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Dose Assessment for Sheep Exposed to Fallout from Nuclear Test Nancy

L. B. Sasser
J. K. Soldat
W. E. Kennedy, Jr.
D. W. Murphy

October 1982

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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SUMMARY

Radiation doses were estimated for sheep wintering on Nevada ranges during the testing at the Nevada Test Site of the nuclear weapon "Nancy" on March 24, 1953. Exposure pathways considered were inhalation of radionuclides from both cloud passage and resuspension, external exposure of the total body and skin, and ingestion of contaminated forage and soil. Physiological, metabolic, and dosimetric data needed for these calculations were obtained from data appropriate for the sheep. Dose rate and radionuclide deposition values for shot Nancy were used. Radionuclide deposition and retention on the desert vegetation were obtained from data collected during several nuclear tests at the Nevada Test Site. Existing dosimetric computer programs, whose libraries were modified to include the sheep data, and specially developed models were used to estimate the dose commitment for the sheep.

The total-body dose for reference sheep located within the 40-mR/hr (H+12) isopleth from all modes of exposure was estimated to be 2.6 rad. Ingestion of fallout on edible vegetation contributed the majority of the dose, whereas inhalation of radionuclides and consumption of contaminated soil from the ground contributed little to the internal doses. The dose to the thyroid of ewes from radioiodine and other radionuclides reaching the thyroid was approximately 400 rad. The calculated uniform dose to the reticulo-rumen was 4 rad; however, if fallout particles were assumed to concentrate in the ventral rumen, a localized dose of 200 rad could have been received by the rumen wall. Estimated dose to the bare skin of ewes was 120 rad. The dose to the fetal thyroid from radioiodine ingested by a pregnant ewe grazing at a location where the dose rate was 40 mR/hr (H+12) was estimated to be 700 rad, or approximately twice the dose to the maternal thyroid.

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CONTENTS

SUMMARY	iii
INTRODUCTION	1
BACKGROUND	2
METHODS	4
APPROACH	4
PHYSIOLOGICAL AND METABOLIC DATA FOR SHEEP	4
LOCATION OF THE SHEEP WITH RESPECT TO THE FALLOUT PLUME	8
SOURCE TERMS	8
DOSIMETRY	11
Inhalation	13
External Exposure During Plume Passage	15
External Exposure From Deposited Radionuclides	15
Beta Skin Dose From Contaminated Soil	16
Contribution From Radionuclides Ingested With Vegetation	17
Contribution From Radionuclides Ingested With Soil	22
Localized Dose to the Rumen Wall	24
Doses to Fetal Lambs	25
RESULTS	28
DISCUSSION	31
REFERENCES	34
APPENDIX A - ORGAN DATA LIBRARY FOR SHEEP - ORGLIB	43
APPENDIX B - RADIONUCLIDE CONTRIBUTIONS TO EWE'S INTERNAL ORGAN DOSES FROM INGESTION	65

FIGURES

1	Location of Range Lands Where Sheep Wintered During 1952-1953 in Relation to Isopleth Contours of Shot Nancy	9
2	Four-Compartment Model of the GI Tract of a Sheep	20

TABLES

1	Metabolic Data for Sheep	5
2	Reported Values of Radionuclide Uptake in Sheep	7
3	Total Activity Ingested, by Nuclide, from Grazing One Week . .	12
4	Effective Radii and Masses of Organs of the Reference Sheep . .	18
5	Clearance Half-Times and Organ Masses for the Ruminant GI-Tract Model	21
6	Values for Parameters Used in Fetal Dose Calculations	27
7	Summary of Calculated Dose Commitments to Sheep Exposed for Seven Days Beginning at Time H+2 Hours	29
8	Summary of Calculated Dose Commitments to Fetus Exposed for Seven Days Beginning at Time H+2 Hours	30
9	Contributions of Individual Radioiodine Isotopes to Fetal Lamb Internal Radiation Doses	30
A-1	Organ Data Library for Sheep - ORGLIB	45
B-1	Calculated Dose Commitments to Internal Organs of Sheep Ingesting Fallout From Nuclear Test Nancy	66
B-2	Calculated Dose Commitments to Compartments of the GI Tract of Sheep Ingesting Fallout From Nuclear Test Nancy	67

INTRODUCTION

In the spring of 1953, the Atomic Energy Commission conducted a series of nuclear tests (Upshot-Knothole) at the Nevada Test Site. One of the nuclear tests (Nancy) was carried out on March 24, 1953, and the resulting fallout cloud passed over the rangeland north of the test site where some sheep were grazing. The sheep were moved from the Nevada winter grazing ranges to the Cedar City, Utah, area in May of 1953. Some sheep owners subsequently reported unusually high numbers of ewe and lamb deaths and they suspected fallout as a possible cause. The purpose of this study was to estimate radiation doses to reference sheep in Nevada resulting from the fallout arising from the test Nancy.

BACKGROUND

Information concerning sheep management practices and desert range conditions was reviewed to identify factors unique to this study. A brief description of this information follows.

Sheep owners in Utah and Nevada in the 1950s commonly grazed sheep on mountain summer ranges and desert winter ranges. Sheep were trailed between ranches and the ranges, in some cases a distance of over 160 km requiring 3 weeks trailing time. Sheep were usually moved to the Nevada winter ranges in late October or early November and returned to their home ranches in mid-to-late April. When winter conditions were poor, some ranchers moved their sheep earlier in the spring. Lambing usually occurred soon after the sheep returned to their home ranches.

The composition of forage consumed by grazing animals in the desert varies tremendously. The consumption of specific plants is influenced not only by the species present but also by their stage of growth, the condition of the range, the abundance of forage, and the climatic condition of the area. The winter grazing ranges are composed primarily of browse species in association with various amounts of grasses. Studies conducted on western Utah desert ranges showed that sheep consume more browse (70%) than grasses (28%) during winter grazing periods in areas where a mixed flora is present (Cook and Harris 1968; Cook 1977). Under poor range conditions, the percentage of browse in the diet decreases and the percentage of grasses increases (Cook and Harris 1968).

Sheep usually arrived on the winter ranges in good body condition after spending the summer months on relatively lush summer ranges at higher elevations. The ewes usually lost weight while on the winter ranges, the most critical period being from mid-February to the first part of April. If weather conditions were good, the ranges improved during the spring and the ewes began to gain back the lost body weight. Fetal growth (Clanton et al. 1959; Harris et al. 1956) also offset some weight lost during the winter months.

Holmes (1979) compiled available information concerning sheep and range conditions in 1953. The grazing conditions on the winter ranges that year

were extremely poor. Although the late winter temperatures were above normal, the lack of precipitation (50% below normal) and unusually cold weather in the spring resulted in reduced vegetation growth. The sheep returning from winter ranges were reported to be in poor condition and were probably undernourished. The sheep were sheared upon arrival in Utah, and lambing started in most herds during the first 10 days of May, although some herds lambled in April. During this period, some of the ranchers began to notice problems in their herds. In March and April, skin lesions were found on the faces and noses of the ewes and on their bodies at shearing in May. In some cases, the wool "slipped" off the ewes. The death rate of the ewes was highest within a few days of lambing. Some lambs were stillborn; others died within a few days of birth. Although some lambs were born stunted, most were full-term lambs.

The total number of sheep grazing winter ranges near the Nevada Test Site in 1953 is not known. Nearly 18,000 sheep were estimated to be in nine herds investigated (Holmes 1979) and another 1700 in a herd later reported to be affected (Sanders 1953). In all, nearly 2000 ewes, approximately 12% of the ewes in the affected herds, and approximately 3000 lambs were reported to have died. The number of lambs born was not recorded, but lamb losses were estimated at 20% to 25%. Losses in some herds investigated were unknown or low and are not included in these estimates.

METHODS

APPROACH

The purpose of this study was to estimate radiation doses to sheep in Nevada resulting from the fallout arising from the test Nancy. An attempt was made to obtain as much physiological, metabolic and dosimetric information as possible concerning the sheep exposed to Nancy in 1953, and to learn the condition of the desert ranges they grazed. Much of this information was obtained from data compiled on winter-ranged sheep and from data published by Utah State University and the U.S. Department of Agriculture (USDA) on sheep foraging winter desert ranges. Where available, data on the metabolism of radionuclides in sheep from laboratory experiments were used. Where appropriate information could not be found for sheep, data from other species were used.

Dose rate and radionuclide deposition values for shot Nancy were obtained from published information. Information on radionuclide deposition and retention on desert vegetation was obtained from measurements made during the period of nuclear weapons testing. Libraries of existing dosimetric computer programs were modified to include data for sheep. Special models were developed to estimate the doses to the ruminant GI tract and the fetus of sheep. Radiation doses to reference sheep were calculated for inhalation and air submersion during cloud passage, external exposure to deposited radionuclides, inhalation of resuspended material and ingestion of contaminated forage and soil.

PHYSIOLOGICAL AND METABOLIC DATA FOR SHEEP

The basic physiological and metabolic data obtained for sheep are listed in Table 1. The sheep were mostly Rambouillet or Rambouillet crosses (Holmes 1979). Although the weight of the ewes varied depending on such factors as grazing conditions, age, health and stage of pregnancy, available information indicates that ewes grazing winter ranges in 1953 probably weighed about 60 kg (Cook et al. 1954; Clanton et al. 1959; Harris et al. 1956). Feed intake of sheep on desert winter ranges varies between 1.2 and 1.5 kg/d (dry weight), depending upon the condition of the range (Harris et al. 1956; Cook et al.

TABLE 1. Metabolic Data for Sheep

Ewe weight (kg)	60	Cook et al. 1954
	54	Clanton et al. 1959
	60	Harris et al. 1956
Lamb weight (kg)		
- at birth	3.9	Clanton et al. 1959
- at birth	4.5	Harris et al. 1956
- at birth	4.5	Rommereim 1978
- at 125 days gestation	3.9	Book et al. 1974
Total products of conception (kg)	8.3	Hafez 1972
Feed intake (kg/d)	1.45	Harris et al. 1956
	1.50	Cook et al. 1954
	1.20	Cook and Harris 1956
Respiration (L/min)	6	Comar 1966
<u>GI Tract Contents (kg wet weight)</u>		
Rumen (young ewes)	5.4	Purser and Moir 1966
	5.8	Church 1975; Church et al. 1980
Omasum	0.2	Church 1975; Church et al. 1980
Abomasum	0.5	Church 1975; Church et al. 1980
Small intestine	1	Church 1975; Church et al. 1980
Large intestine	1.2	Church 1975; Church et al. 1980
<u>Clearance half-time (min)</u>		
Rumen ingesta	811	Grovum and Williams 1973
Abomasum ingesta	37	Grovum and Williams 1973
Cecum colon ingesta	400	Grovum and Williams 1973
<u>Thyroid mass (g)</u>		
Maternal	8	Bustad et al. 1953
		Comar 1966
		Book et al. 1974
Fetal - 130 days gestation	2	Barnes et al. 1954
- 125 days gestation	0.8	Book et al. 1974

1954; Cook and Harris 1956). Although feed consumption is generally less on ranges in poor condition, a conservative feed intake value of 1.5 kg/d was used here. Birth weights of lambs ranged between 3.9 and 4.5 kg (Clanton et al. 1959; Harris et al. 1956; Rommereim 1978; Book et al. 1974).

Weights for the gastrointestinal contents of sheep were taken from Church 1975 and Church et al. 1980 and adjusted to a 60-kg sheep. The half-times for clearance of ingesta through the rumen and intestinal tract were estimated from the data of Grovum and Williams (1973). Mean retention times of 20 to 30 hours have been reported by others for sheep (Nagy and Alldredge 1979) and for goats (Castle 1956). The rate of passage of simulated fallout particles through the gastrointestinal tract is similar to that of ingesta in sheep and goats (Lovaas and Johnson 1971; Jones 1975).

