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Agricultural Research Laboratory, AEC

University of Tennessee

Oak Ridge, Tenn.

VULNERABILITY OF FOOD CROP AND LIVESTOCK PRODUCTION TO FALLOUT RADIATION

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Prepared for:

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ABSTRACT

In this report, a review has been made of the effects of radiation on food crops and livestock in order to properly evaluate the vulnerability of food production to fallout radiation. Food supplies and food production have always played important roles in recovery from major disasters. Much more information is needed on the radiation sensitivity at different stages of growth for the principal food crops to gamma and beta radiation. Direct retention of fallout data are needed for plants and animals along with gastrointestinal sensitivity data for grazing livestock. Cattle are one of our main food reserves valued at $16 billion and data are needed on interaction of radiation insults to these livestock which have little protection from fallout.

CONTENTS

TABLES

ILLUSTRATIONS

I. INTRODUCTION

Historically, food production and food supplies have played important roles in effective recovery following extensive disasters. Drought, flood, frost, hail, insect infestation, and disease are ever-present hazards to agricultural production throughout the world. The sustained high productivity of United States agriculture through good years and bad years is a tribute to the resourcefulness and management capabilities of our farm operators and agricultural technicians. The accumulated experience and a continuing flow of research information on ways of meeting these hazards protect us from drastic fluctuations in food supply. The potential hazards posed by radioactive fallout are unfamiliar to most and their implications for food production should be assessed.

In the event of a nuclear disaster, there is little research information available to help the livestock and crop producer cope with contamination of food supplies and to prevent a serious reduction in food production capacity. Some estimates are now available concerning the severity of contamination of food supplies by radioactive fallout, and the pathways of some fission products in the human food chain have been determined. Considerable data are also available on movement of fission products in soils and absorption into crop plants as well as the effects of gamma irradiation on seeds and animals. Conversely, the direct effects of radioactive fallout on the production of food crops and livestock have received little attention and these hazards were not even discussed in The Effects of Nuclear Weapons (Glasstone, 1962). Inadequate information has led to widely varying and possibly misleading estimates of damage. Agricultural defense boards need research information concerning fallout hazards in order to recommend management procedures to farmers that could minimize damage and restore productivity.

The objectives of this report are to briefly discuss the importance of food; to provide a brief review of radiation effects on major food crop and livestock production; and to indicate the type of research needed to evaluate properly the vulnerability of our food production to early postattack radioactive fallout.

II. FOOD

While most of the people in the world are involved in food production, many are suffering from the lack of food. In contrast, only 6 percent of the U.S. population produces an abundance of food for our use plus much for export. Our food production is accomplished through rapid and efficient application of research and technological developments. This efficient food production system depends heavily on the continued supply of land, water, labor, fuel, fertilizer, and equipment. It is only through efficient food production that most of our people are now available for nonagricultural industries. In times of emergency, we could not resort to primitive production methods because of lack of manpower and technology. Urban labor would be needed for many other skills for which they are much better prepared. There appears to be little promise from the use of exotic food production methods for meeting emergency needs.

It appears that there is a dangerous tendency among nonagricultural planners to anticipate that food deficits in underdeveloped nations, or in this nation in time of disaster, will be miraculously solved by some technical innovation. The 1967 Report of the President's Panel on the World Food Problem stated that although some nonconventional sources of food appear to offer great potential for the long-term, none of these can be expected to lessen the demand on the conventional sources during the next two decades. The implications for civil defense planning are clear. No radically different food supplies can be expected to be developed in time of disaster. The impact of any large scale reduction in food supply on national recovery and productivity can be measured in terms of present food crop and livestock consumption. Research efforts should be focused, initially at least, on the major food items in the United States diet, as listed in Table 1.

Food production and food supplies have always played key roles in recovery from disasters. For example, food energy influenced directly the factory productivity in Germany during World War II (Kraut and Muller, 1946), and livestock reserves have been a major factor in the survival of the populace in northern Europe during prolonged periods of acute food shortage (Hanunian, 1966). Another example is the positive influence of massive shipments of food (6 million tons of grain) to Japan immediately after World War II which contributed to the rapid recovery of that nation. The situation in Japan was severe because of a normal pattern of direct grain consumption by humans and the lack of livestock reserves. It has been estimated (Leonard, 1966) that 10 million Japanese would have starved during the winter of 1946 if prompt shipments of grain had not been provided.

