recommends simplifying the guides for the general population, and uses the minimum guide (0.5 rem per year to the whole body for an individual in an uncontrolled area) for all body organs. The National Council on Radiation Protection and Measurements emphasizes that this is a simplifying administrative decision, rather than a reduction of the guides based on new technical information.

The maximum observed concentration of cesium-137 in edible deer tissue was 2,900 pCi/kg in liver from a deer collected on the NTS following the Buggy Event. At the hypothetical consumption rate of 500 g/d, the annual dose received by the standard man would be 32 mrem. The annual dose is calculated on the basis of a factor of 0.022 mrem/yr per pCi/d intake.

The maximum observed concentration of cesium-137 in edible tissue from cattle was the 770 pCi/kg obtained from the three-herd composite muscle tissue sample collected in 1958. Under the assumed conditions this would result in an annual dose of 8.5 mrem.

Comparing the calculated hypothetical doses to the 500 mrem guide the 32 mrem dose from deer liver is equivalent to 6.4 percent of the guide. The 8.5 mrem hypothetical dose from cattle muscle is 1.7 percent of the guide.

Other radionuclides, in particular ruthenium-106, cerium-144, zirconium-95, plutonium-238, and plutonium-239, were occasionally measured in edible tissue samples. In some cases, the absorbed dose due to these radionuclides received by the critical organ approached the doses due to cesium-137. However, because of such factors as shorter physical half life, generally low concentrations, or less frequent occurrence, the other radionuclides were less important contributors to dose over the period covered than cesium-137.

The maximum observed concentration of strontium-90 in bone from all animals sampled during the period of this report was 94 pCi/g ash in a steer from the NTS. If the dose factors for cattle are comparable to those for humans (0.9 rem/y per nCi/g calcium) that concentration would result in an annual dose of 71 mrem to the bone marrow. This maximum value is 14 percent of the 500 mrem guide for humans. Since people do not normally consume bones, this result is provided for comparative purposes only.

NECROPSY AND HISTOPATHOLOGICAL EXAMINATIONS

Since 1956, sacrificed animals were generally necropsied and samples of selected tissues and lesions (if present) were collected and submitted for histopathological evaluation. After 1972, blood samples were frequently collected and submitted for hematological examination. The results of these examinations are maintained in the files of the AIP or have been published in the annual reports since 1969.

Prior to the cessation of atmospheric testing in 1962, there were occasional reports of beta burns suffered by cattle and horses exposed to heavy fallout. Systemic effects in these animals were not noted by investigating officials (Congressional Hearings, 1979).

Since 1957, a beef herd has been maintained on the ranges of the NTS. This herd obtains all of its food from the natural vegetation and frequently grazes over the sites of nuclear tests. The husbandry for this herd is consistent with that practiced on area commercial ranches. The NTS herd has been studied intensively with semiannual sacrifices, necropsies, and sampling for histopathological and radionuclide analyses.

Reproduction and production data for the NTS herd have been kept since 1964. The average annual calving percentage has generally exceeded 90 percent and has never been below 70 percent. The average annual weaning weights for the calves has ranged from 375 to 410 pounds. The most recent survey (Rogers 1965) of the commercial range cattle industry of southern Nevada reports that the average calving percentage was 59 percent and the average weaning weight was 354 pounds.

Clinical conditions encountered on a recurring basis in the NTS beef herd have included actinobacillosis (lumpy jaw), traumatic reticuloperitonitis (Hardware disease), pneumonia, and ocular squamous cell carcinoma (cancer eye). The first two conditions are caused by bacteria invading tissue that has been penetrated by a foreign body. Pneumonia is also caused by micro-organisms. Ocular squamous cell carcinomas are frequently observed in aged Hereford cattle exposed to severe sunlight (Moulton 1961).

A frequent histologic finding is the presence of sarcocysts in both cardiac and skeletal muscle. This protozoan parasite is found commonly in cattle and other species and generally has little clinical significance (Merck, 1979).

Other histologic findings were usually consistent with the condition of the individual animal or were the result of agonal struggling. Occasionally observed microscopic pathology, e.g., hemosiderosis of the spleen, capsular melanosis of the adrenal, mineralization of kidney tubules and hyperplasia of

the tracheobronchial lymph nodes were estimated to be within normal levels by the examining pathologists. No pathology, gross or microscopic, has been observed that has been directly attributed to ionizing radiation.

The EPA began analyzing blood samples from the NTS beef herd in 1972. Since that time the maximum strontium-90 concentration observed in bone was 15 pCi/g ash. Assuming the same conversion factor from concentration to dose as for humans, this would result in an annual dose to the bone marrow of 11 mrem. Any effects of radiation dose to the bone marrow would be expected to be observed as changes in the hemopoietic system with resultant blood dyscrasias. No such changes have been observed that could not be related to the health status of the individual animal.

SUMMARY OF ATMOSPHERIC NUCLEAR TESTING

Atmospheric nuclear testing at the NTS began with the five-shot Ranger series in January and February of 1951. During October and November of 1951 the seven-shot Buster-Jangle series was conducted. Five of the 12 atmospheric tests of these two series had explosive yields equal to or less than 1.2 kiloton (kt) of TNT. The eight tests of the Tumbler-Snapper series in April, May, and June 1952 included two with yields of 1 kt and six of 11 to 31 kt. Upshot-knothole in March and April 1953 had two tests of 0.2 kt yield and nine with yields of 11 to 61 kt. The Teapot series in February to May 1955 consisted of 14 shots of which half had yields of 4 kt or less and the remainder ranged from 7 to 43 kt. In 1957 the Plumbbob series was conducted from May through October. This series consisted of 24 shots of which 7 were equal to or less than 4.7 kt and the remainder ranged from 8 to 74 kt. One of the smaller tests was a high-altitude rocket test and one was underground, neither of which resulted in any local fallout. The last major atmospheric test series at the NTS was Hardtack Phase II in September and October 1958. This series consisted of 15 atmospheric tests and four underground tests, three of which resulted in some venting to the atmosphere. Only one test of this series had a yield as great as 22 kt, and the majority were below 1 kt. Several safety tests during the Plumbbob and Hardtack Phase II series resulted in small nuclear yields ranging from a few tenths of a ton to 38 tons equivalent yield.