Data on radionuclide uptake in sheep were available for the radionuclides listed in Table 2. Existing dosimetric computer programs were modified to incorporate this information into their libraries. Otherwise, existing data on fractional uptake from the GI tract and biological half-times in various organs were used (see Appendix A).

Most of the data needed to calculate the thyroid doses were taken from studies conducted on sheep. The maternal thyroid uptake of iodine-131 was assumed to be 40% of the amount ingested (Wood et al. 1963; Ragan et al. 1963), and the ewe's thyroid was assumed to average 8 g (Comar 1966; Bustad et al. 1953; Book et al. 1974). Both of these values may vary in individual animals depending on stable iodine intake and season of the year. The biological half-time of iodine-131 in the ewe's thyroid was taken to be 14 days (Wood et al. 1963). The peak fetal thyroid uptake was taken from Book et al. (1974) to be 7.7%. The reported weights of fetal thyroids in late gestation ranged from 0.8 (Book et al. 1974) to 2 g (Barnes et al. 1954). A value of 0.8 g was used for this study because the Utah lambs are assumed to have been small. The thyroid biological half-time was not found for fetal sheep, but was reported to be 1 and 3 days in the human (Aboul-Khair et al. 1966) and guinea pig (Book 1977), respectively. The use of the guinea pig value was justified because fetal thyroids of guinea pigs and sheep become active at equivalent periods of gestation, and radioiodine uptake rates are similar in both species.

TABLE 2. Reported Values of Radionuclide Uptake in Sheep

Isotope	Organ	% Reaching Organ ^(a)	Biological Half-Times (days)	Reference
⁶⁰ Co	Total body	30		Comar et al. 1946
⁷⁵ Se	Total body	35		Wright and Bell 1966
⁹⁰ Sr	Total body	5-10		Burov et al. 1969 Comar 1966
	Fetus	1		Burov and Buldakov 1964 Buldakov 1964
⁹⁹ Mo	Total body	25		Bell et al. 1966
¹¹⁵ Cd	Total body	1		Mraz and Eisele (unpublished)
¹³¹ I	Total body	100		Stara et al. 1971
	Thyroid	40	14	Wood et al. 1963
		45		Ragan et al. 1963
		42		Barnes et al. 1954
	Thyroid (inhalation)	7		Willard and Bair 1961
	Fetal thyroid	7.7	3	Book et al. 1974 Book 1977
¹³² Te	Total body	24		Wright and Bell 1966 Casey et al. 1963
¹³⁷ Cs	Total body	60	5-10	Buldakov 1964
		60-80		Stara et al. 1971
		50-80		McClellan et al. 1962
			15-21	Goldman et al. 1965
¹⁴⁴ Ce	Total body	0.01		McKenny et al. 1961
¹⁸⁵ W	Total body	2		Bell and Sneed 1970

(a) All values are for ingestion by the ewe unless otherwise indicated.

LOCATION OF THE SHEEP WITH RESPECT TO THE FALLOUT PLUME

Figure 1 illustrates the location of the winter ranges assigned to ranchers in 1953 (stippled areas) and the dose rate isopleths, in mR/hr, for 12 hours after the detonation of shot Nancy (i.e., at H+12). These ranges are scattered across nearly 150 km of the Nevada desert and are separated by several mountain ranges. From ground zero at the Nevada Test Site, the nearest winter range is 50 to 60 km away; the farthest is over 150 km away. In most cases, a herd of at least 1500 sheep grazed each range in 1953. Even though only two or three of the affected herds were within the area circumscribed by the 0.4-mR/hr contour, affected sheep were reported in almost all herds. The sheep that could have received the greatest dose were ranging northwest of the Lincoln Mine in Penoyer Valley, Nevada, and could have been within the 40-mR/hr H+12 fallout isopleth. Most of the other affected herds were located outside the 0.4-mR/hr contour of shot Nancy. Most of the herds left the Nevada ranges 10 to 25 days after the March 24 testing of shot Nancy. The sheep located in Penoyer Valley near the Lincoln Mine left for Utah approximately 2 weeks after the Nancy shot.

SOURCE TERMS

The quantity of radionuclides ingested by the animals during the week following the deposition of fallout can be calculated using the equation:

$$I = \sum_{0}^{t=7 \text{ d}} H_{12} \cdot DP \cdot P/W \cdot F \cdot T_w \quad (1)$$

where: I • total radionuclides ingested, μCi

H_{12} • mR/hr at H+12 hours

DP • normalized ground deposition factor based on time of arrival of fallout plume, $\mu\text{Ci}/\text{m}^2$ per mR/hr (Hicks 1981)

P • fraction of particles deposited that are initially retained on vegetation, unitless

W • vegetation biomass, kg/m^2

FIGURE 1. Location of Range Lands Where Sheep Wintered During 1952-1953 in Relation to Isopleth Contours of Shot Nancy

F = daily forage intake, 1.5 kg

$$T_w = [0.75e^{-(0.693/5)t} + 0.25e^{-(0.693/18)t}], \text{ weathering factor where } t \text{ is in days post-deposition.}$$

The isopleths for the fallout pattern for the test Nancy were taken from the U.S. Weather Bureau report (Nagler and Telegades 1956). The maps contain an analysis of the dose rates normalized to 12 hours after detonation (hour H) and the approximate plume arrival times. The H+12 notation referred to the normalized exposure rate in mR/hr at 1 meter above the ground. The values for the normalized ground deposition factors for radionuclides (DP) were taken from Hicks (1981). These data provided the types and amounts of radionuclides deposited at any given time post-detonation that corresponded to a measurement of 1 mR/hr at a 1-m height at H+12 hours. This information was used to estimate the ingestion of specific radionuclides.

Studies on particle deposition and retention by Witherspoon and Taylor (1970; 1971), Lovass and Johnson (1971), Romney et al. (1963), and Lindberg et al. (1959) indicate that the initial interception of particles was highly dependent on the amount of above-ground biomass, plant species composition and weather. The average of biomass available for livestock from the intermountain ranges was about 30 g/m² (Hutchings and Stewart 1953; Holmgren and Brewster 1972). However, no laboratory-controlled experimental information was found concerning values of P (fraction of particles deposited per unit area that are initially retained on vegetation) for desert vegetation.

A value was derived for P/W from the data of Lindberg et al. (1959) and Romney et al. (1963). They measured the concentration of radionuclides on native vegetation and the radioactivity per m² at several locations following nuclear detonations. The ratio of these measurements is equivalent to P/W. The values for P/W calculated from their data range from 8×10^{-4} to 1.3 m²/kg (average = 0.15). Using data obtained at locations between 30 and 160 km from ground zero yields an average P/W of 0.2 m²/kg.

A weathering factor (T_w) was used to adjust for normal particle losses from the vegetation by wind, rain, and agitation. The studies performed by Witherspoon and Taylor (1970; 1971) indicate that the weathering expression has

two or more components varying from 7.6 to 84 days (for four time periods). The weathering half-time for iodine-131 has been determined to be 18 days (Martin 1963); however, Martin's initial data were not collected until 5 days after the nuclear detonation. The 18-day weathering half-time appears consistent with Witherspoon and Taylor's values for the period from 14 to 28 days after the detonation. Their data revealed that the long-term decay component represented less than 25% of the activity initially deposited. Thus, for this study, 25% of the particles initially deposited were assumed to weather with an 18-day half-time. The remaining 75% would weather with a 5-day half-time based on the data from Witherspoon and Taylor. These values are also compatible with the short-term weathering data of Lovaas and Johnson (1971).

The quantities of the various radionuclides ingested by sheep over the 1-week grazing period following shot Nancy are listed in Table 3. The radionuclide intake was estimated using a P/W value of $0.2 \text{ m}^2/\text{kg}$. These values represent the radionuclide ingestion in a zone where the exposure rate was 1 mR/hr measured at H+12 hours. These values can be converted by a ratio to any other H+12 value for the same arrival time.

DOSIMETRY

Radiation doses to adult sheep were estimated from various exposure modes present in an area of fresh fallout. These included:

- inhalation of radionuclides during initial passage of the fallout plume and resuspension
- external exposure to airborne radionuclides during initial passage of the fallout plume
- external exposure to deposited radionuclides
- beta exposure of skin from contaminated soil
- ingestion of contaminated vegetation and soil
- localized exposure of the rumen wall.

TABLE 3. Total Activity Ingested, by Nuclide, from Grazing One Week
(P/W = 0.2 m /kg)

Nuclide	μCi	Nuclide	μCi	Nuclide	μCi	Nuclide	μCi
Fe-59	8.0×10^{-4}	Nb-97	1.8×10^0	Sn-127	2.1×10^{-1}	Cs-136	5.1×10^{-3}
Co-60	6.2×10^{-5}	Mo-99	1.3×10^0	Sb-127	1.6×10^{-1}	Cs-137	1.4×10^{-3}
U-237	2.3×10^{-1}	Tc-99m	1.2×10^0	Te-127	1.5×10^{-1}	Cs-138	2.1×10^0
U-239	1.8×10^0	Mo-101	9.3×10^{-2}	Sn-128	3.5×10^{-1}	Ba-139	5.3×10^0
Np-239	9.1×10^0	Tc-101	5.1×10^{-1}	Sb-128m	4.2×10^{-1}	Ba-140	5.2×10^{-1}
Se-83	4.1×10^0	Mo-102	1.5×10^{-2}	Sb-128	2.3×10^{-1}	La-140	8.1×10^{-1}
Br-84	1.5×10^{-1}	Tc-102	7.6×10^{-3}	Sb-129	1.5×10^{-1}	Ba-141	1.3×10^{-1}
Rb-88	3.0×10^0	Ru-103	2.1×10^{-1}	Te-129m	1.2×10^{-2}	La-141	3.9×10^0
Rh-89	8.4×10^{-2}	Rh-103m	2.5×10^{-1}	Te-129	1.5×10^0	Ce-141	2.5×10^{-1}
Sr-89	1.8×10^{-1}	Tc-104	1.4×10^{-1}	Sb-130	3.0×10^{-1}	Ba-142	7.4×10^{-3}
Sr-90	1.2×10^{-3}	Ru-105	2.6×10^0	I-130	6.0×10^{-3}	La-142	2.3×10^0
Sr-91	3.3×10^0	Rh-105	9.2×10^{-1}	Sb-131	2.7×10^{-1}	Ce-143	1.3×10^0
Y-91m	3.2×10^0	Ru-106	2.9×10^{-3}	Te-131m	2.5×10^{-1}	Pr-143	2.4×10^{-1}
Y-91	1.4×10^{-1}	Pd-109	2.7×10^{-1}	Te-131	1.2×10^0	Ce-144	1.9×10^{-2}
Sr-92	2.4×10^0	Pd-111m	2.3×10^{-1}	I-131	8.1×10^{-1}	Pr-144	1.9×10^{-2}
Y-92	2.7×10^0	Ag-111	1.7×10^{-2}	Te-132	1.9×10^0	Pr-146	2.8×10^{-1}
Sr-93	1.3×10^{-1}	Ag-112	8.4×10^{-2}	I-132	1.9×10^0	Na-147	1.6×10^{-1}
Y-93	1.3×10^{-1}	Cd-115	4.4×10^{-2}	Te-133m	8.1×10^{-1}	Nd-149	4.8×10^{-1}
Y-94	1.9×10^{-1}	In-115m	3.1×10^{-2}	Te-133	1.7×10^{-1}	Pm-149	2.9×10^{-1}
Y-95	8.9×10^{-3}	Cd-117	1.7×10^{-1}	I-133	4.4×10^0	Pm-151	1.7×10^{-1}
Zr-95	3.1×10^{-2}	In-117	1.1×10^{-1}	Te-134	1.5×10^0	Eu-156	3.9×10^{-3}
Nb-95	6.8×10^{-3}	Sn-125	1.6×10^{-2}	I-134	5.1×10^0		
Zr-97	1.9×10^0	Sb-125	1.2×10^{-4}	I-135	5.2×10^0	TOTAL	8.8×10^1

Existing dosimetric computer programs were modified to include data for sheep when available. Where data were not available for sheep, parameters for Standard Man were used.