Food energy is unequivocally of prime importance to national survival and productivity. The World War II studies of Keys (1946) on the conscientious objectors who volunteered for the starvation experiments at the University of Minnesota are classical examples of the importance of food to man. These young men, on a 1600 calorie diet, lost about 25 percent of their body weight in 6 months and also lost 80 percent of their capacity for strenuous labor and 20 percent of their capacity for light work. The impact of food deficiencies on behavior in these and other studies has been summarized by Brozek (1959). Drastic or abrupt changes in dietary intakes of survival types of diets has met with a high incidence of headaches and digestive disturbances in both sheltered and non-sheltered population samples. In a Georgia shelter study, 90 volunteers consumed only 800 of the 1000 calorie daily allowance of survival foods (Hollingsworth, 1966). These data demonstrate the importance of considering the vulnerability of food crop and livestock production so that we can not only maintain human life but also maintain a productive population.

In political and military diplomacy at the international level, the mere presence or absence of food reserves, primarily grain and livestock, has served as a major strategic deterrent to aggressive action.

III. LIVESTOCK

Livestock Productivity. Importance of animal agriculture has increased as we have increased our standard of living. The American farmer represents less than one percent of the world population, yet produces about 1/4 of the meat and over 1/3 of the fluid milk in the world. In addition, we annually import about 3 percent of our per capita consumption of over 200 lb of meat. We are known for our large numbers of livestock as shown in Table 2, but the total of these animal units is not as large as the number in either India or mainland China (Byerly, 1966). Even in countries of great population pressures, livestock are needed for work, for scavengers to consume by-products, for production of animal food products, and as a food reserve. The developing countries of the world with 60 percent of the livestock numbers produce less than 30 percent of the world's livestock products of meat, milk, and eggs. Inadequate nutrition along with animal diseases and pests are the major limitations to world animal productivity (The World Food Problem, 1967).

Grains and storable supplementary items have been considered as our main food reserves. However, the inclusion of livestock products provides a diet which is better balanced in the required nutrients. Data in Table 2 show the importance of considering livestock as a significant food reserve worth about 19 billion dollars in January 1967. Most of this reserve is in cattle (16 billion dollars) which has little protection from radioactive fallout and has a slow rebuilding rate as shown in Figure 1. In contrast, swine and poultry numbers can be quickly replenished, but they require a more expensive diet of grain and protein supplements than cattle and sheep and compete more directly with humans for grain. Some of the feed energy for cattle comes from grain and in the event of grain shortages, the ruminants (cattle and sheep) can be fed roughages, grain by-products and synthetic protein substitutes such as urea, which are not in competition with man. Feed consumption by United States livestock is listed in Table 3 to show the larger quantities of roughages consumed by cattle (Bell, 1966a). Since about 40 percent of our agricultural land is not now suited for other than forage-crop production, the importance of considering the vulnerability of this production input is evident. In the eastern and western coastal areas, the local production of livestock requires shipment of most of the feed into the area. Without this feed, drastic alterations in feeding practices and/or the rapid reduction in livestock number would be required.

Livestock are good protectors against undesirable contaminants in our diet by screening or discriminating against many forms of pollution. In considering the incorporation of radioactive fallout into the food chain to man, most of these fission products are not absorbed by livestock, and meat contains very little of the ingested fallout radioactivity.

Forage Production. Pasture forages include a wide variety of improved and native grasses which may be injured or killed by early fallout. Many of these are grazed the year round with supplemental feeding to the livestock only during the winter months. Woodwell (1967) reports that radiation levels which reduced the number of wild plant species by 50 percent had no effect on the dry-matter yield of the area. In general, pasture and hay crops appear to be less sensitive than grain crops. Pasture forages and cereal grains killed by early fallout might still be used for grazing after some decay of radioactivity. Also, cereal grains irradiated at levels to prevent grain formation might still be used as forage for cattle and sheep.

The possibility of creating a "dust bowl" after killing of forages and crops by early fallout needs to be considered but may not be very likely, since there is such a wide variation in plant resistance to radiation. Also the rapid reestablishment of ground cover from seed and underground parts would be expected.

