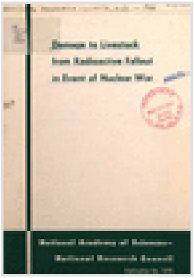

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Damage to Livestock from Radioactive Fallout in Event of Nuclear War

A Report by the
SUBCOMMITTEE ON LIVESTOCK DAMAGE
of the
ADVISORY COMMITTEE ON CIVIL DEFENSE
NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL

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FOREWORD

In the fall of 1960, the Advisory Committee on Civil Defense of the National Academy of Sciences was requested by the Office of Civil and Defense Mobilization to provide advice on the best procedure for assessing damage to livestock from radioactive fallout, particularly in connection with the mission of the National Resources Evaluation Center. Pertinent paragraphs of the letter containing this request were:

> "The damage assessment in livestock as a result of nuclear weapons relates not only to the immediate effects such as casualties produced, extent of blast damage, and fallout hazards, but also to the evaluation of such things as food and medical supplies, and to other resources important to the rehabilitation and reconstruction of the country and its economy.
>
> In evaluating the food situation, it is necessary to estimate the effects of an attack upon livestock. Since most livestock will be beyond the range of the initial effects of the weapons, the problem predominantly is that of estimating the effects of fallout radiation exposure. Many of the animals likely would be in the open and would receive radiation damage from external exposure to gamma radiation and external beta radiation, as well as from the radioactive material ingested. Other animals would be in a barn or under some cover and would be fed from reserve food supplies. In this case only the effects of external exposure to gamma radiation need be considered. And, finally, there would be the case of animals similarly protected, but fed contaminated food supplies. In this case the combination of external gamma radiation plus damage from internal emitters must be considered."

Accordingly, the Advisory Committee on Civil Defense established a group to meet the request. At its first meetings the group made several interim suggestions in response to specific questions. The group was established as a semi-permanent subcommittee to review the information available, and to refine and extend the "best estimates" on which the interim suggestions were based. This is the Subcommittee's report.

L. S. Taylor, Chairman
Advisory Committee on Civil Defense

CONTENTS

FOREWORD

SUMMARY

The Subcommittee on Livestock Damage of the National Academy of Sciences' Advisory Committee on Civil Defense has examined experimental and observational reports of the effects of radioactive fallout upon laboratory and domesticated animals. In some areas the information is adequate for reasonable estimates of damage to farm animals, but in others the data are scant. This lack of information is particularly noticeable when an attempt is made to assess the relationship between external and internal exposure to fallout. This store of information must be improved and increased.

Generally in the case of ground burst detonations of nuclear weapons, the hazard to animals will be largely a result of particulate fallout which delivers external total-body radiation to animals in the fallout field, i.e., when they are relatively close to the point of detonation. These particles are not readily metabolized by either ingestion or inhalation. As the distance from or time after detonation increases there is a change in character and solubility of the fallout particles, and the hazard becomes one chiefly related to the ingestion of radioactive particles. In air bursts, much less local fallout will be produced, though it will probably be readily metabolized by plants and animals.

Animals are less sensitive to protracted low radiation dose rate exposures than to brief high radiation dose rate exposures. Therefore, if there is a delay of several hours in the arrival of fallout (so that radiation intensity is lower than immediately after the burst) it is likely that farm animals can withstand a considerably higher dose than we have estimated for the $LD_{50/30}$ for brief exposures. In particular, it has been noted that swine require a very great increase in exposure to produce the median lethal dose if it is given at a rate of 50 r/day instead of all within 24 hours. In other animals this effect may not be so great but still is substantial.

The effects produced on genes and fertility by fallout are probably not serious problems in farm animals. Present practices of selection of breeding animals reduces the genetic consequences substantially. Animals, both male and female, observed for a number of years have not become permanently sterile after exposure to doses in the $LD_{50/30}$ range or higher. It is believed there is little likelihood that any population of farm animals surviving total-body radiation will be eliminated because of infertility.

It is highly unlikely that food such as muscle meat, milk, and eggs derived from exposed but surviving animals will contain enough radioactivity to result in immediate deleterious effects upon the consumer. It

is basic, however, that wherever choice exists, consumption should be limited to food of the lowest contamination available. During an emergency period, food that is unacceptable by peacetime standards may have to be used to sustain life and to provide the energy needed for performing essential tasks, since starvation and the leaving undone of essential tasks may pose a far more serious threat than the radiation injury to consumers.

Persons handling or slaughtering exposed animals might be in danger of inhaling contamination from dusty hides and of external exposure from fallout particles remaining on the animal hides or in discarded organs. The degree of danger will depend upon the precautions taken by the handler and the protection that can be afforded him.

Food-producing animals can serve to filter or partially cleanse food eventually consumed by man. Advantage should be taken of this entrapping and filtering or holdup capacity. Table X of this document gives the reduction ratios of three common fission radioisotopes and the amount of these nuclides to which a cow may be subjected before the food it produces is at the maximum level that may be permitted for man in an emergency exposure. It is suggested that in an emergency these values be used to guide decision-makers, particularly in connection with food for children, after the levels of the specific isotopes in question have been determined. They can also be used to predict the concentration levels in the food produced if the amount of these radioisotopes in the forage is known.

We also suggest that the flesh and eggs of poultry may serve as a particularly useful protein source. Poultry are more resistant to radiation exposures than mammals: hens quickly eliminate the metabolized fission products such as radiostrontium and radiobarium by way of the egg shells by a rapid and frequent mobilization of labile bone salts. Furthermore, their usual housing gives them a moderate protection; they are usually fed stored and hence unexposed foods; and finally, they are easily transported, can be slaughtered and dressed by consumers, and do not require refrigeration since they can be kept alive until they are needed and can be consumed immediately after slaughter.

Marine foods, both fresh and salt water, could also serve as a reasonably safe substitute or additional protein source. Furthermore, large water masses will be safe for fishermen very quickly following the arrival of fallout, because the particles will settle rapidly to the bottom and the intervening water will provide shielding from the gamma radiations of the particles.

1. INTRODUCTION

1.1 NREC Mission, Facility, and Procedures

The national mission for assessing damage is carried out in the National Resources Evaluation Center (NREC). Briefly, that mission is to meet the most urgent requirements of all United States government agencies for:

(1) pre-attack estimates of attack hazards, and
(2) post-attack estimates of resource status.

The post-attack phase of the mission can be further broken down into an immediate post-attack task of estimating national levels of damage, and a later, more deliberate assessment of resources to serve as a basis for resources management.

In carrying out damage-assessment procedures by computer techniques, an estimate of damage at each of some thousands of resource locations is made for the various weapons effects. For fallout, the radiation intensity at each resource location is estimated from information on ground-zero locations, on weapon yields, on wind vectors, etc. The computer then arranges the results in such a way as to make possible the printing of an outline fallout map of the United States. Blast and thermal damage are similarly estimated.

1.2 Special NREC Problems Involving Livestock

NREC is using a livestock casualty computing procedure (recognized as tentative) which estimates the effects of external gamma radiation on various classes of livestock 30 days after attack. This procedure is not sufficiently responsive to requirements for time-phased estimates of food availability. In certain areas, the availability of local supplies during the first few weeks may be crucial. Therefore, NREC requires means for computing the percentages of grazing and non-grazing livestock fit for slaughter for food purposes at given times after detonation of weapons producing given intensities of gamma radiation standardized to a hypothetical value, one hour after burst.

Also, NREC requires reliable information concerning the effects on livestock of beta and gamma radiation from iodine-131, strontium-90, and possibly other isotopes. More specifically, the following questions appear to require detailed exploration:

(1) What are the effects, in terms of time-phased and other casualties, of various intensity levels of iodine-131, strontium-90, and other hazardous isotopes on the various types of grazing livestock and poultry?

(2) What are the factors for measuring the time-phased effects of human consumption of milk and meat from grazing livestock and of eggs and flesh from poultry under the conditions mentioned in question 1?

(3) How can the combined effects of gamma radiation and of beta radiation from iodine-131, strontium-90, and other isotopes be estimated?

1.3 Subcommittee Approach

After the initial review of the problem, it was very apparent to the members of the Subcommittee that the concept of "maximum permissible level or concentration" of radioactive fallout elements was not very satisfactory for a possible emergency situation that would introduce factors such as famine and produce radiation hazards that would go far beyond the levels expected in peacetime disasters. It was obvious that an estimate of the biological effects on livestock that could be expected at different exposure levels was more appropriate. Decision-makers could use such estimates in preparing their plans and programming their data.

The Subcommittee recognized that the estimates that can be made will usually be statistical evaluations from widely scattered information and observations. More accurate data dealing with the effects of radiation on the sickness and death rates of livestock, including poultry, can be obtained only by further testing under simulated moderate- to high-level fallout conditions. The importance in our diet of meat, milk, and eggs warrants the special attention of those administering the research funds that might be used in this area.

The Subcommittee agreed that the most critical problem resulting from the irradiation of food-producing animals is to minimize the radiation hazard to man, and, at the same time, to maximize his prospects for survival. These basic guides lines were identified:

(1) The first effort should be to sustain and protect the people at the time of a national emergency; the second to feed them during the recovery period; and the third to maintain the animal populations as a continuing food resource during the rebuilding period.

(2) Thus the hazard to animals, as such, would not be an important consideration, but their availability as food or food producers would be of greatest importance.

(3) Present radiological health or related public health practices may have to be compromised during the emergency period, but they should be re-established as quickly as possible.

The problems of the exposure of livestock to fallout of concern to civil defense and agricultural decision-makers can be divided into three phases or time periods, which may overlap or be missing, and which relate to the time after a detonation. In the early period it is likely that there will be no information about the amount or the nature of the fallout. In the second period the information will be confined largely to the magnitude and location of the fallout but not its identity. During the final phase the magnitude and variety of radionuclides are known. It is in the interest of effective preventive measures that the last period be established as quickly as possible. The conclusions in this document will cover these various phases.

Experimental and empirical evidence has established that a variation of susceptibility to radiation injury occur among different animals even of the same species. However, a standardized sigmoid or probit curve can be used to estimate the response of all edible animals at various exposure levels. Such a curve can be determined from experimental evidence obtained from a number of species of domesticated animals, and can afford a satisfactory estimating device.

1.4 Fallout Types

Early or local fallout is largely particulate, but includes much of the radioiodines. Therefore the biological effects to animals of most concern are:

(a) the total-body gamma radiation exposure,
(b) the external collection of beta-ray-emitting particles on the skin of the back and on the feet,
(c) the total-body dose from the radioiodines, and
(d) the exposure delivered to the thyroid gland.

Of these, the dose to the thyroid is of most concern to the consumer of animal food products, while the radioactive material on the back and feet is of some concern to the food processor or the husbandman. To the animals the whole-body exposure is the most important effect.

Delayed fallout consists of the long-lived radioisotopes, to a large degree radiostrontium, radiocesium, and radiobarium. Their distribution is world-wide and relatively dilute. The problems arising from their prolonged consumption by animals are most important, with only slight concern for the total-body radiation exposure hazard.

With the exception of the radioiodines, early fallout is characterized by relatively large, insoluble particles; hence, retention by herbage is slight. Wind or rain readily removes retained particles.

1.5 Time and Intensity of Exposure

The problem of time-intensity relationships in biological responses has been considered at some length. It is probable that no serious error will be introduced if we accept the working hypothesis that all exposure of equal magnitude from external gamma rays received within the first 96 hours of exposure can be considered as having the same effect. They will be called brief* exposures. An inspection of Table I will reveal that the most substantial portions of the brief exposures will take place the first 96 hours after a detonation, particularly if the fallout arrives within 10 hours.

Table I

Time Distribution of Gamma-Ray Dose from Fallout Arriving at Various Times (from $t^{-1.2}$ formula)

Based on radiation intensity of 100 r/hr standardized to one hour after burst

	Daily dose (r)				Accumulated dose (r)			Percent of 14 day dose received in first 96 hrs
Fallout arrival (hrs after burst)	1st day	2nd day	3rd day	4th day	4 days	2 wks	1 yr	
1	235	34	19	12	300	335	400	89
4	114	34	19	12	180	215	380	84
10	51	34	19	12	115	150	195	78
24	0	34	19	12	65	100	145	65
48	0	0	19	12	30	65	125	46

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* The term "brief" is substituted for "acute" since "acute" is a well-established clinical term.

The table also reveals that when fallout arrives 24 to 48 hours after a detonation, a protracted* total-body exposure by the ambient gamma rays of fallout will be delivered. These facts are of considerable importance since the response of farm animals to a given total dose is not always the same for protracted exposures as it is for brief ones. Also there is an interspecies variation. For example, the equine and porcine species would lose about the same number of animals with brief exposures in the lethal range; but with protracted exposures the porcine species would withstand substantially greater doses and would constitute a food resource for much longer periods of time. In Table II (page 9) a comparison of these species is made on the basis of available data.

It should be noted that in this report the brief doses (r) or absorbed doses (rad) are considered to have been received within the first 96 hours of exposure. In other words, we have not considered recovery factors, nor have we taken into account attenuation, weathering, etc. There is need for getting more data on these factors, and applying them in future calculations.

1.6 Distribution of Fallout (See also Appendix A)

The radiation injury to the gastrointestinal tract will be related to the amount of radioactive material ingested. Radioactive elements metabolized by plants through their roots will not be a serious immediate hazard to animals or to man utilizing them as a food resource. The immediate hazard, if any, will be related to the retention of surface deposits of fallout by the herbage.

The uptake by plants of strontium-90 from the soil generally is not more than one per cent of the total contamination per year, whereas the amount collected upon plants from direct fallout may range from less than one per cent to 40 per cent (Windscale experience) depending upon various physical factors. The physical factors that govern the amount of retention by herbage are the size and nature of the fallout particles, the variety and density of the herbage, and environmental conditions such as wind speed and humidity. From field measurements and analyses of various types of fallout, laws governing the distribution of fallout material, particularly for silica-laden detonations, have been deduced. Large insoluble particles will be found near the detonation and small soluble particles will increase in proportion as the distance from the detonation increases. In general the physical and chemical characteristics of fallout also dictate the hazard that may result from ingesting the material. This hazard, in contrast to the external gamma exposure of the animals, may be important both to the animal, and ultimately to persons consuming the flesh or the food derived from or produced by the exposed animals. The Subcommittee has considered whether the radiation effects from external

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* "Protracted" is substituted for "chronic", another well-established clinical term.

exposure to gamma rays, external exposure to beta particles, gastrointestinal exposure to ingested mixed radionuclides, and tissue exposure to biologically available radionuclides are synergistic, additive, or competitive. In our opinion, the effects are not completely additive in many instances. These judgments are not specifically noted but are a basic part of the many evaluations that were made.