For external exposure to airborne radionuclides, doses to the sheep's bare skin and to the total body were calculated. For external exposure to deposited radionuclides, only the dose to the total body was calculated. For internal exposure, doses were calculated for the total body, bone, lung, and thyroid. The doses to the GI tract from ingestion were calculated based on a four-compartment mixed-tank model formulated specifically for sheep.

Inhalation

The dose from inhaled radionuclides deposited in internal body organs can be delivered for years following the initial intake. Inhalation could have taken place during both the initial passage of the fallout cloud and subsequent resuspension of deposited material. Estimates of the internal doses to sheep resulting from inhalation were made using a modified version of the DACRIN computer program (Houston et al. 1976). The DACRIN computer program was originally designed to use the lung model proposed by the International Commission on Radiological Protection (ICRP) Task Group on Lung Dynamics (1966) and metabolic data from the ICRP (Publication 2, 1959; Publication 6, 1964; Publication 19, 1972). For estimating inhalation doses to sheep, modifications of the DACRIN computer program were made to permit the use of organ data for the reference sheep contained in the ORGLIB data library (see Appendix A).

The DACRIN computer program is designed to accept input values for the total atmospheric release Q_0 (in curies), the exposure time E (in seconds), the air concentration (E/Q) during the exposure time ($\text{seconds}/\text{m}^3$), and the total dose commitment time (in seconds).

The total amount of fallout deposited during the period of cloud passage can be expressed by:

$$G_i = Q_{0i} \cdot (E/Q)_i \cdot V_{di} \quad (2)$$

where: G_i • total ground concentration of radionuclide i, Ci/m²
 Q_{oi} • total release of radionuclide i, Ci
 $(E/Q)_i$ • time-integrated air concentration of radionuclide i during the exposure period per curie released, s/m³
 V_{di} • deposition velocity of radionuclide i, m/s.

Rearranging Equation (2) yields:

$$\frac{G_i}{V_{di}} = Q_{oi} \cdot (E/Q)_i \quad (3)$$

Thus, the available estimates of ground concentrations coupled with estimates of deposition velocity can be used to replace the standard input data required by the DACRIN computer program.

The ground concentrations used were the same ones used previously to derive the estimates of the quantity of various radionuclides ingested. The deposition velocity of fallout material is a complex function of the particle size of the material involved. For this study, it was assumed that the fallout consisted mainly of material with an activity median aerodynamic diameter (AMAD) of approximately 40 μ m. Such material was estimated to have an average deposition velocity of 0.1 m/s. It was further assumed that less than 1% of the material in the fallout was of respirable size (i.e., of less than 10- μ m AMAD). Hence, the fallout material inhaled by the sheep was assumed to have a 5- μ m AMAD and represented 1% of the airborne activity.

Material resuspended after initial deposition could add to the total quantity inhaled by the sheep. A time-dependent resuspension formula developed by Anspaugh et al. (1975) at the Nevada Test Site was used to determine the impact of such resuspension. The basic equation for determining the resuspension factor K is:

$$K = \left[10^{-4} \exp (-0.15 t^{\frac{1}{2}}) \right] + 10^{-9} \quad (4)$$

where: K • resuspension factor, m⁻¹
t • days after deposition.

Using this equation, the average resuspension factor during the first week after fallout deposition was estimated to be about $7 \times 10^{-5} \text{ m}^{-1}$. This factor was used to calculate the time-integrated air concentrations of resuspended material over the period from 2 to 168 hours after detonation. It was found that resuspension probably added less than 10% to the total amount of material initially inhaled by the sheep.

External Exposure During Plume Passage

External doses to the sheep from airborne radionuclides during passage of the fallout plume were calculated using the computer program SUBDOSA (Streng et al. 1975). Skin and penetrating total-body doses were estimated for the same air concentrations that were used in the inhalation dose calculations (previously discussed). The external radiation dose from airborne radionuclides depends upon the type of radiation emitted and the spatial distribution of the radionuclides surrounding the receptor. Tissue depths used for calculating doses to the skin and total body of the human are 0.007 and 5 cm, respectively. Although it was recognized that the skin thickness in sheep may be different and that additional shielding is afforded by the wool, the Standard Man parameters were used to estimate the maximum dose to bare skin areas of the sheep.

External Exposure From Deposited Radionuclides

The external total-body dose to the sheep was calculated from the air exposure measurements determined at 1 m above ground at H+12 hours. Data on radioactive decay and dosimetry of fallout material from Glasstone and Dolan (1977) were used to estimate the integrated air exposure over the period from 2 to 168 hours. This value was then corrected from 1 to 0.3 m above ground using data in Figure 3.1 (4) of Dunster (1971). The height of 0.3 m was assumed to be the sheep centerline. Correction factors were then applied to convert air exposure to tissue dose at 5 cm (the depth of interest normally used for Standard Man external dosimetry). A brief description of the calculations follows.

Assuming a reading of 1 mR/hr at H+12 hours, the exposure rate at H+1 hours would have been about 100 mR/hr, and the integrated air exposure would have been about 50 mR over the period from 2 to 168 hours. Data (Dunster 1971)

indicated that the ratio of the exposure at 0.3 m over a contaminated infinite plane to that at 1 m was relatively constant at 1.2 over the range of photon energies from 0.1 to 3 MeV. Applying this factor to the 1-m exposure yielded a 60-mR air exposure at 0.3 m above ground.

Conversion from air exposure to air dose (0.87) and attenuation through 5 cm of tissue (0.95) yielded an integrated total-body dose of approximately 0.05 rad to the sheep. This value was obtained for a location where the exposure rate was 1 mR/hr at H+12 hours. The external dose to the sheep at any other location can be obtained by multiplying the air exposure rate at H+12 hours for that location by a factor of 0.05 rad per mR/hr.

Beta Skin Dose From Contaminated Soil

The radiation dose to bare sheep skin while the sheep were lying on the ground, or to the muzzle while they were grazing, was estimated from the information in Figures 3.1(3) and 3.1(4) in Dunster (1971). These figures present beta dose rate in air and gamma exposure rate in air at various heights above a contaminated infinite plane. Comparison of the two figures indicated that the gamma contribution to skin dose would only be about 3% of the beta dose rate; therefore, only the beta dose was calculated. The lowest height for which beta doses were given in Figure 3.1(3) was at 1 cm. At this distance, the beta dose rate in air was shown to be about 10^3 rad/hr per Ci/m^2 . The value of 1 cm was thought to be a reasonable distance above the ground surface for bare skin during the time the sheep were lying on the ground. In addition, it was taken to be the average distance of the muzzle from the ground during grazing.

The initial surface concentration of fallout material (at H+1 hours) was given as $2450 \mu\text{Ci}/\text{m}^2$ by Hicks (1981). Integrating this concentration over the period from H+2 to H+168, using the decay function of $T^{-1.2}$, yielded a value of $6300 \mu\text{Ci}\cdot\text{hr}/\text{m}^2$. The following equation was then used to calculate the beta skin dose to the sheep.

$$\begin{aligned} \text{Dose}_{\beta, \text{skin}} &= \left(\frac{6300 \mu\text{Ci}\cdot\text{hr}}{\text{m}^2} \right) \left(\frac{10^{-6} \text{Ci}}{\mu\text{Ci}} \right) \left(\frac{10^3 \text{rad/hr}}{\text{Ci}/\text{m}^2} \right) (0.5) \\ &= 3.1 \text{ rad} \end{aligned} \quad (5)$$

where: 0.5 • the estimated fraction of the time the skin and/or the muzzle is close to the ground surface.

No attempt was made to estimate the reduction in beta dose from radiation scattering caused by ground roughness.

The value of 3 rad was estimated for a location where the exposure rate was 1 mR/hr at H+12 hr. If the sheep were located where this exposure rate was 40 mR/hr, the dose to the bare skin or muzzle would have been about 120 rad.

Contribution From Radionuclides Ingested With Vegetation

In addition to the internal radiation dose received from inhalation, internal doses can also result from ingestion of fallout material deposited on forage and associated soil. A modified version of the ARRRG computer program (Napier et al. 1980) was used to perform the dose calculations for organs other than the GI tract. This program uses the models described in ICRP Publication 2 (1959) for calculating internal dose and dose commitment factors to a Standard Man. For this model, effective decay energies for radionuclides were calculated based on the assumption that the entire organ burden of a given radionuclide was located at the center of a spherical organ. For acute (or short-term) intake, the equation for the dose to an organ is given by:

$$F_{ijp}(t_2) = 1.87 \times 10^{-2} E_{ij} f_{wij} \left[\frac{1 - e^{(-\lambda_i t_2)}}{\lambda_i M_j} \right] \quad (6)$$

where:

$F_{ijp}(t_2)$ • dose or dose commitment factor for radionuclide i, ingested through pathway p to organ j, accumulated over a period of t_2 years, rad/pCi

1.87×10^{-2} • a conversion factor

$$= 1.602 \times 10^{-8} \left(\frac{\text{g} \cdot \text{rad}}{\text{MeV}} \right) \left(\frac{0.037 \text{ dis}}{\text{s} \cdot \text{pCi}} \right) \left(\frac{3.15 \times 10^7 \text{ s}}{\text{yr}} \right)$$

- E_{ij} • effective decay energy of radionuclide, in organ j, MeV/dis
- f_{wij} • fraction of radionuclide i ingested reaching organ j
- λ_i • effective removal constant, calculated from the biological half-time, T_{bi} , and the radiological half-life, T_{Ri} , as:
- $$\lambda_i = 0.693(T_{Ri} + T_{bi})/T_{Ri}T_{bi}, \text{ in years}^{-1}$$
- M_j • the mass of organ j, grams.

Doses to sheep from ingestion of fallout were estimated using Equation (6). Modifications to the ARRRG computer program were made to permit the use of specific metabolic and physiological data for sheep, where available. Where such data could not be located (i.e., for radionuclide-specific values of f_{wij} and λ_i), default values for humans from ICRP Publication 2 were used. This version of the ARRRG computer program used an organ data library for sheep containing data on 66 radionuclides. The data in this library (ORGLIB) are listed in Appendix A. The effective organ radii and organ masses used to estimate E_{ij} values for the organs of the reference sheep are listed in Table 4.

The model and equations developed by the ICRP in Publication 2 for estimating dose to the GI tract in man were not deemed appropriate for calculating the radiation dose to the GI tract in ruminants, such as sheep. For ruminants, Garner (1964) reports a simplified model for calculating

TABLE 4. Effective Radii and Masses of Organs of the Reference Sheep

<u>Organ</u>	<u>Effective Radius (cm)</u>	<u>Organ Mass (g)^(a)</u>
Total body	30	60000
Bone	5	6000
Lung	10	1000
Thyroid	2	8

(a) Based on the organ masses of ewes with a total body mass of 60 kg.

time integrals of the concentration of radionuclides in various parts of the GI tract. This simple model was also deemed to be inappropriate because it does not account for the transfer of material into the bloodstream from the small intestine. In the present study, doses to the GI tract were estimated using the solutions to differential equations developed for a four-compartment model similar to that developed in ICRP Publication 30, Part I (1978). In this model, material entering each compartment was assumed to be immediately and uniformly mixed with the contents of the compartment. The material passing from each compartment was assumed to have a single clearance half-time. The four compartments considered were: 1) the reticulo-rumen (RTR) (including the omasum), 2) the abomasum, 3) the small intestine, and 4) the cecum-colon (Figure 2). The clearance half-times and organ masses for the ruminant GI tract of our reference sheep are listed in Table 5.