Damage Estimates to Livestock. Gamma radiation has been considered as the major hazard to livestock due to effects on the hematopoietic system. Estimated $LD_{50/30}$ for mature food-producing animals of 550 R in 4 days (NAS-NRC, 1963) is probably satisfactory for gamma fallout calculations. These estimated values vary with dose rate, species, and radiation characteristics. Variations in $LD_{50/30}$ for gamma exposure among animal species are small, with the exception of poultry which is estimated to have an $LD_{50/30}$ of around 900 R. Individual variations within species are rather great and some animals build up radiation resistance.

Gastrointestinal injury and retention of fallout on plants and animals appear to be the major areas lacking in valid information which can be applied to livestock, forage, and food crops under a variety of conditions. The data presented by Rhoads (1967) on plants, and Engel (1967) on animals, along with the information on the Alamogordo cattle (Brown et al., 1966), demonstrate that the direct surface damage from fallout is real and that this damage cannot be attributed to gamma irradiation. Also the data presented by Miller (1966) on the retention of volcanic ash with particle size comparable to that of early fallout and the data of Ward and Johnson (1966) on world-wide fallout show that plant contamination is of considerable significance. Under heavy fallout conditions, grazing animals could ingest large quantities of early fallout which might be lethal. Although meaningful field studies will be difficult to perform, they are clearly needed for realistic damage estimates. Much of the laboratory results is not directly applicable to field conditions of food crops and livestock production. The limited field results using aerosols of iodine (Barth and Seal, 1966; Bunch, 1966) and the distribution of glass or fused particles (Menzel and James, 1961) on forages provide us with some useful information in this area.

It is difficult to understand the continued neglect of the investigation of fallout retention on plants and animals in view of discrepancies in the available data and the lack of evidence on any measured detrimental gamma effects under these field conditions. It is true that more information on gamma effects is needed and it is also true that gamma-irradiation studies are "cleaner" and much easier to perform and interpret than beta studies which must involve plant retention.

Data on the estimates of gastrointestinal damage due to ingested radioactivity are very limited. In NAS-NRC (1963) an assumption is made of one percent retention of fallout on plants with the gastrointestinal injury being less than the whole-body gamma effects. At an assumed 20 percent retention, which is conservative by some more recent studies (Miller, 1966), the gastrointestinal insult would probably be of major importance if data on sheep (Bell, 1966b) and goats (Nold et al., 1960) are applicable to cattle. Reliable dosimetry of radiation from sources of mixed beta and gamma emitters to the gastrointestinal tract is difficult due not only to the variable anatomical and physiological factors but also to the variable mass and water content of the ingesta. It has been predicted that the major gastrointestinal damage from mixed fission products will be limited to the large intestine of both single stomach animals and ruminants (NAS-NRC, 1963). However, sheep fed levels of ^{144}Ce-^{144}Pr, which were lethal to about 25 percent of the animals showed gross lesions primarily in the omasum and a few lesions in the rumen (Bell, 1966b).

No experimental data were found on effects of feeding cattle fission products at levels high enough to produce gross damage to the gastrointestinal tract. Data on ruminants reported in NAS-NRC (1963) were obtained by feeding tracer levels of ^{90}Y to goats. Data on gastrointestinal dosimetry in dogs and laboratory animals are probably not applicable to grazing livestock. Variables to consider in ingestion studies include direct retention of fallout by pasture forages; dust blown on to the forages (Ward and Johnson, 1966), rain splash, and level of grazing. Ruminants under ideal grazing conditions consume soil at the rate of one percent of dry-matter intake while in overgrazed pastures, soil ingestion may amount to 14 percent of the dry-matter intake (Field, 1964; Healy and Ludwig, 1965). Swine and poultry, depending mostly on supplemental grains, would ingest much smaller amounts of contaminated soil.

Fallout retention by pasture forage would be expected to be similar to retention by grain crops except that the more productive, improved types of permanent pastures would provide a more dense ground cover and might retain most of the radioactive fallout. Foliar retention of volcanic ash by plants has been investigated under a variety of conditions by Miller (1966) and similar data are needed for forage crop conditions in the United States.