2. EFFECTS OF EXTERNAL IONIZING RADIATION ON FARM ANIMALS

2.1 Species, Rate, and Quality Differences of Gamma Exposures

The severity of the symptom complex following total-body irradiation is related to the dose, rate, fractionation, and quality of the radiation received. There is a direct symptomatic relationship to the total dose and to the rate of administration. Animals that have received lethal doses at a slow rate, e.g., less than 25 r per day, may survive several weeks. On the other hand, deaths may occur within a few days from the same total dose delivered in a few hours (Table II). The lethal dose for various species of domestic animals for brief exposures falls within a narrow range but differs widely when exposures are protracted.

Table II

Comparison of Lethal Doses of Animals from Brief and from Protracted Exposures

Species	MLD for Brief Exposure r/dose	MLD for Protracted Exposure average dose(r)	r/day	Exposure Ratio protracted/brief
Burro	785	1500	50	2
Pig	610	8540	50	14

Gamma rays will be the principal cause of the total-body irradiation syndrome. Beta radiation following nuclear detonations has an average penetration of less than the skin thickness of most domestic animals. Thus, injury from beta particles would for the most part be superficial. Beta-radiation effects are discussed in Sections 5.1 and 5.2.

It is the general consensus that animals close enough to a detonation to be exposed to a neutron flux capable of producing serious biological damage will in general have sufficient external injury from thermal or blast effects of conventional nuclear weapons to make the total-body irradiation syndrome comparatively unimportant; i.e., the effect upon the animal from heat and blast will be far greater than the injury from ionizing radiation.

2.2 Effects on Cattle

The clinical response of cattle is similar to that of other large animal species. However, there are breed and individual differences. These individual differences in response seem greater than the differences between species.

In a study of cattle the $LD_{50/30}$ was calculated to be 540 r, with 95 per cent confidence interval of 520-570 r. The mean survival time of the decedents was about 20 days for exposures in the range of 450-700 r. Exposures were at the rate of 55 r per hour.

During the first three days after irradiation, the animals were apprehensive and easily excited when handled. In many there were generalized trembling and muscle tremors. The general behavior and appearance of the animals were normal for the next seven to ten days. There were occasional blood-tinged stools, heavy mucous around the anus, and the beginning of diarrhea.

At the end of the second week and during the third week, a number of changes were readily apparent. The most common were: knuckling of fetlock joints of the hind legs, fever, generalized weakness (most pronounced in hind parts), depression, decrease or loss of appetite, shortness of breath, and diarrhea. Near the animal's death, severe hemorrhage in the large intestines was indicated by defecation of large amounts of blood.

Other changes or conditions less frequently observed were: swelling of leg(s), "milk fever" attitude, and "traumatic gastritis" attitude. Alternating deep to very light respirations (Cheyne-Stokes) frequently preceded death.

At the end of the irradiation period, the rectal temperatures of the irradiated animals were generally one to three degrees F above normal. (The normal temperature of the bovine species is about 101.5°F.) Within 24 hours, all temperatures had returned to normal and remained so until approximately the 14th day following irradiation. Temperatures of 108°-110°F were recorded in several of the animals that died. The average survival time of the decedents was five days after the onset of fever. Most of the animals destined to die had an elevated temperature beginning at about the 15th day, and those that lived had a modest rise (103°F) near the end of the third week.

Food consumption was not greatly affected during the first 15 days after irradiation. Depressed appetite was generally associated with onset of fever. Loss of appetite was evident in most of the animals one to two days before death; however, some of the animals still had an appetite until a few hours before death. The weight loss during the first 30 days, including both the survivors and non-survivors, was less than 10 per cent.

Appetites were back to normal in survivors after the 40th day and the weight loss was soon recovered.

An abnormal thirst was evident during the third week, particularly in those animals most severely affected.

The first indication of damage to the intestinal mucosa was a thick mucous discharge from the anus which was generally accompanied by blood-tinged stools. This was observed during the latter part of the first week following irradiation.

A mild diarrhea was usually noted among all exposed animals eight to ten days after exposure and was generally pronounced in twelve to sixteen days. In those animals that had a severe diarrhea, large quantities of dark to bright red blood passed in the stool. Pronounced involuntary straining to defecate or urinate was noted in several animals, usually during the terminal period of one to two days before death.

Respiratory distress was a common condition even in the survivors. In the highest-dose group (700 r), it was first observed at the end of the second week. The onset of the condition was characterized by rapid, shallow respirations, occasionally with a raspy sound, and was accompanied by thick, stringy, clear or light yellow, nasal discharge. The condition progressed very rapidly in some animals to forced respirations, with sounds audible several yards away, and coughing. The nasal discharge frequently became red from the hemorrhage occurring in the membranes of frontal and maxillary sinuses.

Respiratory distress was generally attributed to edema of the larynx and lungs. In one animal, edema of the larynx completely obstructed the air passage.

At necropsy, multiple disseminated hemorrhages were observed in all irradiated animals, and were seen most prominently and frequently in the heart, intestinal tract, splenic capsule, lungs, and gall bladder. Other frequent and severe lesions were frank, massive hemorrhage into the small and large intestinal lumina, pulmonary edema, and ulcers in the mucosae of the pharynx and gastrointestinal tract.

The most pronounced microscopic lesions were hemorrhage, atrophy of lymphoid tissue and bone marrow, superficial mucosal ulcerations in the gastrointestinal and pharyngeal regions. Bacterial colonies were numerous around the ulcerated areas as well as within many of the parenchymatous organs.

2.3 Effects on Burros

The development of the total-body irradiation syndrome in burros receiving brief and protracted gamma radiation and brief gamma ray/neutron exposure can serve as another example. It has been studied in great detail.

For about two days after a single large dose (375-800 r) of ionizing radiation, or concurrent with receiving repeated (25-400 r/day) or continuous dosing (approximately 50 r/hr), the animals appeared in moderately good health. They then became apathetic for up to five days. A few animals died at this time. Food and water consumption was below normal. During the period of apathy, irritability and hyperesthesia sometimes increased. For the next five to seven days, animals seemingly recovered, some even showing euphoria, but this was followed by a period of apathy and inappetence accompanied by severe weight loss. Much time was spent at or near water although the actual consumption of water was not increased. About 14 days after exposure, edema, ulceration, and bleeding from small wounds on the skin and mucous surfaces were noted. Shortly thereafter, a second wave of deaths occurred. A severe edema involving the respiratory apparatus developed. Death often followed a respiratory embarrassment and a neutropenic pneumonia.

No hair loss (epilation) was seen in animals exposed to high-energy gamma rays. This is in contrast to low energy gamma rays and exposures to bomb gamma-ray/neutron flux, which produce extensive epilation. Suppurative wounds were not seen. Diarrhea was not a constant finding. Blood-tinged feces were occasionally seen. Animals surviving for 30 days had a good chance of ultimate recovery. However, among these survivors were some that died three or four years after the exposure showing a hemorrhagic syndrome resembling the initial radiation effect.

Neuromuscular signs such as twitching of the face muscles and spasmodic retraction of the lips were occasionally seen within 48 hours after exposure. Spasmodic flexion of the joints, rhythmic upward jerking of the head, and a rapid fly-switching of the tail (in the absence of flies) were also seen. Several days later some animals developed encephalitis-like symptoms, such as a forward-pressing behavior during which the animal pressed its head against a fence or manger for considerable periods of time.

Early eye lesions were conjunctivitis, keratitis, corneal ulcers, nebulae, leucoma, and corneal vascularization, which are not to be confused with delayed lenticular opacities following X- or gamma-radiation. The eyes of animals with conjunctivitis wept copiously and the conjunctiva became edamatous (this was also marked in swine), and ectropion occurred.

Changes in blood were always dramatic. The number of lymphocytes fell precipitously immediately following exposure, and within a few days they were absent from the blood. The number of erythrocytes fell more slowly.

A gradual lengthening of the clotting time was related to the disappearance of platelets from the circulating blood.

Among burros exposed to the neutron/gamma-ray flux of a conventional nuclear device, a substantial number died within a few hours after exposure manifesting marked central nervous system disturbances. Histological examination of the brains revealed changes not unlike the actinic-ray-initiated herpes lesions in the brain of man. Also within a few days, the surviving animals developed large masses of papillomas, presumed to be viral, about the mouth and face. This suggests that the controlling immune mechanism is disturbed or possibly a virus is activated by the radiation exposure.

2.4 Effects on Goats

A study of goats exposed to lethal levels of radiation (exposures lasting over a few seconds) from nuclear detonations showed that those exposed to the highest doses were quite active for the first two or three days; some showed increased irritability of hyperesthesia followed by a periodic diarrhea, loss of appetite, and apathy. These symptoms persisted until death, which usually occurred three to five days after the explosion. Goats receiving less exposure were slower in developing symptoms (three to seven days). These included diarrhea, serous rhinitis, petechiae, epilation, and, to a variable degree, much of the syndrome exhibited by those more severely exposed. Symptoms continued for 9-15 days, until all animals died. The length of the post-exposure, latent, symptom-free period varied with the intensity of the dose of total-body irradiation, as did the severity of the symptoms. Survival time was increased as the exposure was reduced. Prognostic signs were clearly defined. A rapid decrease of leukocytes to 2,000 cells per milliliter of blood in the first 48 hours was usually followed by death before the sixth day. An unfavorable prognostic sign was the appearance of diarrhea on the second or third day. Death ordinarily did not occur unless epilation had taken place; however, epilation might occur with less than a lethal dose.

2.5 Effects on Swine

The $LD_{50/30}$ for swine exposed to cobalt-60 gamma radiation at a dose rate of 50 r per hour has been reported to be 618 r, with 95 per cent confidence intervals of 525-682 r. Another report gives an $LD_{50/30}$ dose of 486 rads (478-496 rads) for swine exposed to gamma/neutron radiation. There are other reports on the lethal response of swine exposed to ionizing radiation, but the above values appear to be representative.

The clinical syndrome is similar at comparable dose levels in all reports. Swine exposed to doses above 1700 rads of gamma/neutron radiation exhibited disturbance of consciousness, hyperesthesia, inappetence, vomiting, diarrhea, and extreme thirst within 48 hours after irradiation. This was followed by a state of lethargy and a rise in rectal temperature. Death occurred within five days. Many of the animals died quietly while others had repeated convulsions for several hours prior to death.

Swine exposed to doses of 900 to 1500 rads exhibited a syndrome similar to that described for the higher doses but less severe. The hemorrhagic syndrome began at seven days in this group.

The clinical syndrome associated with exposures in the $LD_{50/30}$ range was characterized by hemorrhage. During the first three to four days after exposure there was a transient decrease in appetite, vomiting and diarrhea, and hyperesthesia in some animals, which was followed by a short period of apparent normal health. At about 10 days following irradiation, the first signs of the hemorrhagic syndrome appeared (bleeding from mouth, nose, and anus, and hemorrhagic feces). Prolonged bleeding from wounds and cutaneous hemorrhage usually occurred near the terminal period. During the latter part of the second week many animals had a rise in rectal temperature, edema in the appendages, lameness and stiff gait, ataxia, dyspnea, and pronounced weakness in the posterior parts. Loss of weight was pronounced in almost all the animals during the second week after exposure. Light-colored or white animals exhibited areas of red to purple discoloration of the skin, which is frequently classified as hyperemia and purpura. This condition occurred near the terminal period.

Blood changes were similar to that reported for other large animal species.

The mean survival time for animals in the $LD_{50/30}$ dose range was approximately 15 days.

Gross lesions most frequently observed were disseminated hemorrhage, pneumonia, pleuritis and ulcerative gastroenteritis.

Swine exposed to fractionated doses (100 r per day) of cobalt-60 gamma radiation exhibited a syndrome similar to that described for swine exposed to single doses in the $LD_{50/30}$ range; however, there was a delay of several days in the onset.

2.6 Effects on Poultry

There are few experimental data on effects of external gamma-radiation exposure of poultry other than chickens. Similarly, there is very little information on the possible deleterious effect of consumed fission products upon poultry. Consequently, many broad extrapolations must be made to establish estimates of such radiation damage in poultry. Until additional information is developed, it will be presumed that the responses of turkeys, ducks, and other domestic fowl will be similar to those of chickens.

A description of the syndrome in mature chickens that received 200 to 1600 r of cobalt-60 total-body gamma radiation is helpful in recognizing the various responses in poultry.

Deaths begin to occur at about the eighth day and continue until the 35th day after exposure. The higher doses initiate the syndrome earlier than do the lower ones. Initially there is a shaking of the head but no evidence of the pseudo-euphoria noticed in mammals. Depression develops within a few days and the birds tend to crouch in a sleeping position for hours at a time. At this time they extend their necks forward and downward over the feed and water troughs, rarely moving for long periods of time.

Combs and wattles develop a pendulous edema. Difficulty in breathing and a serous discharge are prominent. The droppings are green at this time. Death follows shortly.

In birds that survive for longer periods there is often a loss of feathers. Egg production is not significantly affected until radiation exposure levels reach 500-600 r. It is reduced to minimal levels during the second and third weeks following brief radiation exposure, and near-normal egg production returns by about the ninth week in those that survive, with rate of recovery apparently directly related to radiation exposure level. At 100-200 r there is no drop in egg production.

To our knowledge, chickens are the most radioresistant of the domesticated animals that have been studied. Some studies indicate that males are considerably more radio-sensitive than females. It is generally believed that the number of chickens surviving more than 30 days following a brief exposure to radiation will be approximately the number expected to survive for 180 days or longer.

2.7 Summary of Radiation Effects on Food-Producing Mammals and Poultry

The experimental irradiation of various species of animals has given information on the amount, energy, and rate of external radiation resulting in sickness and death.

Table III shows how the lethal dose varies with different energies and rates for the different species tested.

Table III

Lethal Response of Mammals and Poultry to Brief Exposures to Nuclear Radiations

Species	Source	Mean Energies (Mev)	$LD_{50/30}$	(95% C.I.)	Rate (r/hr)
Burro	Co^{60}	1.25	784	(753-847)	50
Burro	Ta^{182}	1.20-0.18	651	(621-683)	18-23
Burro	Zr^{95}-Nb^{95}	0.74	585	(530-627)	19-20
Swine	Co^{60}	1.25	618	(525-682)	50
Sheep	Zr^{95}-Nb^{95}	0.74	524		20
Cattle	Co^{60}	1.25	540	(520-570)	25
Swine	X-ray	1.0	555	(418-671)	180
Swine	X-ray	2.0	388	(323-441)	90
Burro	neutron/gamma	various	402 (rep)		
Poultry					
Males	Co^{60}	1.25	600	(est)	50
Females	Co^{60}	1.25	1000	(est)	50
Chicks	X-ray	0.250 (peak)	900	(est)	very short

Table IV presents estimates of how mammalian food animals would respond over a period of time to three dose levels. These are generalized estimates based on tests made with several species.