Since September 1, 1961, all nuclear detonations, except for three slightly above ground or shallow underground tests of Operation Dominic II and eight nuclear earth-cratering experiments, have been conducted underground and were designed for containment. In addition, some fissionable material was detected off the test range complex as a result of three transportation safety tests in 1963. Review of the interim reports and aerial surveillance activity reports prepared for each event by the Offsite Radiation Safety Program shows that radioactivity was released to the atmosphere from 60 of the underground tests designed for containment conducted at the NTS since September 1, 1961. These releases resulted from either failure of containment or from post-test operations. Only 31 of the accidental releases were large enough to be detected off the test range complex-(U.S. Department of Energy, 1980). The total amount of activity added to the atmosphere from these accidental releases was rather insignificant in comparison with that released during the period of active atmospheric testing prior to 1961.

The United States (U.S.) was not alone in testing of nuclear devices. In 1949 the Union of Soviet Socialist Republics (U.S.S.R.) conducted its first atmospheric nuclear test, and the United Kingdom (U.K.) conducted its first atmospheric nuclear test in 1952. The Republic of France began atmospheric nuclear testing in 1960. Atmospheric nuclear testing was begun by the

Peoples' Republic of China in 1964. Figure 17 shows the worldwide cumulative fission yield for air bursts from 1945 through 1976. Approximately 64 percent of the total occurred during the heavy testing period by the U.S., U.K., and U.S.S.R. in 1957 and 1958.

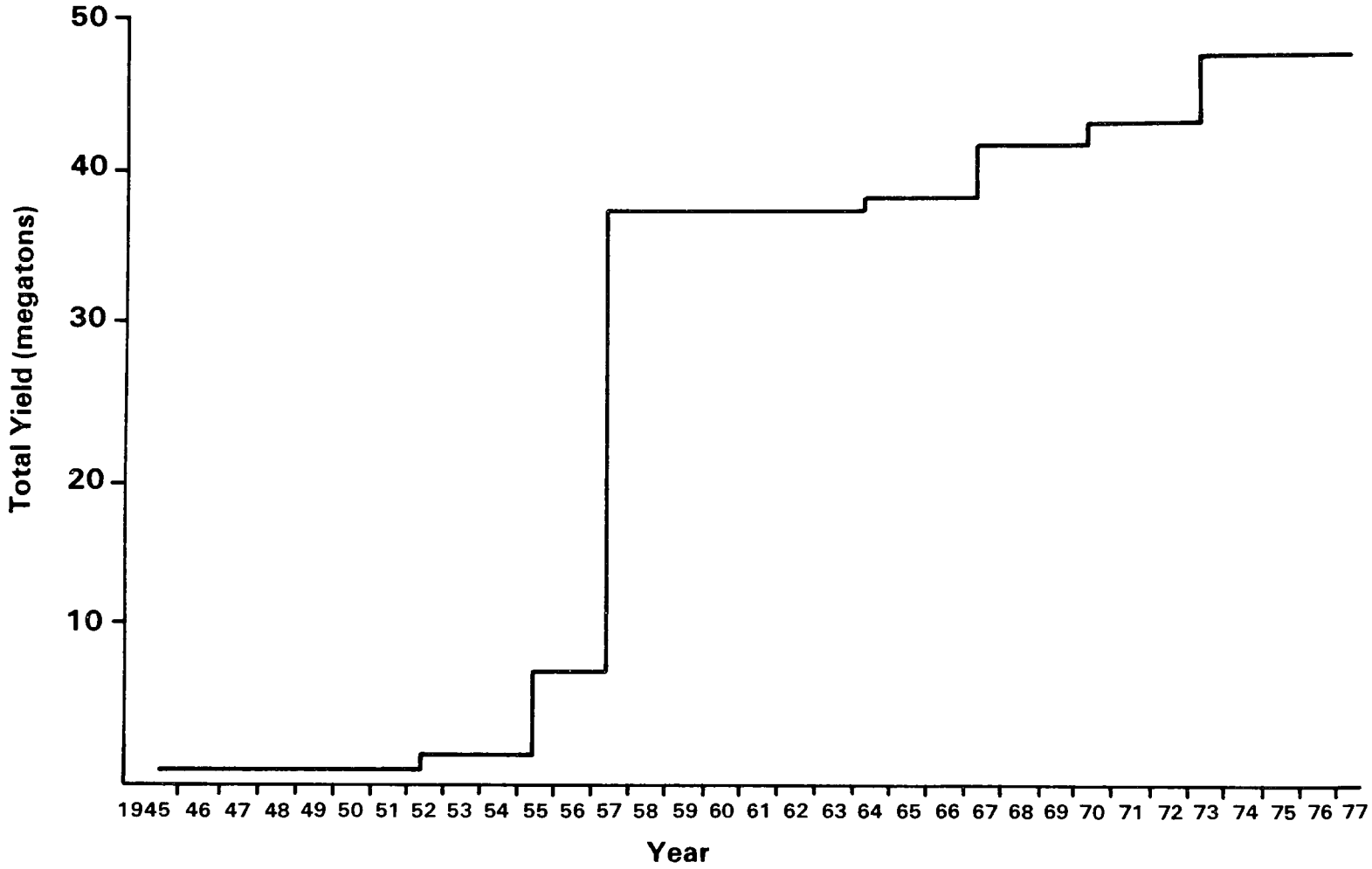

Figure 17. Cumulative world fission yield -- air bursts only.