Although the skin injury of the Alamogordo cattle was of little consequence to the productive life of the cattle exposed to the early fallout from the first atomic bomb explosion, it was the only positive damage to these cattle (Brown et al., 1966). Most of these animals were sacrificed because of anaplasmosis infection and the scar tissue from the beta injury were probably more susceptible to insect carriers of the infectious anaplasmosis. Estimates of radiation dose were 37,000 rads to the skin surface from the beta activity and 150 rads to the whole body from gamma activity (Brown et al., 1966). This beta to gamma ratio is much greater than the estimates for early fallout reported in Figure 2 (Brown, 1965). Information has been found in only one preliminary report on the effects of exposing cattle skin to beta radiation. Much more data are available on swine and small animals.

Limited information shows that some of the animals dying of whole-body irradiation develop bacteremia. The salvage of these animals for human food has not been recommended even though cooking would probably be sufficient to provide a wholesome and safe food. Normal meat inspection regulations prohibit the use of meat from animals with elevated temperature characteristic of lethal radiation exposures.

IV. FOOD CROPS

The food requirements of America are met by a tremendously diverse production pattern of many crops under widely varying cultural conditions. Fruits, vegetables, cereals, and many other crops are combined with livestock products to supply nutritional requirements for energy, protein, minerals, and vitamins. The major sources of energy and protein, and per capita consumption of these major food groups are shown in Table 1. Direct consumption of crop products accounts for 60 percent of the energy and 32 percent of the protein in the United States diet. Animal production is in turn dependent on forage and feed crop production. Production data for the nine principal food croops in the United States are shown in Table 4. The first six of these represent 3/4 of the caloric intake of the people either directly or after conversion into meat, dairy, and poultry products. The seasonal fluctuation of stocks of grain and protein supplies in the United States in relation to emergency needs has been summarized by Shinn (1967).

The evaluation of the possible hazard of fallout radiation through direct injury to growing crops is a complex problem. Plants are especially vulnerable to the beta component of fallout radiation from ground contamination and particle retention by leaves and other plant parts. Beta to gamma dose ratios vary with depth of tissue and air distance from the particles as shown in Figure 2. This figure was prepared from calculations supplied by S. L. Brown of Stanford Research Institute for the contributions of 153 beta emitters present in early fallout (private communication). (See also Brown, 1965). Beta to gamma dose ratios range from four for meristematic tissues protected by 2 mm of surrounding tissue and one meter from a contaminated surface to over sixty at leaf surfaces or for exposed pollen grains. Experimental data are badly needed in this area.

The wide range in radiation sensitivity among plant species and the relatively high resistance of dry seeds has led to a general underestimation of the threat of radiation injury to crops. Reasons for concern may be illustrated by the example of the cereal grains which occupy a key role in food supplies. Radiation effects on wheat yields may vary by a factor of 6 due to varietal differences (Donini et al., 1964). Wheat plants may be killed by doses of 4000 rads and pronounced changes in development occur at much lower doses. Grain yield was reduced to less than 50 percent by 1000 rads at the seedling stage with no effects when irradiated at the bloom stage (Davies and Russell, 1966). Grain production of barley was reduced to 16 percent of that of the control by exposure to only 600 rads. Effects on seed yield are highly dependent on the growth stage at irradiation. Straw production may be increased by doses that prevent grain formation (Yamashita, 1964).

Effects of high levels of ionizing radiation on the hematopoietic systems of animals and man are dramatic. Radiation effects on plants are more subtle, although potentially just as serious in their effect on food supply.

Plants receiving killing doses of radiation may not show any gross effects for 2 to 3 weeks after exposure. For example, plants will remain erect and green. Many of the physiological processes, such as photosynthesis, amino acid and protein synthesis, proceed at the same or even more rapid rates than before. Thus, limited growth may continue and some plants may actually flower. However, the processes of cell division and development of new tissue are disrupted. New growth is seriously reduced and the normal developmental pattern of the plant is interrupted. At superlethal doses, plants will show premature signs of aging and leaves will wilt and drop off. Although plants receiving sublethal doses appear healthy, they may be dwarfed, remain vegetative, and grain or fruit may fail to form. At even lower doses, plants will react to the stress of radiation in much the same ways that they would react to unfavorable temperature or moisture conditions. At these levels, radiation exposure of plants presents an added insult from the environment which by interaction with stresses of nutrient deficiency, lack of moisture, temperature extremes, disease or insect infestation, may tip the balance with disastrous effects on final yields.