Table IV

Estimated Fate of 100 Mature* Food Mammals
Exposed to Brief Total-Body Radiation

(Exposure time = 4 days or less. Energy = 250 KVP)

Days or years following exposure	D1	D2	D3	D7	D14	D21	D30	D90	D180	1 yr.	5 yrs.
Dose = 350 r ($LD_{0/30}$)											
Dead	0	0	0	0	0	0	0	0	0	0	1
Living	100	100	100	100	100	100	100	100	100	100	99
A.M.reject**	0	0	0	0	0	2	2	0	0	0	1
P.M.reject**	0	0	0	0	0	1	0	0	0	0	0
Salvageable	100	100	100	100	100	97	98	100	100	100	99
Dose = 550 r ($LD_{50/30}$)											
Dead	0	0	0	0	20	48	50	51	52	52	55
Living	100	100	100	100	80	52	50	49	48	48	45
A.M.reject	0	0	2	2	75	50	25	0	0	0	0
P.M.reject	0	2	0	4	5	2	25	2	0	0	0
Salvageable	100	98	98	94	0	0	0	47	48	48	45
Dose = 750 r ($LD_{100/30}$)											
Dead	0	0	0	0	65	90	100				
Living	100	100	100	100	35	10	0				
A.M.reject	0	2	10	30	35	10	0				
P.M.reject	0	0	5	15	0	0	0				
Salvageable	100	98	85	55	0	0	0				

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* It is likely that young animals and old animals will respond more severely to an exposure; therefore lowering the estimate by 100 roentgens will give a better value for them.

** A.M. = antemortem inspection; P.M. = postmortem inspection. Criteria for A.M. reject: elevated temperature, increased rate of respiration, lethargy. For P.M. reject: lesions of internal organs evidencing possible bacterial disease.

Table V is a guide for assessing the probable response of poultry to external gamma radiation.

Table V

Estimated Morbidity and Mortality in Poultry
in Per Cent of Pre-Attack Total

(Based on total-body gamma-radiation exposure
for periods up to 48 hours)

Total dose in roentgens	By 14 days Well %	 Sick* %	 Dead %	By 30 days Well %	 Sick* %	 Dead %
300	90	10	0	100	0	0
400	65	30	5	95	0	5
500	50	40	10	90	0	10
600	30	50	20	75	5	20
700	15	55	30	65	5	30
800	5	45	50	40	10	50
900	0	30	70	10	20	70
1000	0	20	80	0	15	85
1100	0	10	90	0	5	95
1200	0	0	100	0	0	100

* Elevated temperature, increased rate of respiration, loss of appetite, or lethargy.

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3. EFFECTS FROM INGESTION OF FISSION PRODUCTS

3.1 Biological Effects on Food-Producing Animals

The effects of the ingestion of fission products on food-producing animals are varied and are in large part determined by the degree of their absorption and distribution, and/or localization within the body. When the amount of consumed fission products is great enough and the retention long enough, nuclides which are widely distributed throughout the body can produce an injury or syndrome resembling that which follows total-body irradiation. Radiocesium is a nuclide that is fairly uniformly distributed. Radiostrontium, on the other hand, is an isotope that is localized and is concentrated chiefly in the bone crystal. If injurious levels of radiostrontium are ingested, the damage will be restricted chiefly to the bones at the epiphyseal plate, beneath the periosteum, and in the bone marrow. The effect upon the hematopoietic centers appears in a relatively short time but that at the epiphyseal plate and beneath the periosteum is usually delayed for many years and will be manifested, if ever, almost entirely as long-delayed osteogenic sarcoma, thrombocytopenia,and aplastic anemia. These effects, however, are not likely to be encountered in animals intended for meat purposes, but may occasionally be seen in animals maintained for breeding stock for a substantial period of time or in dairy cows maintained to old age. Radioiodine, too, is localized and is concentrated principally in the thyroid gland.

In this chapter the three important fission products, iodine-131, strontium-90, and cesium-137, will be discussed and some estimate made of the lethal and seriously damaging doses of each.

3.2 Radioactive Iodine, Strontium, and Cesium

In discussing the effects of these three important isotopes, the situations to be evaluated are: a) the amount of radioactive iodine, strontium, and cesium that will produce death or serious injury in animals, and b) the amount of these radionuclides that will reach man through consumption of meat and milk from contaminated animals. The hazard-evaluation data are in many cases best estimates. Where values are available for the adults of one species, they are in some instances applied to adults of another species on the basis of body weight or quantity of feed consumed. It is unlikely that serious error will result from this extrapolation.

The external radiation dose will be the principal consideration in early fallout, with an insignificant contribution coming from ingested or inhaled radionuclides. Probably less than five per cent added whole-body dose will be contributed by metabolized fission products. (See Appendix C.)

Metabolized fission-produced radionuclides will probably become the chief husbandry concern if animals receive protracted exposures from contaminated pasture or water. An indirect hazard to man may result from the use of meat and milk from animals grazing on contaminated pasture. Animals will serve, however, as a hazard-reducing step in the food chain of man, since an animal's filtering or entrapping capacity will prevent much of the contamination from reaching its edible tissues or food products.

3.3 Metabolic and Toxicity Information on Iodine-131

Thyroid uptake of radioiodine following a single oral administration in sheep, swine, and cattle is dependent on age and stable iodine intake. In the adult on an adequate dietary iodine intake, a 20-40 per cent uptake by the thyroid is often seen with a peak concentration at one to two days. Young lambs (thyroid weight one to three grams) may show an average uptake of ten per cent of the administered dose per gram of thyroid. Preliminary work on sheep indicates that less than ten per cent of an inhaled dose of iodine-131 as a vapor or particulate appears in the thyroid and 20-60 per cent of the body-burden is in the thyroid.

A thyroid dose of several thousand rads seems necessary before any thyroid damage can be observed. A dose of 50,000 to 100,000 rads to the thyroid is required for ablation. A single oral dose of 3 mc of iodine-131 (~30,000 to 40,000 rads to the thyroid) may not completely destroy the thyroid of young adult sheep, and they may continue to reproduce normally for several years. A single oral dose of greater than 300 mc of iodine-131 is probably required to cause sub-acute deaths in young adult sheep. Sheep have survived several hundred days when fed 1.8 mc per day (thyroid dose > 150,000 rads during the first month). Animals fed 240 μc/day of iodine-131 for 450 days (thyroid dose 50,000 rads or more during first four months) conceived and bore offspring though their offspring did not survive longer than five days. Young animals whose thyroids have been destroyed by iodine-131 may survive but will fail to grow. Adult sheep may appear fairly normal under the same circumstances. Eventually, however, lethargy, constipation, flatulence, and dry skin and wool develop. Such animals are suitable for food if conditions dictate such a use.

If an animal is given a single dose of iodine-131 so that the resulting maximum concentration in its thyroid is 1μc per gram of tissue, then the total dose to this organ is about 100 rads. After a single contamination event, grazing sheep maintained on the contaminated pasture will show a peak concentration in 8-12 days. If the initial concentration is 1 μc of iodine-131 per gram of dry vegetation eaten (or 0.2 μc per gram on succulent pasture), the infinity thyroid dose will exceed 100,000 rads. Animals grazing pasturage with this contamination level for 30 days will show some evidence of the total-body irradiation syndrome, and probably will have ablated thyroids. (See Appendices C and D for further data.)

In applying the data derived from sheep to swine and cattle, the results will be qualitatively similar if consideration is given to differences in body weight and food intake. The short half-life of most radioiodines produced in high yields in fission guarantees that they will essentially have disappeared after a few months. Iodine-129 is considered comparatively insignificant as a biological hazard because of its very long half-life.

The concentration of iodine-131 in the fetal thyroid in advanced gestation may be one to two times that of the adult thyroid in sows, two to three times in ewes, and up to six times in cows. If a thyroid-ablative dose is received by the fetus in the latter half of gestation, the animal will not survive beyond the first week of life unless therapy is initiated.

The relative concentration of iodine-131 at equilibrium in the various body tissues of ruminants can be stated in relation to the concentration of iodine-131 in the blood. Thus, if the blood has a concentration of 1 μμc/g, other tissues will have the following:*

Muscle, spleen thymus, pancreas	1	μμc/g
Kidney, liver, ovary	2-3	"
Salivary glands, urine	3-5	"
Feces, milk	5-15	"
Thyroid	10,000	"

A cow may secrete in its milk each day about one per cent of the daily iodine-131 dose per liter of milk. As noted above, the iodine-131 concentration in the feces is also quite high. Monogastric animals, unlike ruminants, excrete much more iodine-131 by way of the urine than by way of the feces.

The contribution of the short-lived isotopes of iodine (I^{132}, I^{133}, I^{134}, I^{135}, I^{136}) to the dose received by persons using the meat and milk of exposed grazing animals in the short-term emergency situation is considered relatively small, especially since a delay of a day or more between milking and consumption of milk is usual. Iodine-132 and iodine-133 may be exceptions, but the hazard from these isotopes is undefined. See Appendix D for calculations of possible iodine-131 doses to the thyroids of those drinking milk from cows grazing contaminated pasture.

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* These values are based on sheep; thyroid and milk concentrations will be somewhat lower in the cow.

The whole-body radiation dose for all animals from radioiodine in soft tissues other than thyroid is about 20-30 mrad/day/μc/kg of body weight.

3.4 Metabolic and Toxicity Information on Strontium-90

The contribution of strontium-89 can be considered as simply additive to that of strontium-90 and will be of greatest concern in the first few months. About 5-15 per cent of the amount of strontium-90 administered in a single, oral dose is absorbed and deposited in the skeleton of adult animals, while up to 30 per cent may be deposited in the skeleton of a young animal. About one to two per cent will be secreted in the milk. With prolonged administration of strontium-90, soft-tissue concentrations of strontium-90 are less than 0.1 per cent of those in bone. For a brief exposure, a lethal dose of strontium-90, administered intravenously, is probably in the range of 0.2 to 1 mc/kg of body weight for most animals. It is reported to be 1.3 mc/kg in goats and for swine it is 0.2-0.3 mc/kg. The whole-body dose from circulating and deposited strontium-90, and its daughter, yttrium-90, in soft tissues is about 60 mrads/day/μc/kg of soft tissue. At the level of 1 μc/g of grazed dry vegetation (approximately two kg/day) maintained for 30 days, definite evidence of the irradiation syndrome will appear. In swine a daily intake of 50 μc/kg of body weight for about two months will result in a manifestation of the total-body irradiation syndrome.

If strontium-90 is given to a pregnant animal in doses large enough to seriously injure or to kill the fetuses, the dam will also be seriously injured or killed.

Manifestations of acute radiation toxicity may include fever, lethargy, weight loss, widespread hemorrhages, oral and cutaneous ulcers, and anemia. The response to high doses of strontium-90 is somewhat similar to that observed following external total-body gamma-ray exposure.

3.5 Metabolic and Toxicity Information on Cesium-137

Up to 100 per cent of ingested cesium may be absorbed from the gastrointestinal tract of ruminants. About 50 per cent of that absorbed will be excreted within the first week. A cow excretes about 75 per cent of an administered amount of cesium in 30 days. The portion of a single absorbed amount remaining after four days has an approximate biological half-life of 20 days. Following the single, oral administration of cesium, a total of about nine per cent is secreted in the milk the first week and about 12 per cent during the first month. With prolonged continuous administration, about two per cent of the daily ingestion appears in each liter of milk. The muscle mass will contain about 25-30 per cent of a single ingestion after one week and about 10 per cent after one month. With prolonged administration, about five per cent of the daily ingested dose will be contained in each kilogram of a ruminant's muscle tissue. For swine, the percentage will be 20-30.

On the basis of radiation dose measurements, the gonads and the whole body are equally important as the "critical organ" in animals receiving cesium-137 daily. It is estimated that sheep carrying a body-burden of 70 mc of cesium-137, or cattle carrying a body-burden of over 500 mc, over a period of a month will develop manifestations of the total-body radiation syndrome. The manifestations of injury following cesium administration will resemble the whole-body radiation syndrome following exposure to an external gamma source. The whole-body radiation dose from consumed radiocesium is about 25-40 mrads/day/μc/kg of body weight in a large animal. An animal consuming 1 μc/g of vegetation for 30 days will eventually show evidence of injury to the hematopoietic system.

3.6 Combined Effects

The combined acute effects of radioactive iodine, cesium and strontium have been assumed to be additive in estimating whole-body dose. Whole-body dose is based upon the concentration in the blood for radioiodine, in the blood or bone marrow for radiostrontium, and in the muscle for radiocesium. The whole-body doses for individual radionuclides for the first week after a single ingestion by sheep are given in Table VI.

Table VI

Whole-Body Dose to Adult Sheep During First Week After a Single Ingestion of I^{131}, Sr^{90}, and Cs^{137}

Radionuclide	Dose (rads/mc ingested/kg body wt)
I^{131}	40
Sr^{90}	10 (400 for bone; 200 for bone marrow at surface)
Cs^{137}	100

The lethal oral dose and the oral dose resulting in serious injury are shown in Table VII. It has been assumed that the effects of these radionuclides will be additive.

Table VII

Oral Dose to Adult Sheep of I^{131}, Sr^{90}, and Cs^{137} Causing Serious Injury or Death

Radionuclide	Oral Dose (mc/kg body wt)	
	Lethal ($LD_{50/30}$)	Causing Serious Injury
I^{131}	15	0.2
Sr^{90}	10	1
Cs^{137}	5	0.5

The oral dose to the dam which would cause serious injury to the fetus is shown in Table VIII. It is assumed that the effects of these radionuclides will be additive.

Table VIII

Oral Dose to Adult Sheep of I^{131}, Sr^{90}, and Cs^{137} Resulting in Fetal Injury or Death (LD_{50}/before gestation)

Radionuclide	Oral Dose (mc/kg body wt)	
	Daily Administration	Single Administration
I^{131}	0.002	0.1*
Sr^{90}	0.015	1.0
Cs^{137}	0.020	0.2

* If administered in latter stages of pregnancy.

4. INTERNAL EXPOSURE TO GAMMA AND BETA RAYS

For all practical purposes, only two means of entrance into the animal's body need be considered. They are (1) inhalation and (2) ingestion.

4.1 Inhalation Hazard

Sheep and dogs exposed to fallout from surface and underground detonations, where the animals received external gamma-radiation exposures several times the lethal dose, showed minute and insignificant amounts of fission products internally. Very small quantities were observed to be retained in the lungs or other internal organs. A similar pattern was observed in the Marshall Island animals following moderate gamma-ray exposure. Measurements on indigenous animals at the Nevada Test Site indicate that inhalation does not contribute an important portion of the uptake of radionuclides.

Laboratory experiments in which mice inhaled simulated radioactive salt water fallout of ionic type (mean diameter 1.8μ; maximum diameter 3.7μ) show that the relatively small uptake of fission products and their short radioactive and biological half-life in mouse tissues following a brief exposure (one hour) result in a relatively low internal dose. The maximum internal dose rate at one hour to the respiratory system was 2.2 rads/hr where the external dose rate was 1700 rads/hr. The hazard from respiratory assimilation can, therefore, be ignored in an emergency situation.