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APPENDIX TABLE 1. SUMMARY OF STRONTIUM-90 CONCENTRATIONS IN HOCK BONES FROM DESERT BIGHORN SHEEP

Year	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/g Ash)	Median of Results Greater Than MDA* (pCi/g Ash)	Remarks
1956	25	25	0.5 - 2.5	1.2**	1956-1963 data from Kramp, 1965
1957	22	22	0.7 - 6.0	2.5**	
1958	19	19	0.5 - 8.7	2.8**	
1959	24	24	1.1 - 12	3.5**	
1960	18	18	1.1 - 7.3	3.4**	
1961	34	34	0.6 - 6.6	3.2**	
1962	22	22	0.9 - 16	5.7**	
1963	17	17	3.4 - 8.9	6.4**	
1964	7	7	3.9 - 24	8.8	1964-1968 data from unpublished files of Animal Investigation Program, EMSL-LV
1965	19	19	2.0 - 24	8.9	Northern Region
	4	4	3.6 - 10	6.9	Southern Region
1966	9	9	6.5 - 14	8.8	Northern Region
	5	5	4.5 - 11	7.7	Southern Region
1967	17	17	5.3 - 33	9.1	Northern Region
1968	21	21	5.3 - 12	9.3	Northern Region
	2	2	8.0 - 12	9.9	Southern Region
1969	13	13	2.7 - 9.1	5.4	Northern Region data from Smith and Giles, 1970
1970	8	5	2.2 - 8.2	2.4	Northern Region data from Smith and Giles, 1974

(continued)

APPENDIX TABLE 1. (Continued)

Year	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/g Ash)	Median of Results Greater Than MDA* (pCi/g Ash)	Remarks
1971	11	10	1.0 - 12	5.5	Northern Region
	1	1	10	10	Southern Region data from Smith and Giles, 1975
1972	9	9	2.6 - 9.4	4.5	Northern Region
	2	2	3.9 - 4.4	4.2	Southern Region Smith, et al., 1976
1973	10	10	1.2 - 11	4.3	Northern Region
	5	5	1.8 - 3.4	2.6	Southern Region Smith, et al., 1977a
1974	4	4	1.9 - 11	4.2	Northern Region
	3	3	1.0 - 3.8	1.5	Southern Region Smith, et al., 1977b
1975	11	11	2.4 - 40	4.8	Northern Region
	7	7	1.9 - 24	2.4	Southern Region Smith, et al., 1978a
1976	10	10	1.8 - 5.6	3.5	Northern Region
	3	3	0.7 - 1.8	1.2	Southern Smith, et al., 1978b
1977	18	17	0.93 - 5.6	3.3	Northern Region
	2	2	1.7 - 2.8	2.3	Southern Region Smith, et al., 1979

*MDA = Minimum Detectable Activity
**Mean results

APPENDIX TABLE 2. SUMMARY OF STRONTIUM-90 CONCENTRATIONS IN HOCK BONES FROM NEVADA TEST SITE MULE DEER

Year	Season	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/g Ash)	Median of Results Greater Than MDA* (pCi/g Ash)	Remarks
1964	4th Quarter	6	6	4.2 - 21	18	1964-1968 Data from unpublished files of Animal Investigation Program, EMSL-LV
1965	1st Quarter	2	2	12 - 13	13	
	2nd Quarter	8	8	7.0 - 19	12	
	3rd Quarter	5	5	4.1 - 12	9.4	
	4th Quarter	6	6	5.5 - 21	11	
1966	1st Quarter	4	4	13 - 19	15	
	2nd Quarter	4	4	6.6 19	13	
	3rd Quarter	3	3	8.0 - 13	9.0	
	4th Quarter	4	4	7.9 - 15	9.7	
1967	1st and 2nd Quarters	2	2	4.5 - 12	8.4	
	3rd and 4th Quarters	3	3	4.0 - 13	5.0	
1968	2nd Quarter	5	5	5.3 - 21	7.9	
	3rd and 4th Quarters	3	3	3.7 - 5.0	3.9	
1969	All 4 Quarters	6	6	1.6 - 15	5.1	Smith and Giles, 1970
1970	All 4 Quarters	6	6	0.9 - 3.5	2.8	Smith and Giles, 1974
1971	All 4 Quarters	4	4	2.0 - 4.0	3.5	Smith and Giles, 1975
1972	All 4 Quarters	4	4	2.3 - 4.0	3.2	Smith, et al., 1976
1973	All 4 Quarters	3	3	2.0 - 3.1	3.0	Smith, et al., 1977a
1974	All 4 Quarters	5	5	1.8 - 3.6	2.3	Smith, et al., 1977b
1975	All 4 Quarters	7	7	0.6 - 3.0	2.6	Smith, et al., 1978a
1976	All 4 Quarters	6	6	1.2 - 3.4	2.0	Smith, et al., 1978b
1977	All 4 Quarters	8	8	1.3 - 2.7	1.9	Smith, et al., 1979

*MDA Minimum Detectable Activity

APPENDIX TABLE 3. SUMMARY OF STRONTIUM-90 CONCENTRATIONS IN BONES FROM WILDLIFE OFF THE NEVADA TEST SITE AND FROM UTAH CATTLE

