WILD DEER AS A SOURCE OF RADIONUCLIDE INTAKE BY HUMANS AND AS INDICATORS OF FALLOUT HAZARDS*

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Abstract—Concentrations of various fallout radionuclides were measured in native forage and in tissues of wild mule deer over a five-year period in north-central Colorado. Concentrations of ^{137}Cs in deer flesh were 5 to 13 times higher than concentrations reported in beef and in pork. The data indicated that consumption of deer flesh could result in a ^{137}Cs intake which could possibly exceed the intake of the nuclide from all other items of the total diet combined. Consumption of deer liver would result in the ingestion of ^{144}Ce, ^{137}Cs, ^{54}Mn, and ^{106}Ru. The data indicated that deer tissues can be useful and in some cases, unusually sensitive indicators of environmental contamination by ^{144}Ce, ^{137}Cs, ^{131}I, ^{54}Mn, ^{106}Ru, and ^{90}Sr. Relationships between forage and deer tissue for ^{137}Cs, ^{131}I, and ^{90}Sr were investigated. During 1963, the radiation dose to the skeleton of yearling deer from ^{90}Sr averaged 330 mrad, which was generally higher than the total dose from natural background and other sources combined. During the same period, the ^{90}Sr concentrations in deer bone were higher by a factor of 35 than reported bone levels in humans. During the study, dose rates to deer thyroid, liver, and muscle reached 20, 0.014, and 0.012 rad/year, respectively.

INTRODUCTION

Studies on radionuclide levels in tissues of wild mule deer (*Odocoileus hemionus hemionus*) during the past four years demonstrated that this animal accumulated measurable concentrations of ^{137}Cs, ^{144}Ce, ^{131}I, ^{54}Mn, ^{106}Ru, and ^{90}Sr. Nuclide concentrations measured were usually considerably higher than those measured in domestic meat products during the same periods. Since flesh of deer and other wild game is consumed by some segments of the human population, it was of interest to study this particular food item.

In addition, because deer accumulate measurable concentrations of fallout, they can be convenient and sensitive indicators of environmental contamination. Deer are harvested in large numbers in many areas of the world through sport, commercial, and control hunting. Samples can also be obtained through mortality from automobiles, disease, starvation, and predators.

Radionuclide levels and calculated dose estimates for deer were much higher than for most humans. Thus, assuming similar radiosensitivities between the species, one could possibly observe radiation effects from fallout in deer populations at considerably lower levels of environmental contamination than would be necessary to produce effects in the bulk of the human population. It therefore seems that we should be concerned about potential indirect effects of radiation on man through damage to the native plants and animals upon which man ultimately depends. In general ecological terms, it is difficult to assess the importance of deer to the well-being of mankind. It is obvious that reindeer and caribou are essential to the Lapps and Eskimos of the arctic regions, but the importance of this family of animals to most Americans for example, is likely more subtle. In economic terms, however, it was estimated that during 1964 in the state of Colorado alone, 168,319 hunters spent over $30 million [1]

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in pursuit of deer, killing approximately 118,840 animals.[2]

METHODS

All sampling was done within the Cache la Poudre drainage west of Fort Collins, Colorado. The area comprises about 580 square miles and ranges between 5200 and 13,000 feet in elevation. Deer were collected weekly from February 1962 to January 1965 from a uniform distribution of locations within the study area by personnel of the Colorado Department of Game, Fish and Parks. Certain deer tissues were also obtained in larger numbers from hunters during October and November of 1961 and 1962.

Quantitative assay for gamma emitters was accomplished by gamma-ray spectrometry. The counting system included a solid 4 in. thick × 8 in. diameter NaI (Tl) crystal which was mounted over three matched photomultiplier tubes and surrounded by 5 in. steel shielding. Electrical pulses were stored in a transistorized 400 channel pulse height analyzer. Gamma-ray spectra were resolved by matrix inversion using an IBM 1620 computer. Samples were counted in bulk form under uniform conditions of geometry. Standards were prepared by contaminating water contained in the same geometrical configurations as the samples in question, with known quantities of each radionuclide requiring consideration.

Strontium-90 was assayed by counting beta particles from the ^{90}Y daughter after chemical separation and preparation. Ground and ashed bone samples were dissolved in nitric acid and the strontium was separated and purified by a series of precipitations with fuming nitric acid. The purified strontium solution was allowed to stand until secular equilibrium of ^{90}Y was established. Yttrium was separated from the ^{90}Sr solution as the hydroxide and converted to the oxalate which was mounted on a plastic disc for counting with a Sharp laboratories low background flow-gas beta counter.