Resuspension values in the environmental air (μc per $cc/\mu c$ per cm^2) lie between 10^{-6} and 10^{-10}, with 10^{-8} the most likely value for dusty operations in the open. In exposures occurring in a heavy-fallout region where the external gamma exposure is about 300 r/hr at one hour after detonation, the inhalation hazard is also slight. The exposed man or animal would have to breathe in all the inhalable radioactivity that would have been deposited on 10 cm^2 of surface to deliver 15 rem in 90 days. This estimate agrees with data on the Marshall Island animals and with other estimates made in the past. One might speculate that the hazard would be greater in grazing animals because of proximity of the external nares to the ground. However, a factor of about 10^6 must be applied in order to place the radiation doses in orders of magnitude similar to those from external exposures.

4.2 Ingestion Hazard

Under expected conditions of fallout the mucosa of the intestinal tract might receive a large absorbed dose, primarily from beta radiation, as radiocontaminated ingesta pass through the digestive tract. Probably the largest source of ingested radionuclides for grazing animals will be succulent green foliage. More may be added by the contaminated water consumed and by radionuclides swallowed after being taken into the body by inhalation.

Studies have shown that the lower large intestine is always the critical organ in both the single-stomached animal and the ruminant. The physiological state of the gastrointestinal system (for example, whether there is diarrhea or constipation) alters the dose delivered by more than an order of magnitude.

Although serial daily sacrifice of dogs following ingestion of 25 mc of Y^{90} showed mild pathologic change (sloughing of villi tips, heterophilic infiltration), the tissues of the lower large intestine were essentially normal in the animals killed on the sixth day following administration of the radionuclide. The total dose to the critical organ in this case was 2000 rads. It was not until the delivered radiation doses reached 5,000-14,000 rads that hemorrhagic enteritis was observed at autopsy. It has not been determined if serious incapacitations or deaths would occur at these dose levels among animals in general, although one might expect a reduction in milk or egg production or in weight.

To receive a given dose from beta radiation, the ruminant must ingest greater total amounts of radionuclides than would be necessary for the non-ruminant. This is because the ruminant has a greater mass of ingesta of which only the "outer shell" irradiates the mucosa. It is the concentration of the radionuclides within the ingesta that determines the dose rate to the rumen mucosa. Also the gut dose is a function of food intake, ingesta dynamics (dehydration, hold-up times, etc.), amount of radioactivities present, and radioactive decay. Therefore there are great differences among different species in the radiation doses delivered, particularly to the lower large intestines, by the ingestion of equal amounts of radionuclides. Likewise considerable differences are noted within single species because of innate physiological differences.

Estimated accumulated doses to cows resulting from fallout levels of 100 r/hr standardized to one hour after the detonation are listed below. It has been assumed that the cows that have been kept in a barn for the first 14 days after attack have been fed on uncontaminated hay. A factor of three has been used for the shielding effect of the barn against gamma radiation.

	Cows start grazing immediately after attack	Cows start grazing at 14 days
90-day whole-body dose	400 r	150 r
90-day gut dose	100 r	30 r

It has been assumed that 560 mc/ft^2 of gross fission products (6100 mc/m^2) will produce 100 r/hr at one hour after detonation. This decays to 15 mc/ft^2 the first day. It has also been assumed that the herbage retains about one per cent of the material falling on the land, and the cow strips 1500 ft^2 per day on an average pasture. Thus a total of 225 mc is ingested each day when reduced to the one-day activity rate. In situations where the herbage retention is higher than one per cent the dose delivered to the gut will be increased proportionately, but the whole-body dose delivered will remain the same. The whole-body dose is related to the absolute amount of radioactive material that falls and is not altered by the amount retained upon the herbage. It should be noted that even a whole-body dose of 1000 r would mean only 250 r to the gut; 1/8 of the dose required to produce the minimal injury noted above.

Laboratory data obtained from goats in the yttrium-90 experiments noted above may provide some insight into the comparative beta-radiation doses to the cow's lower large intestine which one might expect from fission products. Each millicurie of yttrium-90 ingested by the goat resulted in an absorbed dose of 17 rads to the lower large intestine. By direct extrapolation of these values to the cow, 225 millicuries of yttrium-90 would deliver less than 4000 rads to the critical organ. This is less than the radiation dose required to observe pathological damage (hemorrhagic enteritis) in the goat. There are several factors that would reduce this estimated dose to the cow. For instance, the ingestion of fallout material less than two and one half days old (the approximate half-life of yttrium-90) would result in lowering the delivered dose, since the half-life of fission products approximates the time since formation. Also, a cow would have to ingest more fission product radionuclides to receive the same dose as the goat, assuming similar digestion dynamics, since only the outer shell contributes to the beta-ray dose to the intestinal mucosa. In addition, the average beta-ray energy of fission products is estimated to be 0.43 Mev at 2.1 days of age compared to 0.89 Mev for yttrium-90. This difference in beta-ray energy would greatly reduce the delivered dose. In summary, it appears that the cow would receive a substantially smaller dose to the gut than would the goat.

In view of the data obtained by direct dose measurement of ingested yttrium-90, it appears that the whole-body radiation dose would probably result in fatalities long before irradiation of the gut would become a critical problem. However, this does not discount the possible additive effects of whole-body and gut irradiation, nor does it evaluate the effects of gut irradiation at the non-lethal level on weight gain, milk or egg production, susceptibility to infection, etc. The physiological disturbances resulting from irradiation-induced diarrhea could conceivably reduce or stop production in the milk cow or laying hen.

Reductions in the potential gut dose can be accomplished by feeding lesser amounts of contaminated roughage feeds soon after detonation, or by withholding all contaminated feeds for as long as possible. The local situation will dictate the more advantageous method. Likewise, the administration of a laxative following ingestion of radioactive feeds, if non-contaminated or less-contaminated feeds are available for subsequent feeding,will reduce the delivered dose to the gastrointestinal tract should this become an important consideration.

The gamma-ray dose of internally-located fission products does not appear to be substantial; its contribution to the total radiation dose received by a tissue is small when compared with the dose associated with beta-ray emissions. For example, in dogs administered cesium-137, the beta/gamma-ray ratio of dose to liver, kidney, muscle, and gonad is approximately two. To a great extent the gamma dose is a function of the geometry of the radiating medium (ingesta): the nearer the approach to the geometrical center, the higher the gamma-ray dose. For the large animal (e.g., cow) the radiation dose from the gamma-ray component of the ingested radionuclides will become more important because of the size of the radiating medium. The contribution of the total dose by gamma rays is assumed to be simply additive to the beta-ray component from ingested radionuclides of fission products. If this is true, the total radiation dose under special circumstances may approach injurious levels in cows because of the combined exposure effects. It is not believed that this is a practical possibility. For possible genetic damage, the gamma component would undoubtedly assume the more important role. In domestic animals, in an emergency, this is not considered to be of any particular importance.

4.3 The Added Hazard to Animals of Consumed Fission Products

There has been no experimental determination of the additional burden that an animal externally exposed to fallout would sustain from a beta-ray dose to its thyroid and from a total-body dose from ingested iodine-131. Investigators have made estimates that vary considerably. However, all are in agreement that the biological effect contributed by the iodine-131 to the thyroid and to the total body is comparatively small. The external body exposure to gamma rays from fission products will always be the limiting factor in an unsheltered situation. Long before the internal dose reaches substantial proportions the animal will have received a fatal exposure from ambient fallout radiation. In view of the scant direct evidence bearing upon this subject, estimates for all the important fission products are given in Appendix C.

From these Appendix C estimates and from calculations in Appendix D, which we believe maximize the hazard to animals and man from the ingestion of fission products, it appears that the direct or indirect added hazard from consumed fission products can be ignored in the early phases, and with close-in fallout. Therefore, if the population needs food for survival or to maintain a capacity for work,the food products from animals that have consumed fission products can be used during an emergency period, provided the animals can be handled, milked, or slaughtered without excessive exposure to the husbandman. Iodine-131 in milk, however, poses a special problem for small children, as is discussed later.

5. EFFECTS OF CONTACT WITH RADIOACTIVE MATERIALS

5.1 External Effects (Radiation Burns)

The external radiation burns due to contact with fission products or other radioactive nuclides following nuclear detonations are principally the result of beta radiation. They are injuries commonly seen on nearby animals following a nuclear detonation when particulate fallout material lodges in their coats or on their skins, thus keeping the radioactive elements in position sufficiently long to produce what has been called "beta burns". There can be a hazard to herdsmen and abattoir employees who handle the animals so exposed. Buildings and equipment can also become contaminated.

It is quite possible that lethal physiological effects from beta radiation may rarely or never be seen in farm animals following nuclear detonations, since levels of beta radiation high enough to cause such effects would under most circumstances be accompanied by gamma radiation of sufficient magnitude to deliver an overwhelming total-body exposure. The cattle accidentally exposed to about 39,000 rep at the Trinity Test in 1945 survived. The ratio of skin exposure to total-body exposure was 39,000 rep (to multiple foci on the back) to 140 r of total-body exposure. Since the physiological response to the effects of beta particles on the skin is expressed by a mechanism different from that used for gamma exposure to the total body, the symptomatic response to a beta/gamma flux could be at most equal to the responses to the two types of radiation injury applied separately. From what is known by the observation of accidentally exposed animals, however, it probably is wise to consider the effects as overlapping and not additive to any marked extent.

5.2 Burn Types

One difference between thermal burns and beta burns relates to time. The response to thermal burns is immediate, while several days or weeks may pass before physical signs of the beta burns are apparent. Doses required to effect a burn vary with the energy (Table IX).

Table IX

Beta Radiation Producing Recognizable Injury to the Skin of a Pig

Isotope	Average Energy (Mev)	Surface Dose (rads)	Estimated Beta Dose at 0.09 mm (rads, μc/cm^2)
Sulfur-35	0.17	20,000	1,200
Cobalt-60	0.31	4,000	1,600
Cesium-137	0.55	2,000	1,700
Yttrium-91	1.53	1,500	1,200
Phosphorous-32	1.71	2,000	-
Strontium-90	2.70	2,000	-

These lesions may be classified by their severity:

(1) Epidermal atrophy which follows a low dose of radiation. Although a slight depigmentation of the coat may be seen a few weeks after exposure, the skin is usually intact and any atrophy recognized is only microscopic.

(2) Exfoliative dyskeratosis which follows a more intensive exposure, in which the skin becomes flaky and exfoliates. (A chronic radiation dermatitis usually follows this type of burn.) Atypical cell forms are characteristically found in the epidermis, hair follicles are usually destroyed, and the surrounding tissues produce a depigmented coat color.

(3) Transepidermal necrosis, the severest type of beta burn which, except for the latent development mentioned above, resembles a thermal burn with edema, bullous desquamation, and lesion, but the coat will not regrow. Around the edges of such a wound may be found the lesions characteristic of the two lesser types of beta burns.

A carcinoma of the skin of the back eventually developed in three beef cows kept for 15-17 years after the Trinity exposure to approximately

39,000 rep skin dose, delivered over 10 per cent or more of the body surface, and 140 r total-body dose. External radiation burns upon the backs and feet of animals will detract little from their food value. It is unlikely that exposures of the back or feet of animals will contribute any substantial increase in the effects of external whole-body irradiation associated with it.

The injury from contact with fallout particles to the skin of food animals, usually the back, depends upon the contamination density and the length of time of the contact. This can be described by the term "accumulated contamination density" and expressed by the unit μc - hr/cm^2. The term includes both the preceding factors and hence can be employed as a measure of hazard of skin irradiation due to fallout. The expression μc - hr/cm^2 implies that it makes no difference whether an exposure of 200 μc - hr/cm^2 results from 200 $\mu c/cm^2$ in contact with the skin for one hour or 20 $\mu c/cm^2$ for ten hours. A very rough empirical relationship is as follows: The beta-ray dose delivered by fission products on the skin (probably most applicable to swine) will be 5 rads/hr when the surface contamination on the ground equals that on the back of an animal and is one $\mu c/cm^2$. (This estimate is adapted from the NCRP Handbook, Report #29.)

6. ANIMALS AND POULTRY AS SOURCES OF FOOD

Usually only muscle of animals would be consumed as meat. Hence levels of radionuclides in bone, gut, and thyroid need not be considered in assessing animals as meat sources, only those in muscle.

6.1 Utilization of Animals Exposed to Total-Body Radiation

Based upon studies of food animals exposed to total-body irradiation, there is no evidence that the flesh of lethally irradiated animals is harmful, even if it is obtained from animals near death from total-body irradiation. Food animals exposed to very large total- or partial-body irradiation ordinarily can be salvaged for food if they are slaughtered within two to eight days after exposure or have completely recovered from the ensuing illness. In the absence of complete information regarding exposure, it will be safe to consider that animals are suitable for food if they show no evidence of illness and their temperatures are not elevated. Because of lowered resistance, infections may develop 8-14 days after exposure and be accompanied by severe generalized illness. An estimate of the salvageable mammalian food animals was given in Table IV.

6.2 Utilization of Internally Exposed Animals

In an emergency the food products of surviving animals that have consumed fission products can be used to sustain life or maintain a capacity for work. Appendix D gives computations of doses to human thyroids from drinking milk from cows that have consumed iodine-131. They show that at the upper limit of radioactive contamination in available milk supplies the thyroid dose to adults from drinking one liter per day of milk will be acceptable for the immediate emergency. Infants, however, should not drink milk with that level of contamination because of the much greater dose their smaller thyroids would receive.

6.3 Assessing the Hazard of Using Food from Exposed Animals

To determine the risk that man would take by eating meat or drinking milk from animals that have consumed fission products requires knowledge of (1) the level of contamination in the animal's intake, (2) the reduction in the contamination concentration that takes place when the animal converts this intake into food products, and (3) the effects of radiation exposure on man. Multipliers or ratios, R, for (2) above have been derived for different types and lengths of exposure to the animal. Another group, expert on the effects of radiation on man, can use these multipliers to complete the hazard assessment.

$$R = A/M,$$

where A is the concentration of radionuclides in the animal's intake (air, food, water), and M is the resulting concentration of radionuclides in food products from that animal.

Since M is the concentration of contaminants in the food consumed by man, it is also a measure of the radiation exposure he receives, and a maximum acceptable concentration value might be assigned and used during emergency conditions by an authority who is informed on the national situation and needs.

The value of R will be dependent upon the specific animal food product to be consumed and upon conditions under which the animal was exposed. In order to obtain the level of contamination (A) in the animal's total intake (air, food, water), R should be multiplied by the concentration (M) that will be allowed for man in a specific emergency situation. The R, or multiplying factor, values are fixed and are listed in Table X. They are based on prolonged exposures to man.

Although values of R have been calculated for milk, meat, liver, and kidney, and for a number of important food-producing species, emphasis will be placed on the limiting values for cattle. The values for dairy cattle are usually limiting and are the only ones indicated in Table X. See Appendix B for details of how Table X was developed.

It is expected that this method of evaluation will not be useful until some days after the nuclear detonation. Considerable detailed information will be needed for the evaluations required.