Year	Species	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/g Ash)	Median of Results Greater Than MDA* (pCi/g Ash)	Remarks
September 1959	Cattle	5	5	1.1 - 6.8	2.1†	Cedar City, Utah
November 1960	Cattle	3	3	0.9 - 1.1	1.0†	St. George, Utah
May 1961	Cattle	3	3	1.1 - 2.0	1.2†	St. George, Utah
1956	Mule Deer	5	5	1.4 - 2.3	1.7‡	Elko Co., Nev.
		13	13	1.2 - 6.5	4.8‡	Lincoln Co., Nev.
		7	7	1.2 - 4.0	2.5‡	Clark Co., Nev.
		5	5	1.9 - 12	2.5‡	Nye Co., Nev.
1957	Mule Deer	4	4	1.3 - 8.5	4.3‡	Elko Co., Nev.
		11	11	3.0 - 9.4	6.2‡	Lincoln Co., Nev.
		2	2	1.8 - 2.5	2.1‡	Clark Co., Nev.
		4	4	2.6 - 3.3	2.8‡	Nye Co., Nev.
1958	Mule Deer§				2.2‡	Elko Co., Nev.
					5.6‡	Lincoln Co., Nev.
					2.5‡	Clark Co., Nev.
					2.5‡	Nye Co., Nev.
1961	Mule Deer	6	6	1.6 - 7.3	3.4‡	Elko Co., Nev.
		13	13	1.5 - 7.2	3.6‡	Lincoln Co., Nev.
		24	24	0.9 - 3.0	2.1‡	Clark Co., Nev.
		33	33	1.2 - 11	4.7‡	Humboldt Co., Nev.
		13	13	1.2 - 5.1	2.8‡	Esmeralda Co., Nev.
1962	Mule Deer	21	21	1.1 - 13	3.8‡	Clark Co., Nev.
December 1967	Mule Deer	1	1	4.3	4.3	Stone Lake, N. Mex.
January 1968	Mule Deer	2	2	9.8 - 23	17	Supplemental Test Site Central, Nev.
December 1968	Mule Deer	2	2	2.3 - 6.1	4.2	White Pine Co., Nev.
August 1969	Mule Deer	5	5	3.7 - 6.4	5.7	Rulison Site, Rifle, Colo.
April 1970	Mule Deer	1	0			Rulison Site, Rifle, Colo.
October 1970	Mule Deer	1	1	2.5	2.5	Lincoln Co., Nev.
October 1972	Buffalo	7	7	1.1 - 6.4	2.5	Flagstaff, Ariz.

* MDA = Minimum Detectable Activity
† Data from Fountain, 1961
‡ Data from Kramp, 1965 (mean results)
§ Only mean results available

APPENDIX TABLE 4. SUMMARY OF STRONTIUM-90 CONCENTRATIONS IN FEMURS FROM NEVADA TEST SITE CATTLE

Year	Season	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/g Ash)	Median of Results Greater Than MDA* (pCi/g Ash)	Remarks
1957	Fall	5	5	3.6 - 11	4.7	Data for 1957-1961 from Fountain, 1961
1958	Spring	4	4	2.6 - 9.7	5.3	
	Fall	4	4	5.5 16	8.3	
1959	Spring	4	4	4.0 29	7.0	
	Fall	Samples lost				
1960	Spring	5	5	11 - 17	15	
	Fall	5	5	9.9 - 15	13	
1961	Spring	5	5	7.0 17	12	
1964	Spring	6	6	5.5 94	8.9	Fall 1961 through 1963 data not available 1964-1968 data from unpublished files of Animal Investigation Program, EMSL-LV
	Fall	5	5	4.9 48	7.0	
1965	Spring	6	6	14 35	19	
	Fall	6	6	14 29	20	
1966	Spring	6	6	16 29	22	
	Fall	6	6	3.0 9.9	5.2	
1967	Spring	5	5	5.2 10	6.1	
	Fall	6	6	2.9 24	8.1	
1968	Spring	6	6	2.9 - 14	6.1	
	Fall	6	6	3.8 - 15	7.3	
1969	Spring	6	6	4.7 - 13	5.1	Smith and Giles, 1970
	Fall	6	6	3.9 - 7.6	5.0	
1970	Spring	6	6	3.1 - 4.5	3.9	Smith and Giles, 1974
	Fall	7	7	1.5 8.3	3.6	
1971	Spring	7	7	2.0 - 37	5.0	Smith and Giles, 1975
	Fall	6	6	2.0 - 19	3.5	
1972	Spring	5	5	2.0 - 8.0	4.0	Smith, et al., 1976
	Fall	7	7	2.5 - 5.3	2.8	
1973	Spring	6	6	2.4 4.5	3.8	Smith, et al., 1977a
	Fall	6	6	2.2 - 5.0	3.1	
1974	Spring	6	6	2.8 9.2	3.3	Smith, et al., 1977b
	Fall	6	6	2.0 4.4	2.2	
1975	Spring	7	7	1.8 15	3.3	Smith, et al., 1978a
	Fall	6	6	1.9 - 3.0	2.5	
1976	Spring	6	6	1.9 4.8	2.7	Smith, et al., 1978b
	Fall	6	6	2.4 11	3.3	
1977	Spring	7	7	2.4 - 3.6	3.2	Smith, et al., 1979
	Fall	6	6	2.9 - 4.3	3.8	