RESULTS AND DISCUSSION

Radionuclide Intake by Humans

From the standpoint of radionuclide transfer to humans from deer, ^{137}Cs is probably the most important. During our studies, deer flesh contained considerably higher mean concentrations of ^{137}Cs than beef and other meats (Table 1). For example, from July 1962 through April 1963, deer flesh contained higher mean ^{137}Cs concentrations than United States beef and pork[3] by factors of approximately 13 and 11, respectively. Comparisons with beef from the Fort Collins, Colorado area[4] during 1962 and 1963 indicated that deer flesh ^{137}Cs concentrations averaged higher than stall-fed and pasture cows by a factor of at least 5. Data indicate that this difference could be explained by normally higher fallout levels in deer forage and possibly by a higher transfer coefficient (flesh/feed ratio) in deer. The percentage of the daily ^{137}Cs intake per kg meat averages less than 4% in cattle (J. E. Johnson, unpublished data) while we have calculated possible values of 15 to 30% in deer.

Comparisons were also made between possible intake of ^{137}Cs from deer flesh and from the total diet (Table 2). In October, November, and December of 1962, the average dietary intake rate of ^{137}Cs in Chicago, New York, and San Francisco was approximately 51 pCi/day.[5] During the same period, deer flesh averaged 575 pCi ^{137}Cs/kg and if one consumed the average U.S. human meat intake of 200 g/day,[5] the intake rate from this source alone would amount to approximately 115 pCi/day. In a similar comparison, the total dietary intake rate of ^{137}Cs in Denver, Colorado institutions during 1964 was 150 pCi/day.[6] The mean ^{137}Cs concentration in deer flesh during 1964 was 872 pCi/kg[7] which could yield a possible intake rate of about 175 pCi/day from deer meat alone. Individual deer collected in 1963 contained as much as 3300 pCi ^{137}Cs/kg of flesh which could lead to an intake rate by humans of 660 pCi/day.

It must be stressed that past and current fallout levels have not been sufficiently high to make deer flesh hazardous for human consumption. Based on present knowledge, the levels of ^{137}Cs would have to be increased by several orders of magnitude to produce somatic effects in deer or in humans.

Since deer liver is considered a choice food item by most hunters, samples collected from May 1963 to August 1964 were assayed for gamma-ray emitting fallout radionuclides.[8] It

Table 1. *Comparison of* ^{137}Cs *Concentrations in Flesh of Colorado Deer with Beef and Pork*

Period	Mean ^{137}Cs concentrations in pCi/kg		
	Deer	Beef	Pork
July 1962–April 1963	698(40)	55(52)*	
July 1963–Oct. 1963	1526(16)		133(52)*
April 1962–Nov. 1963	1213(76)	226(20)†	

Sample sizes given in parentheses.
* United States averages.[3]
† Pasture and feedlot cattle from Colorado.[4]

Table 2. *Comparison of Possible* ^{137}Cs *Intake from Colorado Deer Flesh with Intake from the Total Diet*

Period	Probable ^{137}Cs intake in pCi/day		
	Deer flesh alone*	Total diet, Tri-cities[5]	Total diet, Denver Institutions[6]
Oct.–Dec. 1962	115	51	
Jan.–Dec. 1964	175		150

* Based upon the average US daily meat intake of 200 g/day.[5]

Table 3. *Summary of data on Gamma-ray Emitting Fallout Radionuclides Measured in* 43 *Colorado Mule Deer Livers from May* 1963 *to August* 1964[8]

Nuclide	Nuclide levels in pc/Kg		Probable amount ingested by humans during period in pCi/liver*
	Means	Std. Dev.	
^{144}Ce	1420	1060	2420
^{137}Cs	440	290	750
^{54}Mn	230	160	390
^{106}Ru	460	370	780

* The adult deer liver weighs approximately 1.7 kg.[9]

was found that ^{144}Ce, ^{137}Cs, ^{54}Mn, and ^{106}Ru were present in liver in readily measurable concentrations. A summary of these data is given in Table 3. It appears that the probable amounts of fallout radionuclides ingested by humans from deer liver during 1963 and 1964 were relatively small. Nevertheless, liver tissue may be a relatively unique but likely insignificant vector for human consumption of ^{144}Ce, ^{54}Mn, and ^{106}Ru.

The chance of ^{131}I being transferred to humans from deer thyroid appears to be very small because of the short half-life of ^{131}I and because this gland is not ordinarily consumed by humans.

Deer are probably not important ^{90}Sr vehicles to humans because we have found that at least 97% of the total body burden of strontium is located in bone which is not ordinarily consumed by humans.

Deer as Indicators of Fallout Levels

Estimation of fallout levels in a given environs is difficult to accomplish with precision because of the normally large sampling variations. Under certain conditions, it may be helpful to sample a free-roaming native animal population, rather than air, soil, or vegetation, because each individual would carry radionuclide burdens which would be more or less representative of an integrated sample of forage from a certain area for some period of time. Also, the concentrations of certain radionuclides in animal tissues may exceed considerably the concentrations in forage or air and in these instances, animal tissues would be simpler to assay with precision. Of course, the problems of sampling variability would still exist for the animal population and an appropriate sample size and sampling design would still need to be determined. Once this was accomplished, the relationship between plant and animal for instance, must be established and this relationship may be subject to rather large uncertainties. We have investigated some radionuclide relationships between deer and native forage.