As an example of the use of Table X, consider the case of a cow subjected to prolonged exposure to strontium-90 through eating contaminated vegetation. The multiplying factor (R) for this situation is 6, and therefore, since $R = A/M$, $A = 6\ M$. This means that the cow may consume vegetation containing a strontium-90 concentration (A) that is six times M, the concentration of radionuclides in water that might be established for man (by the authority referred to earlier), before her milk contains a concentration equal to M.

As a result of radioactive decay and elimination of the radionuclide from the animal, the values for the multiplying factors (R) will increase with time following single exposure. For example, in order for milk to contain a concentration of strontium-90 equal to the concentration (M) in water acceptable for man, the water or feed consumed, or air breathed by the cow the day previous to secreting the milk could have been, respectively, 10 and 60 times the concentration for man (M). In the event that the average concentrations of strontium-90 in the cow's water or air was 500 or 3000 times the respective permissible concentrations for man in water and for man in air, milk produced after the 20th day would be below the permissible concentration in water for man.

Table X

Relationship of I^{131}, Sr^{90}, and Cs^{137} Concentrations in Animal's Intake to those in Animal's Food Products

(Based on estimated concentration levels at end of the day on which the animal consumed the contaminated herbage)

		Ratios or multiplying factors - R*					
		When I^{131} is in		When Sr^{90} is in		When Cs^{137} is in	
Days from exposure of animal to start of consumption by man	Product	animal's water**	animal's air	animal's water	animal's air	animal's water	animal's air
		Prolonged consumption by the animal					
	Milk	2	6	6	40	1	6
	Meat (muscle)	6	20	40	200	1	6
	Liver	3	10	-	-	1	6
		Single or brief consumption by the animal					
1	Milk	4	20	10	60	4	25
	Meat (muscle)	20	100	70	400	9	50
	Liver	10	50	-	-	10	60
5	Milk	10	60	60	300	10	70
	Meat (muscle)	60	300	400	2,000	9	50
	Liver	30	150	-	-	10	70
10	Milk	20	100	200	1,000	20	100
	Meat (muscle)	100	600	1,000	7,000	8	50
	Liver	50	300	-	-	20	100
20	Milk	50	300	500	3,000	30	200
	Meat (muscle)	200	1,400	3,000	20,000	10	70
	Liver	100	700	-	-	30	200

* An acceptable concentration (A) for domestic animals (based on the cow as the limiting case) is that which would result in a concentration (M) in the animal's tissue or milk equal to an acceptable level (M) for man's drinking water; i.e., R = A/M.

** The concentration of radionuclides in vegetation is assumed to be the same as that in water.

In the case of iodine-131, if the animals remain on the pasture following a single contamination event, each liter of milk produced would contain about one tenth the concentration per kg in the dry vegetation consumed. (For reference purposes, the Day 5 values from Table X would apply.) If the determinations are based on succulent pasture, the values would have to be scaled down appropriately (see Table XV).

6.4 Utilization of Poultry

The eggs and flesh of poultry will represent an important resource of fresh food of animal origin which may be available following a nuclear attack. This belief is strengthened by the fact that all poultry are easily slaughtered at the place at which they are raised or one to which they can be transported by hand. It is an accepted procedure in farm homes to prepare and cook poultry immediately after slaughter; therefore refrigeration need not be a limiting factor. Poultry, especially chickens, are often reared under shelter or are provided with optional shelter for protection from normal environmental changes. This should provide an added margin of safety for poultry exposed to radioactive fallout. In addition, over a large part of the year poultry are often fed prepared feeds (suitable only for poultry) which are in storage. This can give some indirect protection to the consumer of poultry against internal exposure to radionuclides from fallout.

From the experience in the Marshall Island animals it is evident that laying hens will rapidly eliminate strontium-90 by way of the egg shells through rapid and frequent mobilization of labile bone salts. Eggs are thus an important food in time of emergency.

6.5 Food Value of Animals Exposed to Blast and Heat

Blast and heat have little immediate effect upon the food value of an animal if wounds and burns are not extensive. Such animals can be slaughtered promptly for consumption if the requirement exists. Present meat-inspection practices should adequately cover contingencies resulting from secondary effects of blast, i.e., flying debris or falling structures.

7. EXPOSURE OF MARINE LIFE

The radiation and local fallout following a nuclear detonation is apparently far less significant to life in a marine environment than to the animal and plant life in a land environment. Dilution of radioactive strontium and cesium in the ocean is sufficient to eliminate them from the category of fallout problems in the ocean. Instead of fission products, neutron-activated nuclides in the form of cobalt-57, -58 and -60, iron-55 and -59, manganese-54 and zinc-65 are predominant in the marine animals. On a short-time basis and as local fallout, iodine-131 seems to be the principal fission-product isotope of concern in marine food resources.

7.1 Effects of Exposure

Radioiodine may concentrate to rather high levels in the thyroid of fish. A recently completed and as-yet-unpublished study of test-site material purports to show that iodine-131 passing through the food chain (algae → invertebrates → fish) may concentrate in sufficient amounts in the thyroid glands of fishes to damage seriously or destroy the thyroid.

Further observations on marine life which may be pertinent: (a) $LD_{50/30}$ for adult fish is in the range of 1000-2000 rads, while for crustaceans it is in the range of 800-100,000 rads and for molluscs in the range of 4000-50,000 rads. (b) The fallout resides on particles of calcium compounds or on NaCl particles. (c) Few fission products appear in fish; of the three long-lived fission products, cesium-137,strontium-90, and cerium-144, only the latter, cerium-144, is readily detected in marine animals. (d) Radiocobalt is apparently concentrated about 10,000 times by clams that are in an area of heavy fallout. (e) Zinc-65 can be identified in tuna fish and in oysters and clams. It has also been shown to be concentrated by oysters and scallops to thousands of times above its level in the water. (f) In about 700 fish specimens collected over a 19-month period at Eniwetok Atoll, only about one per cent of the total beta radioactivity of the tissue counted was in muscle.

7.2 Utilization as Food

Considering the very low levels of radionuclides in the marine environment not in the immediate vicinity of a detonation, together with the above information, it would appear that the muscle of fish, crustaceans, and molluscs can be a highly recommended, relatively safe food source in a disaster situation. The visceral mass of fish should, however, be discarded, particularly if they are caught near the area of detonation and major fallout zone. Clams and oysters, which are eaten whole, should be avoided if harvested from such a contaminated area.

8. STERILITY, SEXUAL, GENETIC, AND EMBRYOLOGIC EFFECTS

8.1 Male Sterility

Studies of the effects of total-body irradiation on sperm production in bulls (400 r), boars (400 r), and rabbits (800 r) show no evidence of induction of permanent sterility. No difference was observed between the semen of the burros exposed to near-lethal levels in an atomic detonation and the control burros at one year after exposure. Breeding capacity and sex drive are not impaired in most cases, even in exposures substantially above the $LD_{50/30}$ level in male burros, until just a few hours before death.

8.2 Female Sterility

Cows surviving 450-700 r total-body exposure,delivered in a brief period,were placed with non-irradiated bulls 60 days after irradiation. All conceived, and all calves were normal at birth. No difference was seen in rate of pregnancy between irradiated cows and controls. The surviving irradiated animals are in excellent health four years after exposure.

No evidence of sterility or lowered fertility has been observed up to five years following exposure of cows to total-body doses of 400 r gamma radiation. Some of this group received an additional dose of 400 r one to two years after the initial exposure. These have continued to exhibit normal fertility. Calves born to these cows have been normal in appearance and growth rate. One female burro that received nearly 800 r total-body radiation exposure (cobalt-60) has produced several normal colts over a nine-year period. Animals surviving exposures in the $LD_{50/30}$ range have shown no evidence of sterility, except for a temporary period, up to nine years later. Swine have shown no evidence of sterility, reduced litter size, or reduced survival at weaning time when sows are bred eight months or longer after irradiation. (See Table XI.)

No appreciable incidence of sterility will be observed in animals surviving heavy exposure to iodine-131 or strontium-90. If, however, a large dose of cesium-137 is received, such as would cause the acute radiation syndrome, sterility might result. See Section 3.3 for data on survival of fetuses receiving thyroid-ablative doses of iodine-131 during gestation.

Table XI

Size and Survival of Litters of Sows Receiving
One Half to One $LD_{50/30}$

	Average of first and second litters after exposure		
Parentage	Per liter	Farrowed alive	Survived at weaning
Non-irradiated	10.3	9.7	8.0
Irradiated ♂ and Non-irradiated ♀	11.0	10.5	7.2
Irradiated (both)	10.6	10.4	9.1

8.3 Embryologic Effects

Irradiation is especially harmful to the embryo. Doses ordinarily without danger to the dam can be of grave consequence to the embryo during early embryonic life. It has been observed that exposure at the time of tissue differentiation is particularly damaging. The aberrations encountered are associated almost entirely with cessation of development or growth of a particular organ or organ system. The embryological effects of radiation exposures and associated problems, however, are of little consequence in animals except for the economic loss of the aberrant young. Sterility of animals irradiated as embryos has not been studied.

8.4 Genetic Effects on Mammals

An increase in the mutation rate of domestic animals may be assumed to follow an increase in exposure to ionizing radiations. The genetic effects are essentially irreparable, cumulative, and self-multiplying. It is impossible to distinguish radiation-induced mutations from those with other causes. Any abnormalities produced will be of the same type as those customarily seen. Since the rate of mutations in domestic farm animals is poorly established in most instances, or unknown in others, incremental changes will probably not be recognized.

There are indications that the effect of a given dose is influenced by ploidy, e.g., the complex organization of chromosome material in higher animals may suffer greater genetic injury than does the simpler organization in the drosophila or even the mouse. However, the common practice of rejecting poor genetic material and the extensive use of zootechnical eugenics obviates a concern for the genetic effects of irradiation in domestic animals.

8.5 Sterility in Poultry

It is believed that the number of chickens that survive for 30 days will be approximately the number that may be expected to survive for 180 days or possibly longer. Limited studies to date fail to reveal any persisting somatic effects on egg production and fertility or hatchability in chickens surviving external radiation. This appears to be in agreement with the experience in the Marshall Islands. Chickens there were exposed to external gamma radiation doses of 280-360 r, plus radionuclide contamination. Studies made on total egg production and rate of production revealed no evidence of any effect of radiation. Fertility of the hens and the hatchability of the eggs produced were normal. The chicks hatched also appeared normal.

9. PROTECTIVE CONSIDERATIONS FOR HUSBANDMEN

9.1 General Guidance

During the first phase of fallout, when little may be known of its intensity and nature, it will be wise for husbandmen to keep their personal exposure to the minimum consistent with the survival of their communities, families and selves. A general rule of guidance can be given when radiation levels have been determined: If the animals or poultry are well and can be attended to without undue radiation hazard to the husbandman (due to ambient radiation), then the flesh or products of such animals or birds can be used for food,for a reasonable emergency period, to sustain life. Finally, when it is possible to identify radionuclides, further refinements in the protective measures will be taken.

It is emphasized that in determining whether animals injured by either blast or thermal effects of a nuclear weapon are to be handled or slaughtered, one must consider the following:

(1) The radiation risk to the persons charged with the care or utilization of the animals.

(2) The nature of the injury to the food animal in question, the sequelae, and the state of its recovery at the time of slaughter or handling.

(3) The total- or partial-body irradiation effects in addition to blast or thermal effects.

(4) The contamination of the animal by radioactive substances.

(5) The critical status of the food stores.

(6) The availability of processing facilities and the means of storage or preservation of the salvaged meat, milk, or eggs.

There is a special warning that should be emphasized. There may be a tendency to slaughter animals needlessly, i.e., panic slaughtering. For example, poultry are easily slaughtered, but it must be remembered that enough of them must be preserved to provide a source of eggs, and, equally important, a breeding stock to replenish the flock. It is suggested that contaminated grain be used for animal feed and the uncontaminated reserved for man in order to take advantage of the ability of animals to serve as filters of contaminating radionuclides. In special circumstances some uncontaminated grains might be used to preserve a nucleus of livestock and fowls for breeding purposes.

9.2 Futility of Therapy

Therapy for large numbers of total-body-irradiated animals is probably futile. If valued animals are exposed to moderate levels of total-body irradiation, the use of antibiotics may be of value where bacterial infection is present. It is suggested, however, that when exposed animals have been subjected to substantial total-body irradiation, it will be better to salvage them for food before the development of the irradiation syndrome than to attempt treatment. Such a decision should be made only after determining that food-preservation methods and facilities are adequate to avoid waste.

9.3 Protection from Fallout

A single brief exposure of up to 300 r of total-body irradiation will be reasonably well tolerated by most farm animals. If it is at all possible, however, food animals should be removed from pasture in fallout areas, placed in barns, and given dry, uncontaminated hay. It is difficult to set an exact external dose rate at which it would be safe to return the animals to pasture, but at 25 r per week all animals would survive and could be handled with safety.

Animals directly exposed to fallout can be washed or wet-brushed (but not dry-brushed) to remove externally deposited radionuclides if this can be done without danger to the husbandman. If available, detergents and chelating or complexing agents can be used to advantage. Care must be taken by animal handlers not to inhale or ingest contaminated dust or spray.

9.4 Feeding Practices

Supplemental feeding from uncontaminated rough forage stocks can materially reduce the daily dose of ingested radioactive material when grazing on contaminated pastures is necessary. If possible, both supplemental feeding and limited grazing time might be utilized when no cover is available and when the level of radioactivity is only moderately high or food resources are limited. In extreme cases and for short periods of time, withholding all food and water can be resorted to.

9.5 Some Special Problems

When meat processing can be resumed under reasonably normal conditions, the usual washing and discarding of inedible parts of domestic animals exposed to radioactive fallout will decrease the total radioactivity by several orders of magnitude. There will undoubtedly be radiocontamination of the processing plants, so consideration must be given to protection of the worker. The skin and viscera of animals should be discarded in such a manner that radiations from these sources will not endanger the processor.

Considerable technical progress has been made in the past few years concerning the removal of radiostrontium from milk. Pilot models of ion-exchange columns capable of removing about 90 per cent of radiostrontium from milk have been developed, but their use has been confined to laboratory experiments. The utility of the ion-exchange process for cleansing milk of radionuclides may depend upon economic factors that are most important. Disposal of radiocontaminated ion-exchange resins can be a critical problem if resins, containers, and transport are in short supply.

The conversion of milk into such long-term products as dry milk, cheese, butter, etc. for storage has received considerable attention and seems a very favorable way to decrease the radiocontamination of short-lived fission products such as radioiodine through radioactive decay.

It is not expected that all food-processing plants can be operated with full power or with sufficient equipment for preserving foods for future use. Moreover, it is expected that transportation may be greatly decreased or disturbed to the extent that food animals for slaughter and necessary operating supplies may not be readily available at the processing plant. It is for this reason that it is vital that methods of preserving food at the farm or ranch be utilized to make available that source of protein in time of national emergency.