Radiobotanists have found a very wide range in radiation sensitivity among plant species. In a natural plant community, some species disappear at radiation exposures under which other species continue apparently unaffected. Ecological studies indicate that plants which have adapted to harsh environmental conditions are more resistant to radiation injury (Woodwell, 1967). Predicted lethal radiation doses for selected vegetables and field crops are shown in Table 5 (Sparrow, 1963). These predicted levels are for acute dose rates as may be expected in a fallout field. The concept of lethal dose can be misleading. The situation is well described by Sparrow:

> ". . . There are differences in tolerance associated with different seasons or different stages in the growth of a particular species or crop. For instance, one cannot generally merely state an overall tolerance for a species. It is necessary to specify whether the seeds, seedlings, young or mature plants, pollen, embryos, etc., were irradiated. . . . For each of the above stages irradiated a different dose may be required to produce a lethal or severe effect or, economically speaking, to destroy the crop. There are too few radiobiological data to be able to know exactly what would happen to most crops after a specified kind and amount of radiation exposure. In other words, if an agricultural economist were asked to predict what would happen in a farming area in the event of an expected level of fallout radiation, he would have great difficulty because the necessary radiobiological data do not exist for most crops or other plants of economic value."

Wide variations in radiosensitivity of cultivated crops are related to their genetic background. For example, radiation sensitivity varied six-fold among 180 varieties of soybeans and also among 200 varieties of barley (Yamashita, 1964). Examination of the geographical distribution showed that the more resistant varieties came from regions with less favorable growing conditions.

Dose-rate effects and stage of development at time of irradiation also contribute to large variations in sensitivity. The lethal dose with a barley test variety varied from 4000 to 1000 rads at dose rates from 63 rads/day to 1000 rads/day. The dose required to reduce grain yield 50 percent varied from 300 to 1200 rads, depending on growth stage. Chronic doses of 30 rads/day reduced grain yield by 50 percent. Although soybeans are among the more resistant crop species, 4000 to 5000 rads reduced vegetative growth by 50 percent and 1000 to 2000 rads reduced seed pods to 50 percent (Yamashita, 1964).

The limited information available indicates that extreme caution should be exercised in applying predictions of lethal doses such as those shown in Table 5 to predictions of crop losses from radiation exposures.

V. LIVESTOCK RESEARCH NEEDS

A. Evaluation of Radiation Effects.

1. Gastrointestinal Exposure to Beta or to Mixed Beta and Gamma Activity. The real test of the effect of early fallout on the animal's gastrointestinal tract lies in a "dirtytest" of feeding livestock high levels of radioactivity to simulate early fallout. Limited data are available on the effect of feeding levels of ^{144}Ce-^{144}Pr which were lethal to about 1/4 of the sheep, but no data have been found for cattle. Refinement of the data are needed for sheep; then similar tests using appropriate radioisotopes should be carried out with cattle to determine both the LD_{50} and LD_{100} levels. In these exposures, consideration should be given to simulated early fallout arrival

and ingestion times to compare with actual grazing conditions. These considerations should include length, rate, and source of exposure as well as feed and water intake of the animals. The establishment of levels lethal to cattle is of prime importance rather than trying to simulate all possible conditions. Emphasis should be on beef cattle because of relative economic importance and because of much greater exposure than dairy cows. It is doubtful if similar work is needed in swine or other single stomach animals which consume a small amount of their diet as pasture forages.

2. Skin Beta Exposure. Information is needed on levels of radioactivity necessary to produce various changes in skin and hair of cattle, since skin damage is the only documented injury to the Alamogordo cattle exposed in 1945 and no record was found of any deaths attributed to gamma irradiation. In these high level exposures of cattle, consideration should be given to breed, hair coat, age, condition, moisture, season, and particle size. Major emphasis should be placed on cattle since information is already available on swine, sheep, and laboratory animals. Long-term effects are also of interest since these exposed animals would probably be more susceptible to insect pests and adverse weather conditions. Decontamination procedures should be evaluated in terms of the personnel exposure risk.