The critical parameters in the differential equations for the compartments of the GI tract were:

- λ_R • the radioactive decay constant of the radionuclide of interest, h^{-1}
- β_{1-4} • the transfer coefficient for each compartment, h^{-1}
(note: $\beta = \ln 2/t_{\frac{1}{2}}$, where $t_{\frac{1}{2}}$ = the clearance half-time for each GI tract compartment, h)
- f_1 • the fraction of ingested material reaching the blood
- P_0 • the total intake of each radionuclide, μCi .

Effective removal rates (λ_{1-4}) in h^{-1} for each compartment are defined as:

$$\begin{aligned} \lambda_1 &= \lambda_R + \beta_1 \\ \lambda_2 &= \lambda_R + \beta_2 \\ \lambda_3 &= \lambda_R + \beta_3 + \alpha \\ \lambda_4 &= \lambda_R + \beta_4 \end{aligned}$$

and,

where

$$\alpha = \left(\frac{f_1}{1 - f_1} \right) (\lambda_R + \lambda_3)$$

$P_o = \mu\text{Ci INTAKE}$

$\lambda_R = \text{RADIOACTIVE DECAY CONSTANT}$

$\beta_{1,4} = \text{CONSTANTS FOR TRANSFER FROM COMPARTMENT 1 TO COMPARTMENT 4}$

$\alpha = \text{ABSORPTION RATE CONSTANT} = \left(\frac{f_1}{1 - f_1} \right) (\lambda_R + \beta_3)$

$f_1 = \text{FRACTION TRANSFERRED FROM GI TRACT TO BLOOD}$

FIGURE 2. Four-Compartment Model of the GI Tract of a Sheep

TABLE 5. Clearance Half-Times and Organ Masses for the Ruminant GI-Tract Model

<u>Compartment</u>	<u>Clearance Half-Time (min)</u>	<u>Mass of Contents (g)^(a)</u>
Reticulo-Rumen (plus Omasum)	800	6000
Abomasum	40	500
Small Intestine	200	1000
Cecum-Colon	400	1200

(a) Mass corrected from those in the literature to those for a 60-kg ewe.

The differential equations developed for each compartment of the GI tract were solved for the limits of time from 0 to infinity. The integration over a long time period simplified the resulting dose equations without significantly overestimating the GI-tract doses, even for those radionuclides with relatively long half-lives. This simplification was valid because the clearance half-times for all compartments are relatively short. The overall clearance half-time from the GI tract is on the order of 1 day, leading to removal of the vast majority of the ingested material within a week. The resulting dose to each of the four compartments follows:

$$\text{Dose}_1 = 1.07 \left(\frac{E_1}{M_1} \right) \left(\frac{P_0}{\lambda_1} \right) \quad (7)$$

(reticulo-rumen)

$$\text{Dose}_2 = 1.07 \left(\frac{E_2}{M_2} \right) \left(\frac{\beta_1 P_0}{\lambda_1 \lambda_2} \right) \quad (8)$$

(abomasum)

$$\text{Dose}_3 = 1.07 \left(\frac{E_3}{M_3} \right) \left(\frac{\beta_1 \beta_2 P_0}{\lambda_1 \lambda_2 \lambda_3} \right) \quad (9)$$

(small intestine)

$$\text{Dose}_4 = 1.07 \left(\frac{E_4}{M_4} \right) \left(\frac{\beta_1 \beta_2 \beta_3 P_0}{\lambda_1 \lambda_2 \lambda_3 \lambda_4} \right) \quad (10)$$

(cecum-colon)

where:

Dose_{1-4} • dose in compartments 1 through 4, rad

E_{1-4} • effective decay energy for each radionuclide in compartments 1 through 4, MeV/dis

M_{1-4} • mass of the contents of each compartment, g

1.07 • a conversion factor

$$= \left(1.602 \times 10^{-8} \frac{\text{g} \cdot \text{rad}}{\text{MeV}} \right) \left(2.22 \times 10^6 \frac{\text{d/m}}{\text{Ci}} \right) \left(60 \frac{\text{min}}{\text{hr}} \right) \left(0.5 \frac{\text{wall}}{\text{mass}} \right)$$

The factor 0.5 (wall/mass) accounts for the ratio of the dose to the wall of the compartment to the dose to the mass of the contents.

To perform the dose calculations, Equations (7) through (10) have been included in a modified version of Napier et al.'s (1980) ARRRG computer program. The effective energies for each compartment of the GI tract were estimated for 66 radionuclides of concern and are listed in Appendix A.

Contribution From Radionuclides Ingested With Soil

For calculation of the potential dose from soil ingestion, the following assumptions were made:

- The sheep ingested 100 g of soil per day.
- The residence half-time in the reticulo-rumen compartment is 800 minutes, the same as for feed material.
- The soil ingested was taken from a layer 1 cm deep on the ground.

The radionuclide intake with the soil was calculated by assuming that essentially 100% of the fallout reached the ground surface and only a small fraction was retained by the vegetation. If A_2 was the total deposition in $\mu\text{Ci}/\text{m}^2$ at 2 hours post-detonation and the sheep consumed 100 g of soil to a depth of 1 cm, their intake of radionuclides with soil on the first day, P_s , is given by:

$$P'_S = \left(\frac{A_2 \text{ } \mu\text{Ci}}{\text{m}^2} \right) \left(\frac{10^{-4} \text{ m}^2}{\text{cm}^2} \right) \left(\frac{1}{1 \text{ cm}} \right) \left(\frac{\text{cm}^3}{D_s \text{ g}} \right) \left(\frac{100 \text{ g}}{\text{d}} \right) \quad (11)$$

where: A_2 = deposition at H+2, $\mu\text{Ci}/\text{m}^2$

D_s = soil density, $1.3 \text{ g}/\text{cm}^3$

Therefore: $P'_S = 7.7 \times 10^{-3} A_2 \text{ } \mu\text{Ci}$ (not corrected for decay).

The intake of radionuclides on vegetation during the first day is:

$$P'_O = \left(A_2 \frac{\mu\text{Ci}}{\text{m}^2} \right) \left(\frac{P}{W} \frac{\text{m}^2}{\text{kg}} \right) \left(\frac{1.5 \text{ kg}}{\text{d}} \right) \quad (12)$$

where: P'_O = radionuclide intake on vegetation for first day, $\mu\text{Ci}/\text{d}$

$P/W = 0.2 \text{ m}^2/\text{kg}$

hence: $P'_O = A_2 (0.2)(1.5) = 0.30 A_2 \text{ } \mu\text{Ci}/\text{d}$.

The ratio (R_I) of radionuclide intake from soil to that from vegetation on the first day is then:

$$R_I = \frac{7.7 \times 10^{-3} A_2}{0.30 A_2} = 0.026 \quad (13)$$

This indicates that, at least initially, the radionuclide intake with soil was insignificant. The radionuclide concentration on the vegetation decreased more rapidly than that in soil because of weathering effects; therefore, at later times, R_I might have increased. Using the decay rate of $T^{-1.2}$ for mixed fallout, the total radionuclide intake with soil ingested over the period from 2 to 168 hours was 5.9 times the first day's intake with soil. Thus, the estimated total intake (P_S) in μCi is:

$$P_S = (7.7 \times 10^{-3} A_2 \text{ } \mu\text{Ci}/\text{d}) \times (5.9 \text{ } \mu\text{Ci} \cdot \text{d}) = 4.5 \times 10^{-2} \cdot A_2. \quad (14)$$

Thus, the total intake of radionuclides with soil ($0.045 A_2$) was estimated to be only 0.15 times the first day's intake with vegetation ($0.30 A_2$).

$$P'_S = \left(\frac{A_2 \text{ } \mu\text{Ci}}{\text{m}^2} \right) \left(\frac{10^{-4} \text{ m}^2}{\text{cm}^2} \right) \left(\frac{1}{1 \text{ cm}} \right) \left(\frac{\text{cm}^3}{D_s \text{ g}} \right) \left(\frac{100 \text{ g}}{\text{d}} \right) \quad (11)$$

where: A_2 • deposition at H+2, $\mu\text{Ci}/\text{m}^2$

D_s • soil density, $1.3 \text{ g}/\text{cm}^3$

Therefore: $P'_S = 7.7 \times 10^{-3} \cdot A_2 \text{ } \mu\text{Ci}$ (not corrected for decay).

The intake of radionuclides on vegetation during the first day is:

$$P_O = \left(A_2 \frac{\mu\text{Ci}}{\text{m}^2} \right) \left(\frac{P}{W} \frac{\text{m}^2}{\text{kg}} \right) \left(\frac{1,500 \text{ g}}{\text{d}} \right) \quad (12)$$

where: P_O • radionuclide intake on vegetation for first day, $\mu\text{Ci}/\text{d}$

$P/W = 0.2 \text{ m} / \text{kg}$.

hence: $P_O = A_2 (0.2)(1,500) = 300 \cdot A_2 \text{ } \mu\text{Ci}/\text{day}$.

The ratio (R_I) of radionuclide intake from soil to that from vegetation is then:

$$R_I = \frac{7.7 \times 10^{-3} A_2}{300 A_2} = 2.6 \times 10^{-5} \quad (13)$$

This indicates that, at least initially, the radionuclide intake with soil was insignificant. The radionuclide concentration on the vegetation decreased more rapidly than that in soil because of weathering effects; therefore, at later times, R_I might have increased. Using the decay rate of $T^{-1.2}$ for mixed fallout, the total radionuclide intake with soil ingested over the period from 2 to 168 hours was 5.9 times the first day's intake with soil. Thus, the estimated total intake (P_S) in μCi is:

$$P_S = (7.7 \times 10^{-3} A_2 \text{ } \mu\text{Ci}/\text{d}) \times (5.9 \text{ } \mu\text{Ci} \cdot \text{d}) = 4.5 \times 10^{-2} \cdot A_2 \quad (14)$$

Thus, the total intake of radionuclides with soil ($0.045 A_2$) was estimated to be only 2×10^{-4} times the first day's intake with vegetation ($300 A_2$).

Localized Dose to the Rumen Wall

An estimate was made of the potential dose to the ventral rumen wall from the accumulation of radioactive fallout particles in localized areas. The dose to the wall depends upon the quantity of radionuclides present, the geometry of the mass, the total mass of accumulated material, and the residence time.

The following assumptions were made:

- The residence half-time for the radioactive particles is the same as that for the feed material, 800 minutes.
- All radionuclides ingested settle to the floor of the rumen.

The mass of the contents of the reticulo-rumen was previously given in Table 5 as 6000 g. With a residence half-time of 800 min, the equilibrium quantity of accumulated soil (m_s) in the reticulo-rumen at an ingestion rate of 100 g/d of soil is:

$$m_s = \frac{100 \text{ g}}{d} \int_0^{\infty} e^{-\beta_1 t} dt = \frac{100 \text{ g/d}}{\beta_1} \quad (15)$$

where: $\beta_1 = \frac{\ln 2}{T_{1/2}} = \frac{\ln 2 (1440 \text{ min/day})}{800 \text{ min}} = 1.25 \text{ d}^{-1}$

Therefore, $m_s = 80 \text{ g}$ of accumulated soil at equilibrium.