10. RESEARCH NEEDS

In preparing this document, lack of experimental evidence in certain areas forced us to make far-reaching extrapolations and intuitive guesses. Some of our conclusions, therefore, may be far too conservative. We believe that study and research can provide the data necessary to make sounder conclusions, i.e., conclusions less likely to result in overly cautious political and operational decisions that could impede recovery from nuclear war.

Since we have not analysed the current research programs, we cannot indicate where work should be initiated or emphasis increased. In any case, however, we believe that the following urgently needed information should be sought:

10.1 Physical Data

Relationship of use, type, and size of nuclear weapons to the size, composition, distribution, and biological availability of the fallout particles on the ground and upon foliage.

Relationship of the physical and chemical nature of the particles to intestinal and pulmonary absorption.

Ways of producing simulated fallout particles for metabolic studies in animals and in their flesh and food products.

Relationship of ambient radiation from fallout to the nature of particles and pulmonary and intestinal absorption.

10.2 Biological Data

General information on the radiation response of land and water animals suitable for protein resources.

Response of such animals to ambient exposures likely to be encountered in a fallout field, i.e., exponential decay field.

Response of such animals in a fallout field to the added burden of internal exposure from consumed and metabolized radionuclides.

Response of such animals in a fallout field to the added burden of consumed but non-metabolized radionuclides.

Response of such animals in a fallout field to the radionuclides that fall or collect upon external parts of the body such as the back, ears, feet, etc.

The total response of such animals to all effects of fallout in a variety of circumstances.

The total response of such animals to direct effects of fallout in conjunction with an altered "way of life" resulting from contamination.

10.3 Defensive Measures

The effectiveness of added iodine and other pharmacological agents in the diet in reducing radioiodine in the milk of cattle.

The effectiveness of various levels of dietary calcium and of other pharmacological agents upon the radiostrontium and radiobarium in the milk.

The effectiveness of laxatives in reducing the radioactive elements in the gastrointestinal tract.

The effectiveness of various methods for removing radioactive debris from the hides of animals, and how to carry out such an operation with a minimum exposure to the personnel involved.

Procedures and equipment for safe slaughtering of contaminated animals, i.e., with minimum exposure to the operators and minimum contamination of the meat.

Inexpensive methods for home preservation of meat and meat food products.

Farming practices that may reduce uptake of radionuclides by farm animals.

APPENDIX A

BIOLOGICAL AVAILABILITY OF FALLOUT IN RELATION TO ITS DISTRIBUTION*

One of the first problems that arises in defining the potential levels of either short-range or long-range hazards from radioactive fallout is the disposition of the various radioactive elements in the fallout material. Since the disposition of the fission products and other radioactive elements in fallout is determined very early after a nuclear detonation occurs, it is of interest to review briefly the process of fallout formation as deduced from measurements on and analyses of various types of fallout.

The radiation injury to specific organs and tissues will be related to the amount and the nature of radioactive materials ingested and it will be limited by the biological availability of the radioactive elements present in the fallout particles. One can make certain generalizations, largely based upon field studies. Silica-laden detonations will serve as an example since they are our principal source of information.

(a) Near the point of detonation particles will be large. The ratio of total radioactivity to biologically available radioactivity will be large. This means that the hazard from external whole-body irradiation will be greater than from the ingestion of fission products as one approaches the detonation point.

(b) As one moves away and downwind from the point of detonation, biological availability increases so that the ratio of the total radioactivity to biologically available radioactivity becomes smaller. At substantial distances the ingestion hazard may predominate. Biologically available fission products, though, may be considerably less quantitatively because they are dispersed over a wide area.

(c) Also, as one moves away from the point of detonation a profile of <u>specific</u> biologically available fission radioisotopes is developed.

In a nuclear detonation near the surface of the earth, some soil is vaporized along with the contents of the weapon. In addition, some soil is melted and large amounts of soil are pulverized. As the fireball rises and expands it cools rapidly; when the temperature falls to about 3000°K

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* Based on material prepared by Carl F. Miller for the Stanford Research Institute Report: Fallout and Radiological Countermeasures (to be published).

or so, some of the more refractory substances such as aluminum oxide, iron oxide, and other such substances in the vapor phase will begin to condense into small liquid oxide drops. These small drops (or particles) in turn serve as condensation nuclei for condensation of refractor fission-product elements such as the rare earths, zirconium, niobium, and others that would not otherwise condense to form liquid drops by themselves. However, this process alone cannot account for the large particles found in fallout. Because of the rapid fall in temperature of the fireball and the fireball size, and because of the low vapor content in the fireball of condensable substances, the largest particles formed by this process alone would be only of the order of 10 microns in diameter.

As the fireball rises, melted and/or pulverized soil particles are drawn into the fireball and, while the temperature of the fireball is greater than the melting point of the soil these particles will melt (at least on their surfaces). As these larger particles sweep through the gas volume they scavenge great numbers of the small vapor-condensed drops (or particles) as well as furnishing more surface for other, less refractory fission-product elements to condense on. While the temperature of the fireball is in the temperature range where soil minerals can exist in a liquid state, the fallout particle formation or condensation process is characterized by the existence of a liquid in contact with a condensing vapor. Thus, at each temperature, each element present has some distribution between the two phases. Elements (or their oxides or compounds) more refractory than the soil will be found in the condensed phase and those that are more volatile will be concentrated in the vapor phase. When a soil particle leaves the reaction zone or when the overall temperature of the system falls below the melting point of the soil, the particles solidify and the composition of the dissolved condensates is frozen inside the particles. If the above processes constitute the first period of condensation in fallout formation, and if this period is characterized by the existence of vapor-liquid phase equilibria, then the second period of condensation which follows is characterized by the existence of vapor and solid phases. Particles that enter the fireball after it has cooled to or below their melting points, and the solidified particles that are still present, can condense on their surfaces only the fractions of the various elements not already condensed.

Hence, the first major disposition of each radioelement in the process described above is in the fraction condensed inside of once-melted particles and the fraction condensed on the outside of solid particles. The fractions are determined mainly by: (1) the melting point of the soil, (2) the vapor or sublimation pressure(s) of the condensing species, and (3) the time when particles of a given size enter and leave the reaction volume. The composition of the radioactive elements in the various particle-size groups will determine the gamma-ray spectrum and ionization-rate decay of the fallout arriving at a given location. The fraction of each element fused into silicate soil particles should not be water soluble or "biologically" available (except as a discrete glassy particle). The only natural processes that could conceivably make this fraction biologically available are solid-state diffusion and particle-surface erosion; both processes should be extremely slow. The fraction of each element condensed on surfaces of the particles may become biologically available to plants and animals. The portion of this fraction that actually becomes available will depend to a large degree on the size of the particle itself and the environment in which it finds itself. For example, the portion of an element condensed on the surface of small glassy particles lying among clay particles could, in a rain, be washed from the glassy particle onto the clay particle and be strongly adsorbed. On the other hand, if these particles fell on vegetation later eaten by animals the same portion could be dissolved by the digestive juices and passed into the body fluids. The fraction of the same element inside the glass particles would stay with the particle in its passage through the gut.

The time sequence of events in the fireball-condensation processes during the fireball rise and cloud formation is very important in determining the trend in the fallout-particle properties with particle size or downwind distance from ground zero. In detonations where a large amount of fallout is formed, the column of particles is clearly seen to enter the rising fireball from the bottom. In this process, the particles circulate through the reaction zone. The larger particles become segregated first because of centrifugal forces in the circulation and because of larger gravitational forces on them when the circulating air current exerts force on them to re-enter the fireball from the bottom. The result is that the larger particles move to the outside of the fireball, are accelerated downward around the periphery of the fireball, and do not re-enter the fireball. One of the results of this toroidal-type circulation of the fireball and the surrounding air is an initial "dumping" of large particles when the circulation starts up (or very soon thereafter), producing high levels of fallout just downwind of ground zero in a rather narrow band. The second result is that these large particles are the most depleted in volatile elements and have relatively few or no elements condensed on their surfaces. As the rate of rise of the fireball (or cloud) decreases and the circulation falls off, the particles thrown out or down by the circulation and pulled away from the bottom of the cloud by gravitational forces become smaller and smaller. Hence, the very small particles should carry the largest fraction of biologically available elements and the biologically available elements are those that have, as precursors, elements that are the most volatile at the time when the melted soil particles solidify. This is consistent with the observed fact that world-wide fallout is biologically available and very close-in fallout is not.

The whole process in the formation of the fallout particles, in which each size group has a characteristic composition of radioelements fused within the particles and on their surfaces, is one in which the combination of soil melting point (and composition), rate of temperature decrease with time of the fireball, volatility of the radioelements, rate of fireball (cloud) rise, toroidal circulation in the fireball, fall rates of particles, and wind velocities act together or in sequence to determine the biological hazards of fallout and the biological availability of any one radioelement at a given location in the fallout area.

A general discussion of the quantitative derivations for the processes described above is given elsewhere.* The derived estimating methods are illustrated here by a summary of some computations of the properties of the fallout from a 15-MT-yield land-surface explosion. The assumed conditions for this detonation include: (1) The soil forms glass particles which solidify at about 1400°C; (2) the wind speed is 15 mph at all altitudes; and (3) the fraction of fission for the weapon is 0.5.

In the model of the fallout process, the particles with approximately equal diameters are grouped according to their fall-velocity vectors (called particle-size designators, α) defined by

$$\alpha = \frac{v_W}{v_f} = \frac{X}{h} \qquad (1)$$

in which v_W is the wind velocity vector, v_f is the particle-fall-velocity vector from its height of origin, h, to the ground at the downwind distance, X, from the point of origin. When h is the height of the center of the cloud (at 6 to 8 minutes after detonation), it is designated as h_0 and the particle-size designator is α_0. The particle groups designated by α_0 are assumed to represent the median particle-diameter of those landing at the downwind distance, X.

Estimates of the particle-size designators, median particle-diameters (d_m), and minimum and maximum diameters (d_{min} and d_{max}, respectively) of the particles landing at downwind distances from 12 to 590 miles from the assumed 15-MT-yield detonations are given in Table XII. The particle-size compositions at locations away from the fallout-pattern center-line, say at a point X, y, where y is the cross-wind distance from the center line, would have the same median particle-diameter (d_m) for a given value of X, but the values of d_{min} and d_{max} would converge towards d_m as y increased. The estimated values of the particle diameters were calculated from dynamic fall-rates through a "standard" atmosphere, and do not include influence of up-drafts in the air-flow or the possible effect of precipitation in the lower altitudes.

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* See footnote App.A, p.47.

Table XII

Summary of Estimated Values of Median Particle-Size Designator, Median Particle-Diameters, and Minimum and Maximum Diameters of Particles at Several Downwind Distances from a 15-MT-Yield Surface Detonation Along the Center-Line of the Fallout Pattern

α_0	X (miles)	v_f (ft/sec)	d_m (microns)	d_{min} (microns)	d_{max} (microns)
0.780	12	28.2	710	240	1100
1.236	19	17.8	450	206	1000
2.406	37	9.14	237	160	800
2.992	46	7.38	198	144	460
3.837	59	5.74	163	129	268
4.487	69	4.90	145	120	211
6.18	95	3.56	116	101	145
9.10	140	2.42	90	78	108
13.01	200	1.69	74	64	99
21.47	330	1.02	57	49	68
29.92	460	0.735	48	42	56
38.36	590	0.574	43	38	48

Note: v_w = 15 mph = 22.0 ft/sec; h_0 = 81,200 ft = 15.4 miles

Next to be considered are the standard intensities (in r/hr at 1 hr) from the particles along the pattern center-line and the number of potentially soluble atoms of various radionuclides in the fallout. The different parameters involved in the relationship between these two quantities are given in the equation

$$N_0^*(A) = \frac{Y_A \left[r_\alpha^*(A) - r_\alpha(A)\right] I(1)}{K_\alpha(1)} \text{ (atoms/sq ft)} \qquad (2)$$

in which

$N_0^*(A)$ is the number of atoms, corrected to zero time, of the end-member of mass-chain A that are condensed on the outside of the particles designated by α;

Y_A is the fission yield of mass A in atoms/fission;

r_α^* (A) is the gross fraction of the element (or mass-chain)condensed within and on the exterior of particles up to the stated size designation;

r_α (A) is the fraction of the element (or mass-chain) condensed within the glassy matrix of particles;

I(1) is the standard intensity, in r/hr at 1 hr, where the particles land; and

$$K_\alpha (1) = 3.90\times10^{-13} \left[r_\alpha (1) + 0.02 \right] \frac{(\text{r/hr at 1 hr})}{(\text{fissions/sq ft})} \qquad (3)$$

in which the constant, 3.90×10^{-13}, is a conversion factor from fissions/sq ft to r/hr at 1 hr at 3 ft above a smooth plane (considering all the gamma-ray abundances and energies) for unfractionated fission products from 8-Mev neutron fission of U-238 and which includes reduction factors of 0.75 for terrain attenuation and 0.75 for instrument response; r_α (1) is the estimated 1-hr gross fractionation number for the fission-product mixture carried by the particles designated by α; and the value 0.02 accounts for the contribution of a nominal amount of induced activities.

The estimates of the values of the various parameters of Equations 2 and 3 for several downwind distances from the assumed 15-Mt-yield explosion are given in Table XIII. At distances less than 11 miles, the estimates give N_0^*(A) values equal to zero. In other words, the larger particles falling within 11 miles of ground zero carry only radioelements fused inside the glassy matrix of the particle. In the model, these larger particles are calculated to be ejected from the circulating fireball while they are still in the molten state. Similar calculations can be made for other nuclides such as strontium(yttrium)-91, ruthenium(rhodium)-103, ruthenium(rhodium)-106, Cesium(barium)-137, barium(lanthanum)-140, cerium-141, and tellurium(iodine)-132, -133, -135.

The data in Table XIII show a major peak in the N_0^*(A) values between 50 and 150 miles downwind from the point of detonation. It may be noted that the ratio of N_0^*(A) to I(1) varies with the particle diameter or downwind distance. Also the ratios of the N_0^*(A) values vary with the downwind distance.

Table XIII

Estimate of Surface Deposition of Potentially Soluble Amounts of Sr^{89}, Sr^{90}, and I^{131} as a Function of Downwind Distance and Fallout-Pattern Center Standard Intensity.