3. Interaction of Gastrointestinal (Beta or Mixed Beta and Gamma), Skin Beta, and Whole-Body Gamma Effects. The interaction of radiation insults needs to be investigated since under heavy

fallout conditions grazing livestock would be simultaneously exposed to internal and external irradiation. Skin and the gastrointestinal tract would be the tissues exposed to the highest levels of beta activity. There are some indications that the combined effects may reduce the productive lifespan of surviving livestock. These survivors could still be used for meat, as unproductive culls are currently used for human food.

4. Dose-Rate Gamma. The importance of dose rate to vulnerability of livestock productivity is well worth considering since fallout arrival times combined with decay may vary the dose rate by several orders of magnitude. It is suggested that research in this area be delayed until after the "Mammalian Dose Rate" Symposium at UT-AEC in April 1968. This select group of speakers should give us information to place the dose-rate effects into the proper perspective for evaluation of further livestock research needs.

B. Evaluation of Potential Radiation Hazard. The exposure of the gastrointestinal tract and skin of grazing animals should be investigated using tracer techniques under field conditions. Data are needed on fallout retention on forage crops and cattle under a variety of the predominant grazing conditions in the United States. Retention of fallout on forage needs consideration of variables such as species, ground cover, stage and rate of growth, indirect contamination, season, moisture and humidity. The early experiments must be limited to the predominant grazing areas of the United States and should be on the major plant and animal species in these areas.

This would probably best be determined using simulated fallout tagged with an appropriate tracer in order to estimate the beta damage to the gastrointestinal tract. The labeling of the particles should be at the tracer level using either a short-lived gamma-emitting radioisotope (less than 15 days half-life) or a conveniently identifiable marker.

This same procedure could be used to measure the retention of simulated fallout on the backs of cattle, swine, and sheep. Variables such as species, hair coat, age, condition, moisture, season, and particle size should be considered for cattle exposure. From these data, dose estimates in relation to whole-body gamma irradiation could be calculated and compared with data published for dogs and goats. These data in combination with lethal-level data from gamma and gastrointestinal irradiation insults are needed before vulnerability data are meaningful.

Data are also needed on soil ingestion by cattle under several grazing conditions to determine an estimate of possible significance to this route of contamination. It matters little in the end result on grazing animals whether the fallout is direct on the forage or first on the soil and then to the plant tissue by either rain splash or blown as dust.

C. Salvage and Disposal. There are no clear-cut answers on salvage of irradiated animals for food. Elevated temperature and instances of bacteremia have been indicative of unsafe food. Tests are needed on safety of meat and other livestock products under these conditions, and this could be accomplished in conjunction with other lethal irradiation studies such as irradiation levels to incapacitate livestock within 48 hours. Disposal procedures for feedlot concentrations of unsalvagable dead animals should be considered as a possible public health hazard.

The triage approach in handling irradiated livestock would be recommended along with the continued search for better biological indicators. Slaughter of livestock may need to be considered due to the lack of feed and water and other stresses which may complicate the irradiation effects.

D. Countermeasures. Although there are few countermeasures that appear practical for the majority of our cattle, there is a need for identification and evaluation of measures to reduce the vulnerability of livestock. Surveys of present shelter possibilities to be completed along with livestock surveys are needed. A calculation of protection factors for available cover is needed for prediction of effects of various attack patterns. Feeding of uncontaminated feeds is an excellent countermeasure for many livestock producers, but is of little value for livestock on range pastures.

Decontamination of live animals to reduce skin or gastrointestinal injury should be evaluated in terms of personnel hazards. Decontamination of livestock prior to slaughter is recommended and these procedures are described in the 1963 USDA Radiological Monitoring Handbook which is currently being revised.

Decontamination of pastures and damaged small grains is indicated as a means of reducing retention of fallout on plants. Methods should be considered in B. above.

E. Recovery. A study is indicated to determine priorities in enabling the livestock industry to function in continuous production of food for man. This encompasses livestock, feed, processing, and transportation.

1. We must consider those animals to be used for food, those to be used for breeding herds, and the time involved to repopulate animal herds to provide the consumer with a stable supply of animal products.