The quantity of radionuclides associated with the ingested soil was previously shown to be negligible. Therefore, the ingested soil essentially provides only additional mass to dilute the nuclides accumulated at the rumen floor and thus reduces the concentration of radionuclides at that point. Increasing the residence time of the soil in the reticulo-rumen also increases the accumulated mass proportionally but does not reduce the dose for long-lived radionuclides because increased mass and the increased residence time compensate for each other. For nuclides whose radioactive half-lives are short compared to the residence half-time, the dose would be nearly independent of the residence time of the accumulated soil on the floor of the reticulo-rumen.

The dimensions of the accumulated soil also affect the calculated dose. If the 80 g of soil with a density of 1.3 g/cm^3 were in a spherical shape, the radius of the sphere of soil would be 2.4 cm. However, the accumulated soil most likely would be in a flattened shape, which, for purposes of radiation dose calculations, would have a larger effective radius than the sphere. By analogy with human organs of various shapes (kidney, liver, GI-LLI), the 80-g mass was assigned an effective radius of about 5 cm.

Using the above assumptions, the localized dose to the wall of the rumen from the accumulated radionuclides and soil was calculated as follows:

$$\text{Dose}_s = \frac{1.07 P_o \cdot E_s}{\lambda_s \cdot m_s} \quad (16)$$

where Dose_s • localized dose to the wall of the reticulo-rumen, rad

P_o • radionuclide intake with vegetation as used in the previous ingestion dose equation, μCi

E_s • decay energy of the radionuclides in the 5-cm-radius soil pocket, MeV/dis

m_s • mass of accumulated soil, g

λ_s • effective residence half-time of the soil and its associated radionuclides in the pocket, h^{-1} ;

where $\lambda_s = \lambda_R + \beta_s$

Doses to Fetal Lambs

Radiation doses to fetal lambs can arise from radionuclides transferred to the fetus from the ewe, radionuclides in the ewe's body, and sources external to the ewe. The specific exposures evaluated in this study are discussed below.

The simplest dose to evaluate was that from radionuclides deposited on the ground. This calculation was described previously for the adult ewes. The external dose to the fetus would be less than that to the ewe, because of shielding provided by the ewe's body. However, it was not possible to estimate this reduction in the fetal dose. Thus, the previously calculated 0.05 rad was used for the external dose.

The major contribution to the fetal dose from radionuclides in the ewe was assumed to be from the contents of the gastrointestinal tract, because the fetus lies close to the rumen and the colon. Shielding by the GI-tract walls, the wall of uterus and the fetal fluid would prevent nearly all of the beta radiation from the GI-tract contents from reaching the fetus. The computer code that calculates the GI-tract doses uses total effective energy per disintegration without distinguishing between the contribution of beta and gamma components. Inspection of the effective energies for a few nuclides, such as yttrium-90 and ruthenium-106/rhodium-106, which emit high-energy beta particles, revealed that more than 95% of the dose to the GI-tract wall would probably be delivered by the beta component. Corrections were not made for these reduction mechanisms, and the dose to the fetus was simply assumed to be less than the dose to the rumen wall of the ewe.

The dose to the fetus and the fetal thyroid from radioiodine transferred from the ewe was calculated using the following equation:

$$D_f = 74 f_w E T_E P_o / M \quad (17)$$

where:

D_f • dose to fetal organ from radioiodine ingested by the ewe, rad

f_w • fraction of ingested radioiodine transferred to the organ

E • effective decay energy in organ, MeV/dis

T_E • effective half-time of the radioiodine in the fetal organ, d

P_o • quality of radioiodine ingested by ewe, μCi

M • mass of the fetal organ, g

74 • a conversion factor

$$= \left(2.22 \times 10^6 \frac{\text{dis/min}}{\mu\text{Ci}} \right) \left(1440 \frac{\text{min}}{\text{day}} \right) \left(1.602 \times 10^{-8} \frac{\text{g} \cdot \text{rad}}{\text{MeV}} \right) \left(\frac{1}{\ln 2} \right)$$

The values used for the various parameters are listed in Table 6.

TABLE 6. Values for Parameters Used in Fetal Dose Calculations

<u>Parameter</u>	<u>Fetal Thyroid</u>	<u>Fetus</u>
Mass, g	0.8	3900
T_B , Biological half-time, d	3	3
f_w	0.077	0.13

RESULTS

The dose commitments for sheep exposed for a week at a location where the external exposure rate was 1 mR/hr at H+12 hours were calculated as the base case. These results, plus those for a location where the H+12-hour exposure rate was 40 mR/hr, are listed in Tables 7 and 8. For the base case, the total-body dose from external exposure to the passing fallout plume and the deposited radionuclides was calculated to be 0.05 rad for 1 week. The major component of organ doses resulted from the ingestion of radioactive fallout intercepted by the vegetation; inhalation contributed little to the total organ doses. Appendix B contains a listing of the contributions of individual radionuclides to the internal organ doses received by the ewe from ingestion of contaminated vegetation. The listing is for a location where the dose rate was 1 mR/hr at H+12 hour. The doses at the 40-mR/hr isopleth would be 40 times as high.

The sheep receiving the highest doses were most likely located within the 40-mR/hr (H+12 hour) isopleth northwest of the Lincoln Mine area in the Penoyer Valley. The total-body dose from all modes of exposure at this location was calculated to be 2.6 rad (Table 7). The thyroid dose of the adult sheep was determined to be approximately 400 rad. The thyroid dose estimate included exposure from the radioiodines, including daughters, and other radionuclides in the fallout mixture that transfer to the thyroid. The largest dose to any portion of the GI tract (assuming a uniform mixture of the radionuclides) was 4 rad to the wall of the reticulo-rumen compartment. If the fallout particles were assumed to separate from the ingesta and concentrate in the ventral portion of the reticulo-rumen, a localized dose of 200 rad might have been received by the rumen wall. Any additional radiation dose to the gastrointestinal tract from the ingestion of contaminated soil would be negligible.

The fetal thyroid dose resulting from radioiodine ingested by a pregnant ewe grazing in the Penoyer Valley was estimated to be 700 rad. The dose to the fetus from external sources (including the ewe) would be less than the ewe's total GI-tract dose of 6 rad (Table 8). The percentage contribution from individual radioiodine nuclides to the internal radiation doses to the fetal lamb are listed in Table 9. About 50% of the doses resulted from ^{133}I and only 15% from ^{131}I .

TABLE 7. Summary of Calculated Dose Commitments to Sheep Exposed for Seven Days Beginning at Time H+2 Hours

Exposure Mode	Dose Period	Organ	Dose Commitment (rad) at	
			1-mR/hr Location ^(a)	40-mR/hr Location ^(a)
External-Ground at 0.3 m at 1 cm	1 week	Total body	5.0×10^{-2}	2×10^0
		Skin (beta)	3.1×10^0	1×10^2
External-Cloud	During passage	Total body	2.3×10^{-7}	4×10^{-6}
		Skin	3.9×10^{-7}	2×10^{-5}
Inhalation-Cloud + Resuspension	4 weeks	Total body	5.0×10^{-7}	2×10^{-5}
		Bone	2.6×10^{-6}	1×10^{-4}
		Lung	7.0×10^{-6}	3×10^{-4}
		Thyroid	9.9×10^{-5}	4×10^{-3}
Ingestion-Forage ^(b) + Soil	4 weeks	Total body	1.6×10^{-2}	6×10^{-1}
		Bone	7.9×10^{-2}	3×10^0
		Lung	1.1×10^{-5}	4×10^{-4}
		Thyroid	1.0×10^1	4×10^2
		Reticulo- Rumen - average	9.9×10^{-2}	4×10^0
		Reticulo- Rumen - local ^(c)	4.9×10^0	2×10^2
		Abomasum	3.7×10^{-2}	2×10^0
		Small intestine	5.8×10^{-2}	2×10^0
		Cecum-Colon	7.3×10^{-2}	3×10^0

(a) Reading at H+12 hours at 1 m above ground (see Figure 1).

(b) Using a value of 0.2 for P/W.

(c) Localized dose to the rumen wall.

TABLE 8. Summary of Calculated Dose Commitments to Fetus Exposed for Seven Days Beginning at Time H+2 Hours

Exposure Mode	Dose Period	Organ	Dose Commitment (rad) at	
			1-mR/hr Location ^(a)	40-mR/hr Location ^(a)
External-Ground	4 weeks	Total fetus	5.0×10^{-2}	2×10^0
-Ewe	4 weeks	Total fetus	$<9.9 \times 10^{-2}$	$<4 \times 10^0$
Internal ^(b) - (iodine only) ^(c)	4 weeks	Total fetus	8.7×10^{-3}	3×10^{-1}
		Fetal thyroid	1.8×10^1	7×10^2

(a) Reading at H+12 hours at 1 m above ground (see Figure 1).

(b) Using a value of 0.2 for P/W.

(c) From placental transfer.

TABLE 9. Contributions of Individual Radioiodine Isotopes to Fetal Lamb Internal Radiation Doses

Radioactive Nuclide	Thyroid		Total Body	
	Dose (rad)	% Contribution	Dose (rad)	% Contribution
I-130	0.4	0.06	0.0002	0.06
I-131	110	15	0.049	14
I-132	30	4	0.016	5
I-133	380	54	0.17	48
I-134	40	6	0.023	7
I-135	150	21	0.092	26
Total	710	100	0.35	100

DISCUSSION

The results in Tables 7 and 8 are our best estimate of the radiation doses received by the reference sheep ranging near the Nevada Test Site during the nuclear weapons test designated "Nancy" in 1953. However, there are several uncertainties associated with this assessment. The events surrounding the death of the sheep occurred nearly 30 years ago, and much of the data needed to make a precise assessment are either missing or unavailable. The data that are available may be either inaccurate or subject to misinterpretation. Accurate determination of the radiation dose received by the sheep is therefore very difficult at this late time. However, we believe that the assessment presented here provides a close approximation to the doses the sheep could have received.

The results of this study show that the critical organs, as far as dose is concerned, are the maternal and fetal thyroid glands. Biological and metabolic data needed to estimate these thyroid doses are fairly well defined in the literature and were applied to this case with some confidence.

There appears to be no correlation between reported deaths and the location of the herds with respect to the fallout pattern shown in Figure 1. Most of the herds were located outside of the 0.4-mR/hr isopleth. The most highly exposed sheep were probably those that grazed near the Lincoln Mine, within the stippled area shown in Figure 1. In this area, the fallout isopleths range from <0.4 to 40 mR/hr (H+12). The possibility exists that slightly higher exposure levels might have been present within the 40-mR/hr isopleth. However, it is our judgment that the 40-mR/hr isopleth is a conservative estimate of the sheep location for the purpose of radiation dose calculations.

The greatest uncertainty lies with the estimate of the initial radionuclide deposition onto the forage ingested by the sheep. Deposition of fallout on desert vegetation has been measured during several nuclear tests at the Nevada Test Site. The results of these measurements have varied widely, depending upon the type of vegetation present, weather conditions, distance from the point of detonation, and the characteristics of the test itself. Of principal interest in this instance was the ratio (P/W) of the fraction of the deposited

particles which were on vegetation to the vegetation biomass, calculated from data collected at distances between 30 and 160 km for several nuclear tests. These P/W values ranged from 0.04 to 0.8 m²/kg, and an average value of 0.2 m²/kg was selected as being representative of the area where the sheep probably had been grazing.