*MDA = Minimum Detectable Activity

APPENDIX TABLE 5. SUMMARY OF STRONTIUM-90 CONCENTRATIONS IN FEMURS FROM DELAMAR VALLEY CATTLE

Year	Season	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/g Ash)	Median of Results Greater Than MDA* (pCi/g Ash)	Remarks
1957	Fall	6	6	2.7 - 8.6	5.9	1957 1961 data from Fountain, 1961
1958	Spring	3	3	1.4 - 9.8	6.3	
	Fall	4	4	3.3 - 7.4	5.0	
1959	Spring	4	4	5.0 - 5.9	5.6	
	Fall	Samples lost				
1960	Spring	5	5	6.6 - 28	17	
	Fall	5	5	6.7 - 14	12	
1961	Spring	5	5	3.7 - 13	11	Fall 1961 through 1963 data not available
1964	Spring	6	6	5.5 - 21	12	1964-1967 data from unpublished files of Animal Investigation Program, EMSL-LV
	Fall	6	6	8.7 - 24	13	
1965	Spring	5	5	13 - 30	18	
	Fall	6	6	13 - 27	17	
1966	Spring	6	6	9.7 - 15	11	
	Fall	Samples lost				
1967	Spring	6	6	6.4 - 14	9.0	

*MDA = Minimum Detectable Activity

APPENDIX TABLE 6. SUMMARY OF STRONTIUM-90 CONCENTRATIONS IN FEMURS FROM KNOLL CREEK CATTLE

Year	Season	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/g Ash)	Median of Results Greater Than MDA* (pCi/g Ash)	Remarks
1958	Spring	3	3	2.4 - 14	11	1958-1961 Fountain, 1961
	Fall	4	4	4.0 - 12	6.1	
1959		Samples lost				
1960	Spring	5	5	18 32	22	
	Fall	5	5	14 - 22	18	
1961	Spring	5	5	3.5 - 22	14	Fall 1961 through 1963 data not available
1964	Spring	3	3	38 - 60	50	1964-1967 data from unpublished files of Animal Investigation Program, EMSL-LV
	Fall	6	6	12 - 39	23	
1965	Spring	6	6	14 - 30	22	
	Fall	6	6	16 - 33	20	
1966	Spring	6	6	15 - 32	17	
	Fall	Samples lost				
1967	Spring	6	4	10 - 16	13	

*MDA = Minimum Detectable Activity

APPENDIX TABLE 7. SUMMARY OF CESIUM-137 CONCENTRATIONS IN SELECTED TISSUES AND RUMEN CONTENTS FROM NEVADA TEST SITE CATTLE

Year	Season	Tissue	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/kg**)	Median of Results Greater Than MDA* (pCi/kg**)	Remarks
1957	Fall	Muscle	1	1	390	390	Data for 1957-1961 from Fountain, 1961
1958	Spring	Liver	1	1	230	230	1958 muscle and liver samples from NTS, Delamar Valley, and Knoll Creek herds were composited and analyzed by gamma spectrometry
		Muscle	1	1	470	470	
	Fall	Liver	1	1	350	350	
		Muscle	1	1	770	770	
1959	Spring	Liver	4	3	140 - 280	180	
		Muscle	4	4	230 - 500	310	
	Fall	Liver	5	5	110 - 230	150	
		Muscle	5	5	120 - 220	160	
1960	Fall	Liver	5	4	76 - 170	120	Spring samples lost
		Muscle	5	5	150 - 440	190	
1961	Spring	Liver	8	5	29 - 100	46	Fall 1961 through 1963 data not available
		Muscle	8	8	39 - 180	100	
1964	Spring	Liver	6	6	130 - 250	240	1964-1968 data from unpublished files of Animal Investigation Program, EMSL-LV
		Muscle	6	6	270 - 490	390	
		Rumen contents	5	5	550 - 1,000	720	
1964	Fall	Liver	4	2	65 - 70	68	
		Muscle	6	5	30 - 300	180	
		Rumen contents	6	5	45 - 380	120	
1965	Spring	Liver	6	6	200 - 560	260	
		Lung	6	6	180 - 580	320	
		Muscle	6	6	360 - 750	530	
		Rumen contents	6	5	150 - 270	200	
1965	Fall	Liver	6	0			The 1965 Fall and 1966 Spring data are very suspect as it is unlikely that the tissue levels of ^{137}Cs would have been as low as reported.
		Lung	6	0			
		Muscle	6	0			
		Rumen contents	6	1	750	750	
1966	Spring	Liver	6	0			
		Lung	6	0			
		Muscle	6	0			
		Rumen contents	6	0			
1966	Fall	Liver	6	2	100 - 110	105	
		Lung	6	3	100 - 140	120	
		Muscle	6	3	100 - 140	120	
		Rumen contents	6	2	85 - 160	120	
1967	Spring	Liver	6	2	56 - 78	70	
		Lung	6	0			
		Muscle	6	5	64 - 120	72	
		Rumen contents	6	0			

(continued)

APPENDIX TABLE 7. (Continued)