2. Consideration should be given to the feed that might be stockpiled in the area where it would be used; feed that was in the process of production; and the production of feed for future use. Human competition for feed grains would have to be considered but the nature of this factor would depend on the extent of the attack, the season of the year, the area of the country and getting the feed to the consumer whether it be man or animal. Fortunately, many of our livestock can be fed forages and by-products which are not in competition with man.

3. Recovery time and the use of auxiliary power supplies would be a major factor in the recovery of commercial processing. There is need for some guide lines to be established in regard to the nature and extent of salvaging livestock. There is a need for additional information on the processing of livestock and livestock products to reduce the radiation hazard. This information should be available on the local level for the county defense boards.

4. The transportation system and its recovery is critical to the recovery of the livestock industry and the distribution of livestock products. A study of this factor should be related to the ideas of bottlenecks in our present system and ways that these might be overcome.

VI. FOOD CROP RESEARCH NEEDS

This review of available information indicates an urgent need for research investigation in the following areas: A. Radiation effects on crop production, B. Fallout retention by food and forage crops, and C. Radiation properties of fallout fields with particular emphasis on beta attenuation. Continued efforts to evaluate pertinent information in the disciplines of agronomy, atmospheric sciences, radiobotany, and radiation physics will be necessary to guide development of research programs and interpretation of experimental results as they become available. General recommendations of research needs and procedures are as follows:

A. Radiation Effects on Crop Production. Radiobotanists and agronomists agree that there is a lack of adequate criteria to predict crop yield losses from radiation exposures. The most pressing need to fill this gap is for field studies of radiation effects in representative production areas for the major food crops. Such "benchmark" studies would serve for predictive purposes and as guidelines for future research investigations. Portable gamma sources designed for irradiation of experimental field plots will be essential for these studies. Wherever possible these gamma exposure studies should be combined with beta radiation exposures using simulated fallout materials. Cylindrical and plane sources of beta radiation could also be used to simulate hazards from contaminated surfaces. The special hazards to research personnel from high activity beta particles could be minimized by shielding and the use of very short-life isotopes.

Field studies should include irradiation of selected commercial varieties at several growth stages. Because of the wide range in sensitivity with differing stages of growth and rates of cell division, these studies should be supported by detailed measurements of crop morphology and environmental conditions.

Supporting greenhouse and controlled environment growth chamber studies at existing facilities will be needed for detailed investigation of radiation effects over a wide range of growth stages and environmental conditions. Dose-rate studies and determination of the effects of various fallout-type exposure patterns will be necessary for development of sound experimental procedures in field studies.

It is recommended that every effort be made to initiate a program of field radiation studies on wheat and corn or soybeans during the 1968 growing season. These studies should then be expanded to other major crops in succeeding years, taking advantage of experience gained in initial studies. The limiting factor in the development of these studies will be the design and fabrication of a suitable portable gamma source capable of delivering dose rates of approximately 100 rads/hr to experimental plots of 24 to 36 sq ft in area.

B. Fallout Retention by Crops. There is a two-fold need for additional foliar retention studies. More data on initial retention and rates of weathering on forage crops are required to determine the consequences for grazing animals, as discussed under livestock research needs. In addition, the distribution of fallout in a crop canopy needs to be established to evaluate the hazards of beta radiation to sensitive plant parts. The effects of particle size and climatic conditions are the principal variables needing investigation. These should be studied for a number of forage crop species as well as the major food crops. A number of techniques for measuring retention show promise in this area including radioactive tracers, chemical tracers, or fluorescent labeling. The capabilities of the Stanford Research Institute group to prepare fallout simulant as well as the experience gained in the volcanic ash studies will be valuable in the development of these investigations.

C. Physical Properties of Fallout Fields. Theoretical and experimental studies of beta attenuation under the varied conditions of fallout distribution in a crop canopy are urgently needed for realistic estimates of the beta hazard to growing crops. Improved techniques of beta dosimetry are needed in the study of radiation effects for both plants and animals.

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REFERENCES

1. Barth, D. S., and M. S. Seal. 1966. Radioiodine transport through the ecosystem, air-forage-cow-milk, using a synthetic dry aerosol. In Radioecological Concentration Processes. Pergamon Press. p. 151-157.