The reasonableness of the P/W value of 0.2 can be checked by the following rough calculation. The wide spacing of the shrubs in desert communities is often measured as canopy cover, a measure of the percentage of ground covered by the spreading branches. Canopy cover varies greatly among different types of plant communities. For example, canopy cover in desert shrub communities in Frenchman Flats and Yucca Flats, Nevada, where sheep had not grazed for over 10 years, ranged between 3% and 24% (Richard and Beatley 1965). Canopy cover on heavily grazed winter ranges was reported to range between 2% and 8% (Hutchings and Stewart 1953). Desert shrub canopies are not 100% efficient at intercepting and retaining fallout. Woody parts of the desert shrubs, which are not eaten by sheep, comprise a large part of the aboveground biomass. If the canopy cover had ranged from 0.02 to 0.08, and if the desert shrub retained as much as 20% of the fallout striking the plant, then 0.4% to 1.6% of the total amount deposited on the ground would be retained on the vegetation. This rough calculation yields a range of P/W values of 0.1 to 0.5, closely bracketing the value used for the desert communities encountered in this study.

Consumption of contaminated soil from the ground was found to be a minor contributor to the internal dose to the sheep. Soil is generally consumed inadvertently by animals eating forage that has been contaminated with soil, for example, in wet, muddy pastures of low production. Healy (1967) reported that sheep grazing wet, low-producing pasture could ingest as much as 400 grams of soil per day, and Field (1964) found that soil intake in range sheep ranged from 10 to 200 g/day. The amount of soil ingested by sheep due to geophagia is not known, but is probably much less than that consumed with contaminated forage. A conservative estimate of 100 g/day of soil ingestion was used in this study.

The GI-tract doses were calculated from a model which assumed that the tract was a series of mixed tanks, with continuous flow through them. Transfer rates between the compartments were those found in the literature for sheep. Although rapid, uniform mixing of the contents does not occur in the fore-stomach of ruminants, this assumption simplifies the mathematical model without introducing a large error in the resultant dose. Average radiation doses to the wall of each GI-tract compartment calculated from this model ranged from only 2 to 4 rad. These doses are so far below those that would be of concern that errors introduced by the model approximations are insignificant.

We also calculated the potential localized dose to the ventral surface of the rumen wall from radionuclides mixed into particulate material that has settled there. In this model, the calculated dose is inversely proportional to the mass present in the localized area. The assumption was made that all of the radionuclides ingested by sheep with both vegetation and soil were associated with a small localized mass of soil. The resultant localized dose was only 200 rad.

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APPENDIX A

ORGAN DATA LIBRARY FOR SHEEP - ORGLIB

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APPENDIX A

ORGAN DATA LIBRARY FOR SHEEP - ORGLIB

This appendix contains a listing of the organ data used to calculate internal organ doses for sheep. A special modified version of the ORGLIB data library, used to permit the calculation of radiation doses to sheep during and after fallout, is listed. Versions of the ARRRG and DACRIN computer programs use the ORGLIB data library in the dose calculations. The data are arranged in blocks by radionuclide. Data within each block are arranged by an organ index. The organs for which data are potentially available for sheep are:

<u>Organ Index</u>	<u>Organ Name</u>
1	Total body
6	Bone
8	Lungs
16	Thyroid
20	Reticulo-Rumen (plus Omasum)
21	Reticulo-Rumen (localized wall dose)
22	Abomasum
23	Small Intestine
25	Cecum-Colon

The data contained on each card image in the ORGLIB library are as follows:

Column 1	Alphabetic element symbol.
Column 2	Atomic weight, also metastable and/or ³ +D" designation.
Column 3	Organ index (1-23).
Column 4	Biological half-life, days.
Column 5	f_w - fraction of ingested nuclide reaching organ of interest.
Column 6	F_2 - fraction from blood to organ of interest (not used by FOOD or ARRRG).
Columns 7, 8, 9	Effective energy absorbed per disintegration in adult organs (MeV). Columns 0 and 9 are only used for organ 8 (lungs).

The ORGLIB FORTRAN format is (A2, A6, 12, 6E8.2). A listing of the modified version of the ORGLIB data library used in the dose calculations reported for sheep in this study is shown in Table A-1.

TABLE A-1. Organ Data Library for Sheep - ORGLIB

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
FE59	1	800.		.10	1.0	.835		
FE59	6	1680.		.01	.10	.946		
FE59	8	3200.		.002	.02	.357	.3570	.3570
FE59	16					.202		
FE59	20					.835		
FE59	21					.298		
FE59	22					.385		
FE59	23					.439		
FE59	24					.357		
FE59	25					.439		
C060	1	9.50		.300	1.0	1.575		
C060	6					1.116		
C060	8					.573	.573	.573
C060	16					.250		
C060	20					1.575		
C060	21					.449		
C060	22					.632		
C060	23					.745		
C060	24					.573		
C060	25					.745		
BR84	1	8.0		1.0	1.0	2.241		
BR84	6					6.601		
BR84	8					1.550	1.55	1.55
BR84	20					2.241		
BR84	21					1.468		
BR84	22					1.560		
BR84	23					1.665		
BR84	24					1.550		
BR84	25					1.665		
RB89+D	1	45.		1.0	1.0	2.533		
RB89+D	6					6.280		
RB89+D	8					1.584	1.584	1.584
RB89+D	16					1.288		
RB89+D	20					2.533		
RB89+D	21					1.469		
RB89+D	22					1.644		
RB89+D	23					1.746		
RB89+D	24					1.584		
RB89+D	25					1.746		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
SR89+D	1	.130+5	.100	1.0	.555			
SR89+D	6	.180+5	.210	.7	2.760			
SR89+D	8				.555	.555	.555	
SR89+D	16				.555			
SR89+D	20				.555			
SR89+D	21				.555			
SR89+D	22				.555			
SR89+D	23				.555			
SR89+D	24				.555			
SR89+D	25				.555			
SR90+D	1	4000.	.1	1.0	1.137			
SR90+D	6	4000.	.0225	.300	5.650			
SR90+D	8				1.137	1.37	1.4	
SR90+D	16				1.137			
SR90+D	20				1.137			
SR90+D	21				1.137			
SR90+D	22				1.137			
SR90+D	23				1.137			
SR90+D	24				1.137			
SR90+D	25				1.137			
SR91+D	1	4000.	.100	1.0	1.834			
SR91+D	6	4000.	.210	.700	6.470			
SR91+D	8				1.437	1.437	1.49	
SR91+D	20				1.834			
SR91+D	21				1.387			
SR91+D	22				1.260			
SR91+D	23				1.305			
SR91+D	24				1.437			
SR91+D	25				1.305			
SR92+D	1	4000.	.100	1.0	2.601			
SR92+D	6	4000.	.210	.700	8.602			
SR92+D	8				1.947	1.947	1.986	
SR92+D	20				2.601			
SR92+D	21				1.867			
SR92+D	22				1.986			
SR92+D	23				2.060			
SR92+D	24				1.947			
SR92+D	25				2.060			

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
Y 91M+D	1	.140+5	.100-3	1.0	.967			
Y 91M+D	6	.180+5	.750-4	.750	3.325			
Y 91M+D	8				.745	.745		.785
Y 91M+D	16				.672			
Y 91M+D	20				.967			
Y 91M+D	21				.717			
Y 91M+D	22				.759			
Y 91M+D	23				.785			
Y 91M+D	24				.745			
Y 91M+D	25				.785			
ZR97+D	1	450.	.100-3	1.0	2.107			
ZR97+D	6	1000.	.360-4	.360	6.30			
ZR97+D	8				1.485	1.485		1.522
ZR97+D	16				1.277			
ZR97+D	20				2.107			
ZR97+D	21				1.406			
ZR97+D	22				1.522			
ZR97+D	23				1.594			
ZR97+D	24				1.485			
ZR97+D	25				1.594			
M099+D	1	5.0	.250	1.0	.547			
M099+D	6				2.121			
M099+D	8				.460	.460		.466
M099+D	16				.426			
M099+D	20				.547			
M099+D	21				.447			
M099+D	22				.466			
M099+D	23				.478			
M099+D	24				.460			
M099+D	25				.478			
TC101	1	1.0	.500	1.0	.697			
TC101	6	25.0	.001	.002	2.44			
TC101	8	5.0	.45-3	.9-3	.543	.543		.553
TC101	16				.492			
TC101	20				.697			
TC101	21				.524			
TC101	22				.553			
TC101	23				.570			
TC101	24				.543			
TC101	25				.570			