I(1) (r/hr at 1 hr)	X (miles)	$r_\alpha(1)$	$r^*_\alpha(89)$	$r^*_\alpha(90)$	$r^*_\alpha(131)$	$N^*_o(89)$ (atoms/sq ft)	$N^*_o(90)$ (atoms/sq ft)	$N^*_o(131)$ (atoms/sq ft)
0	11	0.34	0.020	0.16	0.016	0.0	0.0	0.0
5,000	12	0.40	0.032	0.23	0.033	1.2×10^{12}	7.5×10^{12}	1.7×10^{12}
50	19	0.69	0.22	0.80	0.76	1.2×10^{12}	4.3×10^{12}	3.0×10^{12}
50	37	0.72	0.33	0.90	0.95	1.7×10^{12}	4.8×10^{12}	4.1×10^{12}
500	46	0.73	0.47	0.96	1.0	2.4×10^{13}	5.1×10^{13}	5.1×10^{13}
5,000	59	0.74	0.60	0.98	1.0	3.2×10^{14}	5.2×10^{14}	5.4×10^{14}
5,000	69	0.74	0.64	0.986	1.0	3.4×10^{14}	5.1×10^{14}	5.4×10^{14}
3,150	95	0.75	0.67	0.989	1.0	2.2×10^{14}	3.2×10^{14}	3.2×10^{14}
1,350	140	0.76	0.71	0.991	1.0	1.0×10^{14}	1.4×10^{14}	1.4×10^{14}
500	200	0.76	0.74	0.993	1.0	3.8×10^{13}	5.0×10^{13}	5.2×10^{13}
50	330	0.77	0.77	0.996	1.0	3.8×10^{12}	5.0×10^{12}	5.1×10^{12}
5	460	0.78	0.78	1.0	1.0	3.9×10^{11}	5.0×10^{11}	5.0×10^{11}
0.5	590	0.78	0.79	1.0	1.0	4.0×10^{10}	4.9×10^{10}	5.0×10^{10}

Note: $r_\alpha(89) = 0.020$; $Y^{89} = 0.0317$ atoms/fission
$r_\alpha(90) = 0.16$; $Y^{90} = 0.037$ atoms/fission
$r_\alpha(131) = 0.016$; $I^{131} = 0.032$ atoms/fission
Weapon Yield = 15-MT; Wind Speed = 15 mph; Fraction of Fission = 0.05

Next, consider the retention of the fallout particles on foliage that may be eaten by animals and in which the amounts of the $N_0^*(A)$ ingested are dissolved in the stomach acids and are subsequently deposited in various body organs. (It may be noted that the amounts of the nuclides computed from the time, $Y_A r_\alpha (A) I(1)/K_\alpha(1)$, of Equation 2 would not be dissolved and would contribute only to the dose to the gut). The foliage-contamination relationships are defined by

$$N_f^* (A) = a_L \ (\alpha) \ w_L \ N_0^* (A) \qquad \text{atoms/ft}^2 \qquad (4)$$

in which

$N_f^*(A)$ is the number of atoms of the element of mass-chain A retained on the foliage per sq ft of soil area;

$a_L \ (\alpha)$ is the contamination factor in number of fissions on the foliage per gram of dry foliage divided by the number of fissions per sq ft of soil area (in the particles falling at the location); and

w_L is the number of grams of dry foliage per sq ft of soil area.

In Equation 4, the product, $a_L \ (\alpha) \ w_L$, is the fraction of the fallout retained by the foliage. The quantity, w_L, is an independent variable giving the surface density of the foliage for a given forage crop. The quantity, $a_L \ (\alpha)$, represents the retention potential of a given type of foliage for retaining particles with the diameter designated by α. Data on the fallout retention by forage crops such as alfalfa, clover, wheat, and mixed grass, which were obtained from measurements near the Nevada Test Site, were used to determine the dependence of $a_L \ (\alpha)$ on α. The relationship found was

$$a_L \ (\alpha) = 9.5 \text{x} 10^{-5} \ (\alpha_0 - 0.34); \ \alpha \leq 0.34. \qquad (5)$$

Equation 5, adjusted to α_0 values for a 15-mph wind speed, represents the observed data on the four types of foliage to better than 10 per cent. The observed values of w_L from which the data were derived varied from 5 to 40 g of dry foliage per sq ft. The observed values of $a_L \ (\alpha)$ were obtained for α_0 values up to about 40 (equivalent to particle sizes of about 40 microns as shown in Table XII).

Values of $a_L \ (\alpha)$, $a_L \ (\alpha) w_L$, and $N_f^*(A)$ are given in Table XIV for $w_L = 20$ g dry foliage/sq ft. The estimated fraction of the fallout particles retained by the foliage varies from about 0.08 per cent at 12 miles to about 7 per cent at 590 miles. However, the peak in the absolute amounts of fallout retained is at a downwind distance of about 70 miles on the fallout-pattern center-line.

Table XIV

Summary of Estimated Values of $N_f^*(A)$ for a Foliage Density of 20 Grams Dry Foliage per sq ft at Several Downwind Distances from a 15-MT-Yield Surface Detonation (Wind Speed = 15 mph)

X (miles)	a_L (α) $\frac{\text{(fissions/gm)}}{\text{(fissions/ft}^2\text{)}}$	a_L (α) w_L	$N_f^*(89)$ (atoms/sq ft)	$N_f^*(90)$ (atoms/sq ft)	$N_f^*(131)$ (atoms/sq ft)
12	4.19×10^{-5}	8.38×10^{-4}	8.8×10^{8}	6.3×10^{9}	1.4×10^{8}
19	8.52×10^{-5}	1.70×10^{-3}	2.0×10^{9}	7.3×10^{9}	5.1×10^{8}
37	1.96×10^{-4}	3.92×10^{-3}	6.7×10^{9}	1.9×10^{10}	1.6×10^{10}
46	2.52×10^{-4}	5.04×10^{-3}	1.2×10^{11}	2.6×10^{11}	2.6×10^{11}
59	3.32×10^{-4}	6.64×10^{-3}	2.1×10^{12}	3.5×10^{12}	3.6×10^{12}
69	3.94×10^{-4}	7.88×10^{-3}	2.7×10^{12}	4.0×10^{12}	4.3×10^{12}
95	5.55×10^{-4}	1.11×10^{-2}	2.4×10^{12}	3.6×10^{12}	3.6×10^{12}
140	8.22×10^{-4}	1.64×10^{-2}	1.6×10^{12}	2.3×10^{12}	2.3×10^{12}
200	1.20×10^{-3}	2.40×10^{-2}	9.1×10^{11}	1.2×10^{12}	1.2×10^{12}
330	2.01×10^{-3}	4.02×10^{-2}	1.5×10^{11}	2.0×10^{11}	2.0×10^{11}
460	2.81×10^{-3}	5.62×10^{-2}	2.2×10^{10}	2.8×10^{10}	2.8×10^{10}
590	3.61×10^{-3}	7.21×10^{-2}	2.9×10^{9}	3.5×10^{9}	3.6×10^{9}

Note: w_L = 20 g dry foliage per sq ft of soil area (column 3).

APPENDIX B

MULTIPLYING FACTORS FOR PERMISSIBLE CONCENTRATIONS

Explanation for Table X

The following data and formulations were considered in making the evaluation found in Table X.

The values utilized for vegetation consumed or air breathed by animals are given in Table XV. The values for vegetation are based upon water consumption. This will apply to an animal on uncontaminated dry feed and consuming contaminated water or grazing on contaminated succulent pasturage and drinking contaminated water. If the animal were consuming contaminated dry feed and uncontaminated water the values in Table X would be about nine times greater.

The critical anatomical data for domestic animals, together with feed, water, and air intake, are also found in Table XV.

Table XV

Anatomical, Physiological, and Intake Data on Domestic Animals*

	Dairy cattle	Beef cattle	Sheep	Swine
Body weight (kg)	500	450	70	200
Muscle mass (kg)	160	180	24	85
Thyroid weight (g)	30	25	8	15
Bone mass (kg)	60	45	7	16
Blood volume (liters)	35	30	5.5	10
Daily water intake on dry feed (liters)	80	60	4	15
Minute volume (liters/min)	90	80	6	15
Daily feed intake (kg)				
dry	9	8	2	4
green	60	50	6	6

* Some values are maximum rather than average figures (e.g., green feed intake).

Assumptions:

1. Average daily milk production of U.S. cows is approximately ten liters.

2. Daily intake value of dry feed listed in Table XV is for the time of year when pasturage is negligible.

3. Cattle on dry rations may be given two thirds of the dry feed value listed, supplemented by 10-15 kg of silage per day.

4. Green feed is the amount of succulent pasturage ingested by a grazing animal.

Available data on radionuclide concentrations were related as follows, with A standing for concentration in animal's intake, and M for concentration in man's intake:

Case A. Ratio (or multiplying factor - R) of A to M for water

The concentration coefficient (C_c) is the ratio of the fraction of administered dose retained in the tissue to the fraction the tissue is of the body weight,

if Q_a = μc of dose in animal's water intake per day or per event,
q_a = μc of dose retained in critical organ or tissue of animal,
K_b = Kg of total body weight of animal, and
K_t = Kg of critical organ or tissue of animal,

then, $$C_c = \frac{q_a/Q_a}{K_t/K_b} = \frac{q_a}{K_t} \times \frac{K_b}{Q_a} \qquad (1)$$

and $\frac{C_c x Q_a}{K_b} = \frac{q_a}{K_t} = M_w$, the concentration in water (meat,milk) for man.(2)

Let Q_a = concentration in animal's water (A_w) times F_{wa}, the water consumed daily by animal, i.e., $Q_a = A_w \times F_{wa}$, then by substituting in Equation (2)

$$\frac{A_w \times F_{wa}}{K_b} \times C_c = M_w \qquad (3)$$

and

$$\frac{A_w}{M_w} = \frac{K_b}{C_c x F_{wa}} = R \qquad (4)$$

Case B. Ratio (or multiplying factor - R) of A to M for air

If Q_m = the μc of radionuclides that man is permitted to ingest or breathe daily,
F_{am} = man's daily air intake, and
F_{wm} = man's daily water intake,

then, $M_w = \frac{Q_m}{F_{wm}}$ (5)

and, since $Q_m = M_a \times F_{am}$, $M_w = \frac{M_a \times F_{am}}{F_{wm}} = 9 \times 10^3 \times M_a$ (6)

Since concentrations of radionuclides received from air and from water are proportional to daily intakes of air and of water,

$$A_a = A_w \times \frac{F_{wa}}{F_{aa}} \quad (7)$$

Combining Equations 7 and 4, $M_w = \frac{A_a \times F_{aa} \times C_c}{K_b}$ or $A_a = \frac{M_w \times K_b}{F_{aa} \times C_c}$ (8)

from Equation 6, $M_a = \frac{M_w}{9 \times 10^3}$, and therefore,

$$\frac{A_a}{M_a} = \frac{9 \times 10^3}{F_{aa} \times C_c} = R \quad (9)$$

Case C. Ratio (or multiplying factor - R)for total daily intake: animal - man

$$M_w = \frac{Q_m}{F_{wm}} \quad (5)$$

Combining Equations 5 and 8 and taking $Q_a = A_a \times F_{aa}$,

$$\frac{Q_a \times C_c}{K_b} = \frac{Q_m}{F_{wm}} \quad (10)$$

Since $F_{wm} = 2.2$ liters/day, then

$$\frac{Q_a}{Q_m} = \frac{K_b}{2.2C_c} = R \text{ (not given in Table X)} \qquad (11)$$

Relevant values for the factors used in the above equations are given in Tables XVI and XVII.

Table XVI

Air and Water Consumption of Animals Relative to Body Weight (Body weight in kg; air and water volume in liters)

Animal	Body weight kg	$\frac{\text{Body weight}}{\text{Daily air vol. animal}}$ $\left(\frac{K_b}{F_{aa}}\right)$	$\frac{\text{Body weight}}{\text{Daily water vol. animal}}$ $\left(\frac{K_b}{F_{wa}}\right)$
Dairy cow	500	4×10^{-3}	6
Beef cattle	450	4×10^{-3}	8
Sheep	70	8×10^{-3}	18
Swine	200	9×10^{-3}	13
Man	70	3.5×10^{-3}	32

Table XVII

Experimental Values for Concentration Coefficients (C_c) for the Cow

$$C_c = \frac{\mu c \text{ retained in tissue}}{\text{Kg of tissue}} \times \frac{\text{Kg of body weight}}{\mu c \text{ of daily dose}}$$

Day	Tissue	I^{131}	Sr^{90}	Cs^{137}
		Prolonged consumption		
	Muscle	1.8	0.15	8
	Milk	9.0	1.0	5
	Liver	3.6	0.15	8
	Kidney	3.6	0.15	8
		Single consumption		
1	Muscle	0.32	0.09	-
	Milk	1.5	0.60	1.5
	Liver	0.64	0.09	-
	Kidney	0.64	0.09	-
5	Muscle	0.10	0.015	0.7
	Milk	0.50	0.09	0.5
	Liver	0.20	0.015	0.5
	Kidney	0.20	0.015	0.9
10	Muscle	0.06	0.005	0.8
	Milk	0.30	0.03	0.3
	Liver	0.12	0.005	0.3
	Kidney	0.12	0.005	0.4
20	Muscle	0.025	0.002	0.5
	Milk	0.13	0.015	0.2
	Liver	0.05	0.002	0.2
	Kidney	0.05	0.002	0.2

APPENDIX C

ESTIMATION OF THE ADDED HAZARD TO LIVESTOCK FROM CONSUMED FISSION PRODUCTS

Iodine-131

Calculations will be given which show the possible magnitude of the doses to the thyroid and to the total body from orally consumed iodine-131.

The people exposed in the Marshall Islands were estimated to have had, at the end of the first day, 6.4 to 11.2 μc of iodine-131 in their thyroid glands. The thyroid burden of iodine-131 in the swine is not known, but it will be assumed to have been 100 times greater*, i.e., 640-1120 μc per gland. The average for this is 880 μc per gland or 59 μc per gram in a 15-gram thyroid. We have estimated in this document that the infinity dose to the thyroid is approximately 100 rads per microcurie per gram of thyroid. The infinity dose to the swine thyroid in the Marshall Islands therefore is estimated to be about 5900 rads. The ablation dose for most food animals of interest is 70,000 rads or greater. The dose the Marshall Island animals received was well below that level, the total-body dose being estimated on the average at 320 r (280-360r) in the same period of time. Thus, even if the whole-body dose was increased to 1000 r, a 100 per cent fatal exposure, the dose to the thyroid would be under 18,000 rads.

In order to estimate the additional contribution that the consumed iodine-131 makes to the external total-body exposure, we have made another estimation. The total-body burden (excluding the thyroid) can be assumed to be four times as great as that of the total thyroid burden, i.e., 3500 μc. Assuming that the swine weighed 25 kilograms, there was an average whole-body concentration (excluding the thyroid) of 141 μc per kilogram weight. We have estimated that there are 0.03-0.05 rads exposure per microcurie per kilogram of body weight. The added dose received by the swine was therefore estimated to be 4.2-7.0 rads to the total body. These estimates are probably high, but probably are not more than two orders of magnitude higher than will be found under emergency conditions.

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* This figure was selected because it is about the largest difference that has been observed between humans and grazing animals getting the same radioiodine exposure from fallout. No direct measurements were made on the Marshall Island swine.

Another method of estimation considers the theoretical nature and distribution of the fallout and how it is metabolized. First the thyroid dose:

The product of the following is determined:

1440-μc/m^2 of Gross Fission Products (GFP) delivers 1 r/hr at H+1 day at 1 meter
0.01 - percentage (1%) of the GFP that is iodine-131,
60 - square meters of pasture herbage consumed per day,
.05 - percentage (5%) retention of iodine-131 on pasture grass,
.20 - percentage (20%) of iodine-131 going to the thyroid, and

which is then divided by

15 - weight of a mature swine's thyroid in grams;

which gives

0.576 - μc per gram of thyroid when the fallout field is 1 r/hr at H+1 day.