Year	Season	Tissue	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/kg**)	Median of Results Greater Than MDA* (pCi/kg**)	Remarks
1967	Fall	Liver	6	2	61 - 140	100	
		Lung	6	1	190	190	
		Muscle	6	1	70	70	
		Rumen contents	6	3	60 90	60	
1968	Spring	Liver	6	4	78 140	100	
		Lung	6	1	160	160	
		Muscle	6	3	65 - 120	84	
		Rumen contents		Not sampled			
1968	Fall	Liver	6	1	110	110	
		Lung	6	1	150	150	
		Muscle	6	1	43	43	
		Rumen contents	6	1	450	450	
1969	Spring	Liver	6	0			1969 data from Smith and Giles, 1970
		Lung	6	0			
		Muscle	6	0			
		Rumen contents	6	0			
1969	Fall	Liver	6	0			
		Lung	6	0			
		Muscle	6	0			
		Rumen contents	6	0			
1970	Spring	Liver	6	2	42 - 92	67	1970 data from Smith and Giles, 1974
		Lung	6	0			
		Muscle	6	5	25 62	41	
		Rumen contents	6	0			
1970	Fall	Liver	7	0			
		Lung	7	1	230	230	
		Muscle	7	2	29 - 50	40	
		Rumen contents	7	0			
1971	Spring	Liver	7	4	20 - 90	30	1971 data from Smith and Giles, 1975
		Lung	7	1	80	80	
		Muscle	7	6	30 - 120	45	
		Rumen contents	7	0			
1971	Fall	Liver	6	6	23 - 57	39	
		Lung	6	6	22 - 190	83	
		Muscle	6	6	27 - 59	40	
		Rumen contents	6	6	35 - 94	75	
1972	Spring	Liver	7	0			1972 data from Smith, et al., 1976
		Lung	7	0			
		Muscle	7	5	29 - 40	30	
		Rumen contents	7	0			
1972	Fall	Liver	7	2	24 - 32	28	
		Lung	7	0			
		Muscle	6	4	29 - 50	35	
		Rumen contents	6	3	31 - 300	40	

(continued)

APPENDIX TABLE 7. (Continued)

Year	Season	Tissue	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/kg**)	Median of Results Greater Than MDA* (pCi/kg**)	Remarks
1973	Spring	Liver	6	0			1973 data from Smith, et al., 1977a
		Lung	6	0			
		Muscle	6	5	20 50	30	
		Rumen contents	6	2	40 - 80	60	
1973	Fall	Liver	6	1	20	20	
		Lung	6	1	20	20	
		Muscle	6	4	14 - 20	20	
		Rumen contents	6	4	20 60	35	
1974	Spring	Liver	6	0			1974 data from Smith, et al., 1977b
		Lung	6	2	22 - 42	32	
		Muscle	6	2	28 - 53	40	
		Rumen contents	5	2	45 - 120	83	
1974	Fall	Liver	6	0			
		Lung	6	0			
		Muscle	6	0			
		Rumen contents	6	2	40 - 79	60	
1975	Spring	Liver	7	0			1975 data from Smith, et al., 1978a
		Lung	6	0			
		Muscle	7	5	41 - 71	44	
		Rumen contents	7	2	19 - 58	39	
1975	Fall	Liver	6	0			
		Lung	6	0			
		Muscle	6	1	29	29	
		Rumen contents	6	3	15 - 27	20	
1976	Spring	Liver	6	2	13 - 21	12	1976 data from Smith, et al., 1978a
		Lung	6	0			
		Muscle	6	2	19 - 39	29	
		Rumen contents	6	1	26	26	
1976	Fall	Liver	6	1	18	18	
		Lung	6	0			
		Muscle	6	0			
		Rumen contents	6	2	27 - 33	30	
1977	Spring	Liver	6	0			1977 data from Smith, et al., 1979
		Lung	6	0			
		Muscle	6	1	16	16	
		Rumen contents	6	1	45	45	
1977	Fall	Liver	6	0			
		Lung	6	0			
		Muscle	6	0			
		Rumen contents	6	2	28 - 36	32	

*MDA Minimum Detectable Activity
**Wet Weight

APPENDIX TABLE 8. SUMMARY OF CESIUM-137 CONCENTRATIONS IN SELECTED TISSUES AND RUMEN CONTENTS FROM DELAMAR VALLEY CATTLE

Year	Season	Tissue	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/kg**)	Median of Results Greater Than MDA* (pCi/kg**)	Remarks
1958	Spring	Liver	1	1	230	230	Data for 1958-1961 from Fountain, 1961. 1958 liver and muscle samples from NTS Delamar Valley, and Knoll Creek herds were composited and analyzed by gamma spectrometry
		Muscle	1	1	470	470	
	Fall	Liver	1	1	350	350	
		Muscle	1	1	770	770	
1959	Spring	Liver	4	4	190 - 450	290	
		Muscle	4	4	250 - 840	380	
	Fall	Liver	3	3	100 - 170	130	
		Muscle	3	3	83 130	120	
1960	Fall	Liver	Samples not analyzed				1960 Spring samples lost
		Muscle	5	5	46 - 91	51	
1961	Spring	Liver	2	2	19 - 22	21	Fall 1961 through 1963 not available
		Muscle	2	2	48 - 100	74	
1964	Spring	Liver	6	4	45 - 75	60	1964- 967 data from unpublished files of Animal Investigation Program, EMSL-LV
		Muscle	6	5	40 - 170	140	
		Rumen contents	6	6	35 - 210	58	
	Fall	Liver	6	6	50 220	110	
		Muscle	3	3	25 - 55	30	3 muscle samples lost
		Rumen contents	6	6	20 - 150	83	
1961	Spring	Liver	2	2	19 - 22	21	Fall 1961 through 1963 not available
		Muscle	2	2	48 - 100	74	
1965	Spring	Liver	6	6	150 - 510	300	
		Lung	6	5	300 - 1,000	560	
		Muscle	6	6	220 - 660	400	
		Rumen contents	6	6	260 - 490	320	
	Fall	Liver	6	0			1965 Fall and 1966 Spring data are very suspect
		Lung	6	0			
		Muscle	6	0			
		Rumen contents	6	0			
1966	Spring	Liver	6	0			
		Lung	6	0			
		Muscle	6	0			
		Rumen contents	6	0			
	Fall	Liver	6	4	60 - 240	80	
		Lung	6	1	750	750	
		Muscle	6	3	85 - 300	180	
		Rumen contents	6	4	120 - 380	120	
1967	Spring	Liver	6	3	72 - 150	110	
		Lung	6	0			
		Muscle	6	4	71 - 150	100	
		Rumen contents	6	1	120	120	