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
RU103+D	1		7.30	.030	1.0	.408		
RU103+D	6		16.0	.240-2	.080	.639		
RU103+D	8					.203	.203	.215
RU103+D	16					.134		
RU103+D	20					.408		
RU103+D	21					.176		
RU103+D	22					.215		
RU103+D	23					.239		
RU103+D	24					.203		
RU103+D	25					.239		
RU105+D	1		7.30	.030	1.0	1.063		
RU105+D	6		16.0	.240-2	.080	3.325		
RU105+D	8					.789	.789	.805
RU105+D	16					.688		
RU105+D	20					1.063		
RU105+D	21					.742		
RU105+D	22					.805		
RU105+D	23					.839		
RU105+D	24					.780		
RU105+D	25					.839		
RU106+D	1		7.3	0.03	1.0	1.534		
RU106+D	6		16.	.24-3	.08	7.078		
RU106+D	8					1.447	1.447	1.452
RU106+D	16					1.418		
RU106+D	20					1.534		
RU106+D	21					1.436		
RU106+D	22					1.452		
RU106+D	23					1.462		
RU106+D	24					1.447		
RU106+D	25					1.462		
AG111	1		5.0	.010	1.0	.383		
AG111	6		30.0	.500-3	.050	1.840		
AG111	8					.372	.372	.372
AG111	16					.368		
AG111	20					.383		
AG111	21					.370		
AG111	22					.372		
AG111	23					.374		
AG111	24					.372		
AG111	25					.374		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
SN125+D	1	35.0		.050	1.0	.946		
SN125+D	6	100.		.020	.300	4.482		
SN125+D	8					.409	.904	.920
SN125+D	16	70.		.500-5	.100-3	.886		
SN125+D	20					.946		
SN125+D	21					.99		
SN125+D	22					.921		
SN125+D	23					.930		
SN125+D	24					.909		
SN125+D	25					.930		
SB125+D	1	38.0		.03	1.0	.367		
SB125+D	6	100.		.003	.1	.623		
SB125+D	8	100.		.0009	.03	.190	.190	.209
SB125+D	16	4.0		.900-6	.300-4	.125		
SB125+D	20					.367		
SB125+D	21					.167		
SB125+D	22					.209		
SB125+D	23					.229		
SB125+D	24					.190		
SB125+D	25					.229		
TE129M+D	1	15.		.250	1.0	.665		
TE129M+D	6	30.		.023	.090	2.985		
TE129M+D	8					.616	.616	.619
TE129M+D	16	9.		.250-3	.001	.599		
TE129M+D	20					.665		
TE129M+D	21					.610		
TE129M+D	22					.619		
TE129M+D	23					.625		
TE129M+D	24					.625		
TE129M+D	25					.625		
TE131+D	1	15.		.25	1.0	1.358		
TE131+D	6	30.		.023	.09	4.666		
TE131+D	8					1.485	1.485	1.49
TE131+D	16	9.		.25-3	.001	.992		
TE131+D	20					1.358		
TE131+D	21					1.356		
TE131+D	22					1.099		
TE131+D	23					1.131		
TE131+D	24					1.009		
TE131+D	25					1.131		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
TE133M+D 1			15.	.250	1.0	2.570		
TE133M+D 6			30.	0.023	0.09	4.955		
TE133M+D 8						1.410	1.410	1.48
TE133M+D16			9.	.25-3	.001	1.024		
TE133M+D20						2.570		
TE133M+D21						1.264		
TE133M+D22						1.481		
TE133M+D23						1.614		
TE133M+D24						1.410		
TE133M+D25						1.614		
I 130 1		1	14.	1.0	1.0	1.622		
I 130 6		6	14.	.07	.07	2.053		
I 130 8		8	14.	.0	.00	.733	.737	.787
I 130 16		16	14.	0.30	0.30	.436		
I 130 20		20				1.622		
I 130 21		21				.620		
I 130 22		22				.787		
I 130 23		23				.890		
I 130 24		24				.733		
I 130 25		25				.890		
I 131+D 1		1	14.	1.0	1.0	.434		
I 131+D 6		6	14.	.070	.07	1.102		
I 131+D 8		8				.277	.277	.287
I 131+D 16		16	14.	.400	.300	.225		
I 131+D 20		20				.434		
I 131+D 21		21				.257		
I 131+D 22		22				.287		
I 131+D 23		23				.305		
I 131+D 24		24				.277		
I 131+D 25		25				.305		
I 135+D 1		1	14.	1.0	1.0	1.483		
I 135+D 6		6	14.	.07	.07	2.227		
I 135+D 8		8				.713	.713	.759
I 135+D 16		16	14.	.200	.300	.466		
I 135+D 20		20				1.483		
I 135+D 21		21				.619		
I 135+D 22		22				.759		
I 135+D 23		23				.845		
I 135+D 24		24				.713		
I 135+D 25		25				.845		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
CS136	1	115.		.6	1.0	1.497		
CS136	6	140.		.400	.400	1.295		
CS136	8	140.		.003	.003	.583	.583	.638
CS136	16					.283		
CS136	20					1.497		
CS136	21					.469		
CS136	22					.638		
CS136	23					.742		
CS136	24					.583		
CS136	25					.742		
CS137+D	1	115.		.6	1.0	.594		
CS137+D	6	140.		.040	.040	1.365		
CS137+D	8	140.		.003	.003	.359	.359	.373
CS137+D	16					.280		
CS137+D	20					.594		
CS137+D	21					.329		
CS137+D	22					.373		
CS137+D	23					.400		
CS137+D	24					.359		
CS137+D	25					.400		
BA140+D	1	65.0		.050	1.0	2.364		
BA140+D	6	65.0		.035	.700	5.139		
BA140+D	8					1.379	1.379	1.437
BA140+D	16					1.061		
BA140+D	20					2.364		
BA140+D	21					1.257		
BA140+D	22					1.437		
BA140+D	23					1.548		
BA140+D	24					1.379		
BA140+D	25					1.548		
CE143+D	1	563.		.100-3	1.0	.933		
CE143+D	6	1500.		.300-4	.300	3.791		
CE143+D	8					.795	.795	.811
CE143+D	20					.933		
CE143+D	21					.786		
CE143+D	22					.784		
CE143+D	23					.827		
CE143+D	24					.795		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
CE143+D	25					.827		
CE144+D	1		563.	.100-3	1.0	1.313		
CE144+D	6		1500.	.300-4	.300	6.443		
CE144+D	8					1.295	1.295	1.296
CE144+D	16					1.289		
CE144+D	20					1.313		
CE144+D	21					1.292		
CE144+D	22					1.296		
CE144+D	23					1.298		
CE144+D	24					1.295		
CE144+D	25					1.298		
EU156	1		635.	.10-3	1.0	1.092		
EU156	6		1500.	.36-4	.36	2.399		
EU156	8					.637	.637	.690
EU156	16					.491		
EU156	20					1.092		
EU156	21					.581		
EU156	22					.664		
EU156	23					.715		
EU156	24					.637		
EU156	25					.715		
RB88	1		45.	1.0	1.0	2.473		
RB88	6					10.700		
RB88	8					2.223	2.223	2.223
RB88	16					2.145		
RB88	20					2.473		
RB88	21					2.193		
RB88	22					2.237		
RB88	23					2.280		
RB88	24					2.230		
RB88	25					2.280		
Y 91	1		.140+5	.100-3	1.0	.612		
Y 91	6		.180+5	.750-4	.750	3.049		
Y 91	8					.61	.61	.61
Y 91	16					.610		
Y 91	20					.612		
Y 91	21					.610		
Y 91	22					.610		
Y 91	23					.610		
Y 91	24					.610		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
Y 91	25					.610		
Y 92	1	.140+5	.100-3	1.0		1.589		
Y 92	6	.180+5	.750-4	.750		7.257		
Y 92	8					1.487	1.487	1.487
Y 92	16					1.454		
Y 92	20					1.589		
Y 92	21					1.475		
Y 92	22					1.493		
Y 92	23					1.505		
Y 92	24					1.505		
Y 92	25					1.505		
Y 93	1	.140+5	.100-3	1.0		1.648		
Y 93	6	.180+5	.750-4	.750		7.967		
Y 93	8					1.607	1.607	1.607
Y 93	16					1.594		
Y 93	20					1.648		
Y 93	21					1.602		
Y 93	22					1.610		
Y 93	23					1.614		
Y 93	24					1.607		
Y 93	25					1.614		
ZR95	1	450.	.100-3	1.0		1.093		
ZR95	6	1000.	.360-4	.360		1.299		
ZR95	8					.481	.481	.481
ZR95	16					.277		
ZR95	20					1.093		
ZR95	21					.404		
ZR95	22					.518		
ZR95	23					.589		
ZR95	24					.510		
ZR95	25					.589		
NB95	1	760.	.100-3	1.0		.525		
NB95	6	1000.	.380-4	.380		.457		
NB95	8					.207	.207	.220
NB95	16					.10		
NB95	20					.525		
NB95	21					.166		
NB95	22					.226		
NB95	23					.262		
NB95	24					.207		
NB95	25					.262		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
NB97		1	760.	.10-3	1.0	.87		
NB97		6	1000.	0.38-4	0.38	2.40		
NB97		8				.645	.645	.660
NB97		20				.87		
NB97		21				.576		
NB97		22				.80		
NB97		23				.85		
NB97		24				.78		
NB97		25				.85		
TC99M		1	1.0	.500	1.0	.084		
TC99M		6	25.0	.001	.002	.094		
TC99M		8	5.0	.45-3	.9-3	.0347	.0347	.037
TC99M		16				.0192		
TC99M		20				.084		
TC99M		21				.0287		
TC99M		22				.0375		
TC99M		23				.0430		
TC99M		24				.0347		
TC99M		25				.0430		
RH103M		1	10.4	.200	1.0	.408		
RH103M		6	16.6	.010	.050	.639		
RH103M		8				.203	.203	.203
RH103M		16				.134		
RH103M		20				.408		
RH103M		21				.210		
RH103M		22				.215		
RH103M		23				.239		
RH103M		24				.203		
RH103M		25				.239		
RH105		1	10.4	.200	1.0	.213		
RH105		6	16.6	.010	.050	.847		
RH105		8				.181	.181	.183
RH105		16				.170		
RH105		20				.213		
RH105		21				.177		
RH105		22				.183		
RH105		23				.186		
RH105		24				.181		
RH105		25				.186		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
PD109	1		5.0	.200	1.0	.375		
PD109	6					1.865		
PD109	8					.373	.373	.374
PD109	16					.373		
PD109	20					.375		
PD109	21					.373		
PD109	22					.374		
PD109	23					.374		
PD109	24					.373		
PD109	25					.374		
CD115	1		200.	.01	1.0	.71		
CD115	8					.70	.70	.71
CD115	20					.71		
CD115	21					.61		
CD115	22					.65		
CD115	23					.68		
CD115	24					.63		
CD115	25					.68		
IN115M	1		48.	0.002	1.0	.26		
IN115M	6		57.	.34-3	0.17	.74		
IN115M	8					.25	.25	.27
IN115M	20					.26		
IN115M	21					.17		
IN115M	22					.21		
IN115M	23					.25		
IN115M	24					.20		
IN115M	25					0.25		
SB125	1		38.	0.03	1.0	.367		
SB125	6		100.	0.003	0.1	.623		
SB125	8					.19	.19	.19
SB125	20					.367		
SB125	21					.167		
SB125	22					.209		
SB125	23					.229		
SB125	24					.190		
SB125	25					.229		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
SB127	1	38.		.03	1.0	.905		
SB127	6	100.		.003	.1	2.226		
SB127	8					.567	.567	.580
SB127	16	4.		9.-7	3.0-5	.455		
SB127	20					.905		
SB127	21					.524		
SB127	22					.588		
SB127	23					.627		
SB127	24					.567		
SB127	25					.627		
TE127	1	15.		.250	1.0	.236		
TE127	6	30.		.023	.090	1.175		
TE127	8					.235	.235	.235
TE127	16	9.0		.250-3	.001	.235		
TE127	20					.236		
TE127	21					.235		
TE127	22					.235		
TE127	23					.235		
TE127	24					.235		
TE127	25					.235		
TE129	1	15.0		.250	1.0	.598		
TE129	6	30.		.023	.090	2.666		
TE129	8					.552	.552	.56
TE129	16	9.0		.250-3	.001	.535		
TE129	20					.598		
TE129	21					.546		
TE129	22					.555		
TE129	23					.561		
TE129	24					.552		
TE129	25					.561		
I 129	1	14.		1.0	1.0	.0872		
I 129	6	14.		.070	.070	.316		
I 129	8					.0876	.0728	.0728
I 129	16	14.		0.30	0.30	.0628		
I 129	20					.0872		
I 129	21					.0694		
I 129	22					.0743		
I 129	23					.0872		
I 129	24					.0876		
I 129	25					.0872		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
TE131M	1	15.	0.25	1.0	1.60			
TE131M	6	30.	0.023	0.09	2.60			
TE131M	8				1.045	1.045	1.045	
TE131M	16	9.	.25-3	0.30	.6			
TE131M	20				1.60			
TE131M	21				1.356			
TE131M	22				1.45			
TE131M	23				1.52			
TE131M	24				1.43			
TE131M	25				1.52			
TE132	1	15.	.250	1.0	2.169			
TE132	6	30.	.023	.090	3.544			
TE132	8				1.093	1.093	1.13	
TE132	16	9.0	.250-3	.001	.738			
TE132	20				2.169			
TE132	21				.958			
TE132	22				1.159			
TE132	23				1.282			
TE132	24				1.090			
TE132	25				1.282			
I 132	1	14.	1.0	1.0	1.921			
I 132	6	14.	.070	.070	2.899			
I 132	8				.934	.934	.994	
I 132	16	14.	0.10	0.10	.608			
I 132	20				1.921			
I 132	21				.810			
I 132	22				.994			
I 132	23				1.107			
I 132	24				.934			
I 132	25				1.107			
I 133	1	14.	1.0	1.0	.830			
I 133	6				2.358			
I 133	8				.567	.567	.583	
I 133	16	14.	0.30	0.30	.479			
I 133	20				.830			
I 133	21				.534			
I 133	22				.583			
I 133	23				.613			
I 133	24				.567			
I 133	25				.613			