The estimated dose for Marshall Island swine was about 320 r in 50 days; fallout arrived at an estimated 10 hours. The back-extrapolated dose at H+1 day would be about 175 r/hr; therefore 0.57 x 175 = 100 μc/g of thyroid. Again assuming that the infinity dose to the thyroid is 100 rads per μc/g, the dose to the thyroid under these circumstances would be 10,000 rads. This should be compared with the estimate of 5900 rads previously made.

Similar steps in calculation can be made for the estimation of the total-body dose to the swine from iodine-131, except that the value of 80 per cent is used for that distributed throughout the body and the weight of the animal is considered to be 25 kilograms. This gives an estimate of 24 microcuries per kilogram of body weight. Again assuming 0.03-0.05 rads total-body exposure per microcurie of iodine-131 per kilogram of body weight, values ranging from 7.3-12 rads are obtained. These are in approximate agreement with the values obtained in the previous calculation. These data therefore also suggest that even the highest estimated doses to the thyroid or the body of the animal are not, in most cases, a critical additional radiation burden. Only at the higher exposures is there a probability of death or serious injury due to the added burden.

Strontium-89 and Barium-140

The next most substantial contributors to the dose of radiation to the body or its specific organs are strontium-89 and barium-140. They can be considered together since they are most heavily concentrated within the calcium salts of the bones. In order to determine the burden on strontium-89 within the body structure, a procedure is followed that is somewhat similar to that used for the determination of iodine-131 levels for swine, i.e.:

The product of

1440 - gross Fission Products (GFP) in $\mu c/m^2$ delivering 1 r/hr at H+1 day,
2×10^{-3} - fraction of GFP as strontium-89,
0.05 - percentage (5%) of fraction of GFP retained upon herbage,
60 - square meters of herbage consumed per day, and
0.01 - percentage (1%) of strontium-89 going to the bone which gives
0.0864 μc of strontium-89 in the skeleton. This product is then divided by
7×10^3 - grams of bone in the skeleton of a 70 kg pig which gives 0.0124×10^{-3} μc of strontium-89 per gram of bone when the ambient external radiation dose is 1 r/hr at H+1 day.

In the current literature there are two estimates that relate the rads received by the total skeleton to the burden of strontium-89. One estimate is that the dose to the skeleton is 5 rads from strontium-89 and barium-140 per microcurie of strontium-89 skeletal burden; the other, 0.5 rad per microcurie. The first case results in a skeletal dose of 0.003 rad per day, the other in 0.0003 rad per day, at 1 r/hr at H+1 day.

Another estimation of the integrated dose from a beta ray emitter (Radiological Health Handbook, 1954, p. 50) is as follows:

The product of

88 - a multiplier constant
0.55 - average energy of strontium-89 beta rays (mev)
52 -effective half life in days, i.e., $\frac{T_{\frac{1}{2}} \times T_b}{T_{\frac{1}{2}} + T_b}$ ($T_{\frac{1}{2}}$ is half-life; T_b is biological half-life of strontium-89)
0.0124×10^{-3} - microcurie of strontium-89 per gram of bone, and
0.171 - $1-e^{-\lambda_{eff} x t}$;(λ_{eff} is the effective decay constant, days $^{-1}$; t = days 15), is equal to
0.00534 rads to the skeleton in 15 days when the ambient radiation is 1 r/hr at one hour after detonation.

The last evaluation, 0.000356 rad per day average, may be an overestimate because it does not take into account the decay of strontium-89 on the herbage, or the wasted radiation delivered to the animal, which increases each day after the first day until it is a substantial proportion by the 15th day. It also does not take into account the added contribution of barium-140, which is probably somewhat less than 1/10 that of strontium-89. Despite this, the estimate is in good agreement with the lower estimate given above, i.e., 0.5 rad to the skeleton per μc of bone burden of strontium-89, which makes the skeletal dose about 0.0003 rad per day from strontium-89 and barium-140 equivalent to 1 r/hr at H+1 day. Therefore, such an exposure will not be an important factor in determining the fate of grazing animals after radiation exposure.

The radiation dose to the total body also has been calculated, but the estimated dose is two to three orders of magnitude less than that to the bone, and therefore has been considered inconsequential.

It should also be noted that the maximum permissible concentration (NBS Handbook 69) for strontium-89 in bone for occupational exposure of man is 4 μc. Compare that value with the estimate of 0.0864 μc at 1 r/hr at H+1 day. It would require an exposure of 46 r at H+1 day to produce a body burden equal to the maximum permissible concentration for occupational exposure of man. An exposure of that magnitude would be an appreciable dose for any domestic animal. One may consider the skeletal burden of strontium-89 of swine in the Marshall Islands with an average total-body exposure of 320 r. When measured on the 82nd day, 23 and 26 kilogram pigs had total skeletal strontium-89 burdens of 2.5 and 2.3 μμc, respectively. It is difficult to believe that such an exposure, even if it were proportionately increased to the expected level for LD 100 external exposure, would be a significant factor in limiting the survival of domestic farm animals.

Several assumptions that are not at first obvious have been made which tend to make these estimates uncertain. The first is that fallout is 100 per cent soluble and therefore can be completely assimilated. This is not true (note Appendix A), but an acceptable percentage cannot be set because of uncertainties regarding when, where, and how a weapon is detonated. There is also no unanimous opinion with respect to the retention of fallout upon pasture grasses and other herbage. Estimates range from 1-25 per cent retention, with the exception of the 40 per cent Windscale experience. For many of the calculations in this document a value of five per cent has been chosen. It is probably high for retention of large, particulate fallout. Another assumption is that the radiated animal will continue to eat its customary amount of food. This is obviously not to be expected. It is probable that animals receiving lethal or above-lethal total-body exposures may have much less of the metabolized fission products in their meat, organs, or milk than would be expected, because of loss of desire for food and inability to muster the energy required to seek food and water.

APPENDIX D

COMPUTATION OF I^{131} DOSE TO THYROIDS OF ADULTS AND CHILDREN FROM DRINKING MILK FOLLOWING NUCLEAR ATTACK

The estimating functions given in Appendix A can be used to calculate the concentration of the radionuclides in milk from cows that might graze on contaminated foliage. Of course, at the distances where the fallout is heavy, unprotected cattle would be exposed to lethal levels of radiation. Also, at some of the slightly lower levels, a husbandman would not be able to take care of animals for some time without exposing himself to more radiation than is tolerable.

The calculated exposure doses at several locations on the fallout-pattern center-line are given in Table XVIII. The exposure doses were calculated by use of a "fractionated" fission product decay curve.

TABLE XVIII

Exposure Doses on Fallout Pattern Center-Line

I(1) (r/hr at 1 hr)	X (miles)	$\bar{t}$ (hours)	$D_a(\bar{t} + 7d)$ (roentgens)	$I(\bar{t})$ (r/hr)	$I(\bar{t} + 7d)$ (r/hr)
500	46	3.07	1,420	103	1.04
5,000	59	3.93	13,100	790	10.3
5,000	69	4.60	12,500	660	10.3
3,150	95	6.30	7,100	300	6.4
1,350	140	9.33	2,640	84	2.7
500	200	13.3	850	21	0.95
50	330	22.0	68	1.2	0.088
5	460	30.7	5.7	0.084	0.0082
0.5	590	39.3	0.5	0.0065	0.00078

Note: $\bar{t}$ is the "effective" time of fallout arrival; $I(\bar{t})$ is the maximum dose rate if all the fallout were deposited instantaneously at $\bar{t}$.

The I(1) values were first multiplied by 1.33 to correct for the instrument response factor of 0.75 included in the I(1) values. The seven-day dose was computed to include much of the early large amounts of dose. Even if one assumed a 2.5 per cent per day biological recovery after four days, the integrated dose to t + 7 days would still be within 92.5 per cent of the effective "brief" exposure dose.

For an $LD_{50/30}$ of 550 roentgens, more than half the cattle would die within about 30 days at distances to about 220 miles (on the fallout-pattern center-line). However, the exposure dose decreases quite rapidly with distance so that at about 260 miles, where the exposure dose is less than about 300 roentgens, only about 10 per cent of the cows would become sick in 30 days. At a downwind distance of 330 miles from the assumed detonation, there would apparently be no radiation sickness among the cattle and the husbandman could take care of the cattle in the usual manner at the cost of an exposure dose to himself of less than 100 roentgens (over an extended period of time), assuming that he spent about 50 per cent of his time in buildings with a shielding factor of 2 or more.

Thus it is possible that milk could be obtained without delay at the downwind distance of 330 miles (or nearer to ground zero at locations off the fallout-pattern center-line) where the standard intensity is estimated to be 50 r/hr at 1 hr; where the fallout arrives at about 22 hours after the explosion, and where the maximum observed dose rate at arrival time would be about 1.2 r/hr. These conditions, from the model computations, should represent the upper limit of radioactive contamination in available milk supplies. The area for which the estimated conditions apply, of course, is very small.

The concentration of the available nuclides in milk (assuming the amounts designated by $N_o^*(A)$ or $N_f^*(A)$ are readily soluble in stomach fluids; an assumption that may be as much as an order of magnitude too high) may be estimated from

$$C_{milk} = \frac{C_r}{V_m} D_i N_f^*(A)\ \lambda_i^* e^{-\lambda_i t} \quad \mu\mu C/\text{liter} \qquad (1)$$

where

C_r is the croppage rate of foliage in sq ft of soil area/day;

D_i is the discrimination factor for the concentration in milk;

λ_i^* is the physical decay constant in $\mu\mu C$/atom;

V_m is the milk produced in liters/day;

λ_i is either the physical decay constant or an empirical constant evaluated from observed variation of C_{milk} with time after exposure; and

t is the time after detonation

Equation 1 can be directly applied to end-mass-chain members that grow in rapidly to 100 per cent of the chain yield. Otherwise $N_f^*(A)$ requires adjustment for the time at the beginning of the uptake cycle. The use of Equation 1 is illustrated only for the uptake of I^{131} from milk for cows grazing on forage crops at $x = 330$ miles. It is assumed that the cow(s) consume 60 kg of green forage per day, which is equivalent to about 12 kg of dry foliage per day. And since it was assumed that w_L for the forage crop was 20 g of dry foliage per sq ft, C_r is 600 sq ft/day. The values assumed for the other parameters are:

$D_i = 0.08$

$\lambda_i^* = 2.71\times10^{-5}$ $\mu\mu C$/atom (8-day half-life)

$V_m = 10$ liters

$\lambda_i = 0.139$ day^{-1} (5-day effective half-life)

$N_f^*(131) = 2.0 \times 10^{11}$ $atoms/ft^2$

The effective value of λ_i is assumed to apply from zero time. It appears that the observed five day effective half-life is due to a combination of a first-order rate sublimation reaction of iodine from the fallout particles and of the grazing habits of cows (they don't eat a single area of 600 sq ft each day). The sublimation process should be occurring more rapidly while the particles are falling through air than when they are on foliage or on the ground (at $x = 330$ miles the particles are in the air for the first 22 hours after they are formed); therefore the assumption that λ_i applies back to zero time should give an upper-limit estimate of the I^{131} remaining on the particles when they are ingested by the animal. The combination of the above parameter values gives, for Equation 1,

$$C_{milk} = 2.60\times10^{7}\, e^{-0.139t}\ \mu\mu C/\text{liter} \qquad (2)$$

If the iodine build-up in the milk in the first few days of intake is neglected, Equation 2 gives a concentration of 1.97×10^{7} $\mu\mu C$/liter at the end of the first day's consumption of forage ($t = 2$ days).

The thyroid dose from drinking the milk from the cows at the selected location may be estimated from

$$D_{ik} = 1.60 \times 10^{-8} \frac{E_{ik}}{m_{ik}} N^{*}_{ik} \begin{pmatrix} t_f \\ t_o \end{pmatrix} \text{ Rads} \qquad (3)$$

where

$$N^{*}_{ik} \begin{pmatrix} t_f \\ t_o \end{pmatrix} = \frac{\lambda^{*}_{i} C^{k}_{i} e^{-\lambda_i t_o}}{(\lambda^{*}_{i} + \lambda_{ik} - \lambda_i)} \left\{ \frac{\left[1 - e^{-\lambda_i (t_f - t_o)}\right]}{\lambda_i} - \frac{\left[1 - e^{-(\lambda^{*}_{i} + \lambda_{ik})(t_f - t_o)}\right]}{(\lambda^{*}_{i} + \lambda_{ik})} \right\}$$

disintegrations (4)

in which D_{ik} is the dose absorbed by the k^th organ from the i^th radionuclide. For the thyroid:

E_{ik} = 0.228 Mev/dis for m_{ik} = 20 g (adults)

E_{ik} = 0.211 Mev/dis for m_{ik} = 2 g (infants)

λ^{*}_{i} = 0.0866 dis/atom/day

λ_i = 0.139 day^{-1}

λ_{ik} = 0.00502 day^{-1}

$C^{k}_{i} = f_{ik} N^{o}_{i}$ atoms/day

f_{ik} = 0.3

N^{o}_{i} = 9.6x10^{11} V atoms/day (V in liters milk consumed 1 day)

t_o = 4 days (allow 2 days for processing), and

$t_f = \infty$ (continuous consumption).

With the above parameters values,

$$N^{*}_{ik} \begin{pmatrix} \infty \\ 4 \end{pmatrix} = 1.13\text{x}10^{12} \text{ V disintegrations (in the thyroid)} \qquad (5)$$

so that

$$D_{ik} = 206 \text{ V Rads (20 g thyroid - adult)} \qquad (6)$$

and

$$D_{ik} = 1910 \text{ V Rads (2 g thyroid - infant).} \qquad (7)$$

The above calculations illustrate a method for estimating the effects of exposure in terms of fallout properties, of relative locations in the fallout area, and of the values of the parameters involved in the on-going processes. Other computations using slightly different methods give answers that are reasonably close. Variations in the assumptions used account for most of the differences. Obviously, if the per cent retention of fallout on foliage is assumed to be two instead of the four used above, there will be a corresponding variation in the result. Similarly, differing assumptions for the half reduction time of radioiodine in milk, or for the period of exposure, lead to different answers.

There appears to be a concensus, however, that if a dairy herd survives the gamma radiation and can give milk, and if the husbandman can tend it without excessive personal risk (e.g., when the standard intensity is about 50 r/hr at one hour), the milk from the herd will not produce an iodine-131 dose to the adult human thyroid great enough to preclude drinking the milk in an immediate emergency situation. The smaller weight of the infant thyroid (e.g., 2 kg as compared with 20 or 25 kg) results in an order of magnitude larger dose, and clearly indicates that young children should not use milk when the radioiodine concentrations in the milk are in the range of those calculated above.

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