*MDA - Minimum Detectable Activity
**Wet Weight

APPENDIX TABLE 9. SUMMARY OF CESIUM-137 CONCENTRATIONS IN SELECTED TISSUES AND RUMEN CONTENTS FROM KNOLL CREEK CATTLE

Year	Season	Tissue	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/kg**)	Median of Results Greater Than MDA* (pCi/kg**)	Remarks
1958	Spring	Liver	1	1	230	230	Data for 1958-1961 from Fountain, 1961. 1958 liver and muscle samples from NTS, Delamar Valley, and Knoll Creek herds were composited and analyzed by gamma spectrometry
		Muscle	1	1	470	470	
	Fall	Liver	1	1	350	350	
		Muscle	1	1	770	770	
1959	Spring	Liver	4	4	160 - 290	200	
		Muscle	4	4	290 - 370	300	
	Fall	Liver	4	4	140 - 210	160	
		Muscle	4	3	240 - 340	240	
1960	Fall	Liver	5	4	53 - 84	82	1960 Spring samples lost
		Muscle	5	4	62 330	160	
1961	Spring	Liver	5	5	5 78	27	Fall 1961 through 1963 data not available
		Muscle	5	5	27 - 98	55	
1964	Spring	Liver	3	3	75 - 230	120	1964-1968 data from unpublished files of Animal Investigation Program, EMSL-LV
		Muscle	3	3	240 - 350	350	
		Rumen contents	3	3	160 - 240	190	
	Fall	Liver	6	6	240 - 770	460	Three muscle and Rumen content samples were lost in Spring 1964
		Muscle	6	5	510 - 1,10	770	
		Rumen contents	6	6	370 - 880	690	
1965	Spring	Liver	6	6	230 - 480	340	
		Lung	6	6	210 - 550	450	
		Muscle	6	6	290 - 700	470	
		Rumen contents	6	4	150 400	300	
	Fall	Liver	6	0			Fall 1965 and Spring 1966 data are very suspect
		Lung	6	0			
		Muscle	6	0			
		Rumen contents	6	0			
1966	Spring	Liver	6	0			
		Lung	6	0			
		Muscle	6	0			
		Rumen contents	6	0			
	Fall	Liver	6	3	120 - 180	150	
		Lung	6	3	180 - 320	280	
		Muscle	6	3	140 - 420	360	
		Rumen contents	6	1	320	320	
1967	Spring	Liver	6	1	32	32	
		Lung	6	0			
		Muscle	6	2	94 - 96	95	
		Rumen contents	6	2	52 - 100	75	

*MDA = Minimum Detectable Activity
**Wet Weight

APPENDIX TABLE 10. SUMMARY OF CESIUM-137 CONCENTRATIONS IN SELECTED TISSUES AND RUMEN CONTENTS FROM NEVADA TEST SITE MULE DEER

Year	Season	Tissue	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/kg**)	Results Greater Than MDA* (pCi/kg**)	Remarks
1964	4th Quarter	Liver	6	1	420	420	1964-1968 data from unpublished files of Animal Investigation Program, EMSL-LV
		Muscle	6	4	110 - 560	290	
		Rumen contents	6	2	440 - 570	510	
1965	1st Quarter	Liver	2	1	350	350	Fawns
		Lung	2	2	75 - 560	320	
		Muscle	2	2	190 - 560	380	
		Rumen contents	2	2	200 - 460	330	
	2nd Quarter	Liver	12	3	190 - 1,100	340	
		Lung	12	7	270 480	300	
		Muscle	12	8	300 800	520	
		Rumen contents	11	8	120 - 600	440	
	3rd Quarter	Liver	5	1	210	210	
		Lung	5	1	670	670	
		Muscle	5	5	140 - 280	210	
		Rumen contents	5	3	130 - 280	200	
	4th Quarter	Liver	6	0			
		Lung	6	0			
		Muscle	6	1	130	130	
		Rumen contents	6	1	290	290	
1966	1st Quarter	Liver	4	1	180	180	
		Lung	4	0			
		Muscle	4	3	130 - 280	220	
		Rumen contents	4	1	350	350	
	2nd Quarter	Liver	4	0			
		Lung	4	0			
		Muscle	4	4	100 - 220	170	
		Rumen contents	4	0			
	3rd Quarter	Liver	3	2	100 - 150	130	
		Lung	3	3	110 - 120	120	
		Muscle	3	3	110 - 300	120	
		Rumen contents	3	0			
	4th Quarter	Liver	4	2	60 - 90	75	
		Lung	4	1	45		
		Muscle	4	3	30 - 440	65	
		Rumen contents	4	1	140	140	
1967	1st Quarter	Liver	2	0			
		Lung	2	0			
		Muscle	2	2	4 - 70	37	
		Rumen contents	2	1	8	8	
	3rd Quarter	Liver	3	0			
		Lung	3	0			
		Muscle	3	1	10	10	
		Rumen contents	3	3	80 - 320	140	

(continued)

APPENDIX TABLE 10. (Continued)