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
TE134+D	1		15.	.250	1.0	1.687		
TE134+D	6		30.	0.023	0.090	4.572		
TE134+D	8					1.428	1.428	1.513
TE134+D	16		9.	.25-3	.001	.953		
TE134+D	20					1.687		
TE134+D	21					1.247		
TE134+D	22					1.513		
TE134+D	23					1.677		
TE134+D	24					1.428		
TE134+D	25					1.677		
I 134	1		14.	1.0	1.0	2.660		
I 134	6					3.947		
I 134	8					1.280	1.280	1.36
I 134	16		14.	0.05	0.05	.827		
I 134	20					2.660		
I 134	21					1.107		
I 134	22					1.362		
I 134	23					1.519		
I 134	24					1.280		
I 134	25					1.519		
CS138	1		115.	.6	1.0	2.289		
CS138	6		140.	.04	.04	5.842		
CS138	8					1.454	1.454	1.502
CS138	16					1.189		
CS138	20					2.289		
CS138	21					1.352		
CS138	22					1.502		
CS138	23					1.596		
CS138	24					1.454		
CS138	25					1.596		
BA139	1		65.	0.05	1.0	.931		
BA139	6		65.	0.035	0.7	4.540		
BA139	8					.931	.913	.914
BA139	16					.908		
BA139	20					.931		
BA139	21					.911		
BA139	22					.914		
BA139	23					.916		
BA139	24					.913		
BA139	25					.916		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
LA140	1	500.	.0001		1.0	1.889		
LA140	6	1000.	.400-4		.400	3.536		
LA140	8					1.011	1.011	1.06
LA140	16					.730		
LA140	20					1.889		
LA140	21					.903		
LA140	22					1.062		
LA140	23					1.160		
LA140	24					1.011		
LA140	25					1.160		
BA141+D	1	65.	.05		1.0	2.365		
BA141+D	6	65.	.035		.710	.040		
BA141+D	8					2.101	2.101	2.116
BA141+D	16					2.014		
BA141+D	20					2.365		
BA141+D	21					2.067		
BA141+D	22					2.116		
BA141+D	23					2.147		
BA141+D	24					2.116		
BA141+D	25					2.147		
LA141	1	500.	.0001		1.0	.951		
LA141	6	1000.	.400-4		.40	4.680		
LA141	8					.940	.940	.940
LA141	16					.936		
LA141	20					.951		
LA141	21					.938		
LA141	22					.940		
LA141	23					.942		
LA141	24					.940		
LA141	25					.942		
CE141	1	563.	.100-3		1.000	.221		
CE141	6	1500.	.300-4		.300	.928		
CE141	8					.194	.194	.196
CE141	16					.186		
CE141	20					.221		
CE141	21					.191		
CE141	22					.196		
CE141	23					.199		
CE141	24					.194		
CE141	25					.199		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
BA142	1	65.		.05	1.0	3.409		
BA142	6	65.		.035	.7	7.755		
BA142	8					2.022	2.022	2.1
BA142	16					1.585		
BA142	20					3.409		
BA142	21					1.855		
BA142	22					2.103		
BA142	23					2.257		
BA142	24					2.022		
BA142	25					2.257		
LA142	1	500.		.0001	1.0	2.133		
LA142	6	1000.		.40-4	.40	4.718		
LA142	8					1.241	1.24	1.29
LA142	16					.9650		
LA142	20					2.133		
LA142	21					1.135		
LA142	22					1.292		
LA142	23					1.390		
LA142	24					1.241		
LA142	25					1.390		
PR143	1	75.0		.100-3	1.0	.324		
PR143	6	1500.		.400-4	.400	1.618		
PR143	8					.324	.324	.324
PR143	16					.324		
PR143	20					.324		
PR143	21					.324		
PR143	22					.324		
PR143	23					.324		
PR143	24					.324		
PR143	25					.324		
PR144	1	75.		.10-3	1.	1.205		
PR144	6	1500.		.400-4	.400	5.944		
PR144	8					1.193	1.193	1.195
PR144	16					1.189		
PR144	20					1.205		
PR144	21					1.191		
PR144	22					1.193		
PR144	23					1.195		
PR144	24					1.193		
PR144	25					1.195		

TABLE A-1. (Continued)

Column Number								
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
ND147	1	656.	.100-3	1.0	.381			
ND147	6	1500.	.350-4	.350	1.560			
ND147	8				.319	.319		.319
ND147	20				.381			
ND147	21				.311			
ND147	22				.302			
ND147	23				.309			
ND147	24				.319			
ND147	25				.309			
PM151	1	656.	.1-3	1.	.474			
PM151	6	1500.	.35-4	.35	1.594			
PM151	8				.359	.359		.366
PM151	16				.321			
PM151	20				.474			
PM151	21				.345			
PM151	22				.366			
PM151	23				.379			
PM151	24				.359			
PM151	25				.379			
U 237	1	100.	0.01	1.0	.220			
U 237	6	300.	.11-2	.11	.720			
U 237	8				.180	.180		.180
U 237	16				.160			
U 237	20				.220			
U 237	21				.180			
U 237	22				.180			
U 237	23				.180			
U 237	24				.180			
U 237	25				.180			
NP239	1	390. +2	.100-3	1.0	.260			
NP239	6	365. +2	.450-4	.450	1.070			
NP239	8				.230	.230		.230
NP239	20				.26			
NP239	21				.21			
NP239	22				.23			
NP239	23				.23			
NP239	24				.21			
NP239	25				.23			

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APPENDIX B

INDIVIDUAL RADIONUCLIDE CONTRIBUTIONS TO DOSE COMMITMENTS
TO SHEEP INGESTING FALLOUT FROM NUCLEAR TEST NANCY

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APPENDIX B

INDIVIDUAL RADIONUCLIDE CONTRIBUTIONS TO DOSE COMMITMENTS TO SHEEP INGESTING FALLOUT FROM NUCLEAR TEST NANCY

This appendix contains tables of calculated dose commitments, by radionuclide, to the internal organs of sheep ingesting fallout from nuclear test Nancy. The dose commitments are calculated using the organ data listed in Appendix A and the modified version of the ARRRG computer program described in the Dosimetry section of this report. A dose commitment period of 4 weeks is considered in the calculations. The sheep are assumed to have ingested the total activity shown in text Table 3 over a 1-week period at a location where the dose rate at H+12 hours was 1 mR/hr. Table B-1 contains a list of the calculated dose commitments by radionuclide to the total body, bone, lungs and thyroid. Table B-2 contains a list of the calculated dose commitments by radionuclide to the reticulo-rumen, abomasum, small intestine, and cecum-colon. The dose commitments listed in Table B-2 were calculated using the four-compartment GI tract model developed for this study. Only radionuclides that contribute 1% or more to the total organ dose are shown in Tables B-1 and B-2.

TABLE B-1. Calculated Dose Commitments to Internal Organs of Sheep Ingesting Fallout From Nuclear Test Nancy

Radionuclide ^(b)	Dose Commitment (rad) ^(a)			
	Total Body	Bone	Lungs	Thyroid
⁵⁹ Fe	-(c)	-	7.5×10^{-7}	-
⁸⁹⁺⁹⁰ Sr	2.2×10^{-4}	2.3×10^{-2}	-	-
⁹¹⁺⁹² Sr	3.1×10^{-4}	2.3×10^{-2}	-	-
⁹²⁺⁹³ Sr	-	6.2×10^{-3}	-	-
⁹⁹⁺¹⁰⁰ Mo	4.3×10^{-4}	-	-	-
¹³¹⁺¹³² I	2.3×10^{-3}	4.0×10^{-3}	-	3.5×10^0
¹³⁵⁺¹³⁶ I	2.7×10^{-3}	2.9×10^{-3}	-	1.3×10^0
¹³⁶ Cs	-	-	7.6×10^{-6}	-
¹³⁷⁺¹³⁸ Cs	-	-	2.3×10^{-6}	-
¹⁴⁰⁺¹⁴¹ Ba	7.4×10^{-4}	1.1×10^{-2}	-	-
^{99m} Tc	-	-	3.8×10^{-7}	-
¹³² Te	3.6×10^{-3}	6.0×10^{-3}	-	-
¹³² I	4.4×10^{-4}	-	-	1.0×10^{-1}
¹³³ I	3.9×10^{-3}	-	-	5.0×10^0
¹³⁴ I	6.4×10^{-4}	-	-	-
Total ^(d)	1.6×10^{-2}	7.9×10^{-2}	1.1×10^{-5}	1.0×10^1

(a) Four-week dose commitments resulting from 1 week of ingestion of contaminated vegetation at a location where the dose rate at H+12 hours was 1 mR/hr.

(b) Only radionuclides that contribute 1% or more of the dose to any internal organ from ingestion are included in this table.

(c) A dash indicates an organ dose contribution of less than 1% of the dose for the radionuclide and organ shown.

(d) The totals listed include the dose commitments for radionuclides that contribute less than 1% of the dose.

TABLE B-2. Calculated Dose Commitments to Compartments of the GI Tract of Sheep Ingesting Fallout From Nuclear Test Nancy

Radionuclide ^(b)	Dose Commitment (rad) ^(a)			
	Reticulo-Rumen	Abomasum	Small Intestine	Cecum-Colon
89+D _{Sr}	-(c)	-	-	7.9 x 10 ⁻⁴
91+D _{Sr}	9.2 x 10 ⁻³	3.5 x 10 ⁻³	6.1 x 10 ⁻³	-
92+D _{Sr}	3.7 x 10 ⁻³	1.4 x 10 ⁻³	1.4 x 10 ⁻³	-
91+D _Y	-	-	-	7.7 x 10 ⁻⁴
97+D _{Zr}	7.9 x 10 ⁻³	3.3 x 10 ⁻³	7.2 x 10 ⁻³	8.6 x 10 ⁻³
99+D _{Mo}	2.2 x 10 ⁻³	1.1 x 10 ⁻³	2.1 x 10 ⁻³	-
105+D _{Ru}	2.5 x 10 ⁻³	9.8 x 10 ⁻⁴	1.4 x 10 ⁻³	9.5 x 10 ⁻⁴
131+D _I	1.2 x 10 ⁻³	4.7 x 10 ⁻⁴	-	-
135+D _I	9.3 x 10 ⁻³	2.6 x 10 ⁻³	-	-
140+D _{Ba}	4.3 x 10 ⁻³	1.6 x 10 ⁻³	4.0 x 10 ⁻³	6.5 x 10 ⁻³
143+D _{Ce}	3.3 x 10 ⁻³	1.6 x 10 ⁻³	3.9 x 10 ⁻³	5.4 x 10 ⁻³
92 _Y	3.4 x 10 ⁻³	1.6 x 10 ⁻³	2.1 x 10 ⁻³	1.2 x 10 ⁻³
131m _{Te}	1.0 x 10 ⁻³	5.3 x 10 ⁻⁴	9.4 x 10 ⁻⁴	1.3 x 10 ⁻³
132 _{Te}	1.3 x 10 ⁻²	4.1 x 10 ⁻³	8.1 x 10 ⁻³	1.2 x 10 ⁻²
132 _I	1.9 x 10 ⁻³	4.5 x 10 ⁻⁴	-	-
133 _I	8.0 x 10 ⁻³	3.3 x 10 ⁻³	-	-
134 _I	3.0 x 10 ⁻³	5.3 x 10 ⁻⁴	-	-
139 _{Ba}	1.7 x 10 ⁻³	6.6 x 10 ⁻⁴	-	-
141 _{La}	3.1 x 10 ⁻³	1.6 x 10 ⁻³	2.1 x 10 ⁻³	1.3 x 10 ⁻³
142 _{La}	1.8 x 10 ⁻³	4.6 x 10 ⁻⁴	-	-
239 _{Np}	7.0 x 10 ⁻³	3.7 x 10 ⁻³	8.7 x 10 ⁻³	1.3 x 10 ⁻²
Total ^(d)	9.9 x 10 ⁻²	3.7 x 10 ⁻²	5.8 x 10 ⁻²	7.3 x 10 ⁻²

- (a) Average four-week dose commitment to the wall of each compartment of the GI tract resulting from 1 week of ingestion of contaminated vegetation at a location where the dose rate at H+12 hours was 1 mR/hr.
- (b) Only radionuclides that contribute 1% or more of the dose to any portion of the GI tract are included in this table.
- (c) A dash indicates an organ dose contribution of less than 1% of the dose for the radionuclide and organ shown.
- (d) The totals listed include the dose commitments for radionuclides that contribute less than 1% of the dose.

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