The correlation coefficient of 0.90 between mean ^{137}Cs levels in deer flesh and in native forage plants which we previously reported,(7) indicates that levels of environmental contamination with this nuclide could be estimated using deer samples. We have found an accumulation of about 0·24 pCi ^{137}Cs/g deer flesh per pCi ^{137}Cs/g air dry vegetation (assuming equilibrium conditions). Of course, the concentrations of ^{137}Cs in deer flesh would reflect levels of the nuclide in the plants consumed by deer and not necessarily the other types of plants which may be preferred by domestic grazing animals.

Earlier communications(10-13) have demonstrated the high sensitivity of deer thyroids for estimating levels of environmental contamination with ^{131}I. More recent data indicate that ^{131}I can be detected in deer thyroids during periods when it is below the detection limit in milk,(13) forage samples,* or in rabbit thyroids. Deer thyroids appear to have concentrations of ^{131}I similar to rabbit thyroids but the deer thyroid usually contains approximately 25–50 times more tissue which greatly facilitates ^{131}I detection and measurement.

Schultz and Longhurst(16) have measured fallout ^{90}Sr in jaw bones of California deer and we have previously discussed factors affecting ^{90}Sr accumulation in Colorado deer.(17, 18) We have found that in 4–5-month-old deer, the skeleton accumulates about 9 pCi ^{90}Sr/g bone ash per pCi ^{90}Sr/g air dry plant material. This simple linear relationship would not hold true for older deer, however, because equilibrium of ^{90}Sr is not reached rapidly as in the case of ^{137}Cs and the bone levels would be slow to respond to rapid changes in forage levels.

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* The estimated equilibrium relationship between ^{131}I in deer thyroid and forage indicates that the thyroid concentration could exceed the forage concentration by at least 1000-fold:

$$\frac{\text{thyroid } ^{131}\text{I conc.}}{\text{forage } ^{131}\text{I conc.}} = \frac{(1500 \text{ g forage/day})\ (0.3 \text{ ingested to thyroid}^{(14)})\ (7.6 \text{ days}^{(14)})}{(0.693)\ (4 \text{ g/thyroid})} = 1{,}235$$

This calculation is in reasonable agreement with experimental work on continual ingestion of ^{131}I by sheep.(15)

Table 4. Estimates of Radiation Dose Rates to the Skeleton of Yearling Colorado Mule Deer from Various Sources during 1963

Source	mrad/yr.
^{90}Sr in bone	330*
Natural background and terrestrial fallout	250–350†
^{137}Ce in muscle	12

* Calculated from mean concentrations of ^{90}Sr in yearling deer bones by a method described elsewhere.[21]

† Based on measurements taken in the Cache la Poudre drainage, Colorado with a calibrated portable scintillation counter.

Schultz has also discussed advantages and disadvantages in using deer antlers for monitoring ^{90}Sr.[19]

Since deer liver accumulates isotopes such as ^{144}Ce, ^{54}Mn, and ^{106}Ru which seldom can be measured in other organs and tissues commonly assayed, the liver may be useful for estimating environmental concentrations of these particular nuclides.[8].

Fallout Hazards to Deer

Although radiation doses to deer from fallout radionuclides during this study have been orders of magnitude lower than those required to produce somatic damage in other mammals, the estimated doses to certain tissues have been higher than natural background levels. Furthermore, the doses received by deer from fallout materials have been considerably higher than doses received by the general human population. It should be pointed out, however, that Lapps[20] and Eskimos received doses from ^{137}Cs which were probably higher than the ^{137}Cs doses received by Colorado deer.

From the standpoint of potential harm to deer from fallout, ^{90}Sr is probably the most important radionuclide to consider. For example, in 1963, it was estimated that the dose to the skeleton of yearling deer was probably greater from ^{90}Sr than from all other sources combined. Estimates of these sources and their relative importance are given in Table 4. It was also found that during 1963, ^{90}Sr concentrations and radiation doses in bone of yearling deer were higher by a factor of about 35 than in 0–20-year-old humans from New York, Chicago, and San Francisco.[22]

Doses to deer thyroids have been low in comparison to a dose required to produce adenomas. However, during the one-year period from April 1962 to April 1963 these deer received a thyroid dose of about 20 rad,[11] which approaches the maximum permissible annual thyroid dose of 30 rad for radiation workers.

Doses to deer liver tissue from fallout radionuclides were estimated to approach 110 mrad/lifetime or approximately 14 mrad/year during this study.[8]

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