Year	Season	Tissue	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/kg**)	Median of Results Greater Than MDA* (pCi/kg**)	Remarks
1968	2nd Quarter	Liver	4	2	1,600 2,900	2,300	Included doe and fetuses sampled in Cat Canyon after Buggy Event
		Lung	4	2	590 1,000	800	
		Muscle	6	5	280 - 4,700	1,600	
		Rumen contents	4	0			
	3rd and 4th Quarters	Liver	5	0			
		Lung	5	1	180	180	
		Muscle	5	2	72 - 120	95	
		Rumen contents	5	0			
1969	All Four Quarters	Liver	5	0			1969 data from Smith and Giles, 1970
		Lung	5	0			
		Muscle	5	0			
		Rumen contents	5	0			
1970	All Four Quarters	Liver	4	0			1970 data from Smith and Giles, 1974 Positive samples collected in September and November
		Lung	4	0			
		Muscle	4	2	30 - 61	45	
		Rumen contents	4	0			
1971	All Four Quarters	Liver	4	2	30 - 37	34	1971 data from Smith and Giles, 1975
		Lung	4	1	55	55	
		Muscle	4	3	32 - 40	34	
		Rumen contents	4	2	30 - 280	160	
1972	All Four Quarters	Liver	3	1	40	40	1972 data from Smith and Giles, 1976
		Lung	3	0			
		Muscle	3	1	24	24	
		Rumen contents	3	0			
1973	All Four Quarters	Liver	4	0			1973 data from Smith and Giles, 1977a
		Lung	4	2	40 - 50	45	
		Muscle	4	2	20 - 30	25	
		Rumen contents	4	1	110	110	
1974	All Four Quarters	Liver	5	0			1974 data from Smith, et al., 1977b
		Lung	5	0			
		Muscle	5	1	20	20	
		Rumen contents	3	1	3,000	3,000	
1975	All Four Quarters	Liver	8	0			1975 data from Smith, et al., 1978a
		Lung	7	2	24 - 43	34	
		Muscle	8	5	23 - 140	38	
		Rumen contents	5	3	15 - 53	29	
1976	All Four Quarters	Liver	6	0			1976 data from Smith, et al., 1978b
		Lung	6	0			
		Muscle	6	0			
		Rumen contents	6	2	24 - 38	31	
1977	All Four Quarters	Liver	8	1	17	17	1977 data from Smith, et al., 1979
		Lung	8	0			
		Muscle	8	3	11 - 52	23	
		Rumen contents	8	3	23 - 69	33	

* MDA = Minimum Detectable Activity
**Wet Weight

APPENDIX TABLE 11. SUMMARY OF CESIUM-137 CONCENTRATIONS IN SELECTED TISSUES AND RUMEN CONTENTS FROM WILDLIFE OFF THE NEVADA TEST SITE AND FROM UTAH CATTLE

Year	Season	Species	Tissue	Number of Samples	Number of Samples Greater Than MDA*	Range of Positive Samples (pCi/kg**)	Median of Results Greater Than MDA* (pCi/kg**)	Remarks
1959	Sept.	Cattle	Liver	2	2	120 - 150	140	Cedar City, Utah
			Muscle	2	2	110 - 140	130	
1960	Nov.	Cattle	Liver	3	3	60 - 60	60	St. George, Utah
			Muscle	3	3	16 - 30	18	
1961	May	Cattle	Liver	3	3	13 - 26	17	St. George, Utah
			Muscle	3	3	21 - 25	24	
1967	Dec.	Mule Deer	Liver	2	0			Near Gasbuggy Site, Stone Lake, N. Mex.
			Lung	1	0			
			Muscle	2	1	70	70	
			Rumen contents	2	1	95	95	
1968	Jan.	Mule Deer	Liver	2	1	58	58	Supplemental Test Site Central, Nev.
			Lung	2	0			
			Muscle	2	1	92	92	
			Rumen contents	2	0			
1968	Dec.	Mule Deer	Liver	2	0			White Pine Co., Nev.
			Lung	2	0			
			Muscle	2	0			
			Rumen contents	2	0			
1970	Oct.	Mule Deer	Liver	1	0			Lincoln Co., Nev.
			Lung	1	0			
			Muscle	1	0			
			Rumen contents	1	0			
1972	Oct.	Buffalo	Liver	7	0			Flagstaff, Ariz.
			Lung	7	0			
			Muscle	7	0			
			Rumen contents	7	0			

* MDA = Minimum Detectable Activity
**Wet Weight

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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4. TITLE AND SUBTITLE SELECTED RADIOISOTOPES IN ANIMAL TISSUES IN NEVADA: ^{90}Sr and ^{137}Cs Measurements from 1956 to 1977		5. REPORT DATE April 1981
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16. ABSTRACT

Measurements have been made since 1956 of the strontium-90 and cesium-137 concentrations in tissues from cattle, deer, and bighorn sheep living on and around the Nevada Test Site (NTS). Examination of this data cumulation indicates that the measured tissue concentrations reflect global fallout rather than local sources of these isotopes.

Maximum strontium-90 concentrations in bone are related to exposure during maximum bone growth. During, or immediately following, periods of high fallout, younger animals exhibited higher concentrations of strontium-90 in bone. During low-fallout periods older animals, which had been young during heavy fallout periods, had the highest concentrations of strontium-90 in bone. The effective half-life of strontium-90 in bone of desert bighorn sheep is estimated to be 4.8 years while the effective half-life of cesium-137 in soft tissue appears to be only a few weeks.

The maximum observed concentration of cesium-137 in edible tissue was 2,900 picocuries per kilogram in liver from a deer collected 5 weeks after a nearby nuclear cratering experiment. Using standard-man data, the daily consumption of 500 grams of such tissue would result in an annual dose of 32 millirem, which is 6.4 percent of the radiation protection guide established for individuals of the general population.

The husbandry, necropsy, and histopathological records of the NTS beef herd indicate that the nuclear testing program has had no observable long-term impact on the herd.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

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