2. Bell, M. C. 1966a. Biomedical aspects of civil defense--U. S. food supplies--livestock. In ORNL TM-1531, Part 1. p. 21.

3. Bell, M. C. 1966b. Airborne radionuclides and animals. Proc. AAAS Symposium on Agriculture and the Quality of Our Environment, Washington, D. C., December 26-31, 1966. 20 p. (In press).

4. Brown, D. G., R. A. Reynolds and D. F. Johnson. 1966. Late effects in cattle exposed to radioactive fallout. Am. J. Vet. Res. 27: 1509-1514.

5. Brown, S. L. 1965. Disintegration rate multipliers in beta-emitter dose calculations. SRI Project MU-5116. Menlo Park, Calif. Fig. 1, p. 6.

6. Brozek, J. 1959. Experimental behavioral studies on the impact of deficient diet on behavior. Borden's Rev. of Nutr. Res. 20(6).

7. Bunch, D. F. 1966. Controlled environmental radioiodine tests. Progress Report No. 2, IDO-12053, USAEC.

8. Byerly, T. C. 1966. The role of livestock in food production. J. Animal Sci. 25: 552-566.

9. Davies, C. R., and R. S. Russell. 1966. Effects of radiation on plants. ARC Radiobiological Lab., Letcombe Regis, Wantage, Berkshire. (Unpublished report).

10. Donini, B., G. T. S. Mugnozza and F. D'Amato. 1964. Effects of chronic gamma irradiation in durum and bread wheats. Rad. Bot. 4: 387-393.

11. Engel, R. E. 1967. Observations of radiation damage in large animals. Work-Study Conference on Vulnerability of Food Crop and Livestock Production to Fallout Radiation. Estes Park, Colo., June 19-20. (Unpublished data).

12. Field, A. C. 1964. The intake of soil by the grazing sheep. Proc. Nutr. Soc. 23: xxiv.

13. Glasstone, S. 1962. The Effects of Nuclear Weapons. USAEC, Govt. Printing Office, Washington, D. C. 730 p.

14. Hanunian, N. 1966. Dimension of survival: postattack survival disparities and national viability. Rand Memorandum RM-5140-TAB. 214 p.

15. Healy, W. B., and T. G. Ludwig. 1965. Ingestion of soil by sheep in New Zealand in relation to wear of teeth. Nature 208: 806-807.

16. Hollingsworth, D. F. 1966. Nutritional principles relating to food defense problems. Food Defense Study Group, Canada, Sept. 8-13, 1966. (Unpublished data).

17. Keys, A. 1946. Human starvation and its consequences. J. Am. Dietetic Assoc. 22: 582-587.

18. Kraut, H. A., and E. A. Muller. 1946. Calorie intake and industrial output. Science 104: 495-497.

19. Leonard, W. H. 1966. Population in relation to food supply. Colo. State Univ., Mimeo. 8 p.

20. Menzel, R. G., and P. E. James. 1961. Removal of radioactive fallout from farmload. Agr. Engin. 42: 606-607.

21. Miller, C. F. 1966. The contamination behavior of fallout-like particles ejected by volcano Irazu. Stanford Res. Inst. Rept. MU-5779. 62 p.

22. NAS-NRC. 1963. Damage to livestock from radioactive fallout in event of nuclear war. Natl. Acad. Sci.-Natl. Res. Council Publ. 1078. Washington, D. C. 93 p.

23. Nold, M. M., R. L. Hayes, and C. L. Comar. 1960. Internal radiation dose measurements in live experimental animals. Health Physics 4: 86-100.

24. President's Science Advisory Committee. The World Food Problem. Vol. 1, May 1967. The White House.

25. Rhoads, W. A. 1967. Radiation damage to plants at the Nevada Test Site. Work-Study Conference on Vulnerability of Food Crop and Livestock Production to Fallout Radiation. Estes Park, Colo., June 19-20. (Unpublished data).

26. Shinn, A. F. 1967. Grain stocks and protein supplies. ORNL Civil Defense Rept. 18 p. (In press).

27. Sparrow, A. H. 1963. The tolerance of plants to ionizing radiation: variations, modifications and predictions. BNL 7435, Upton, N. Y. 42 p.

28. Sparrow, A. H. 1965. Comparisons of the tolerances of higher plant species to acute and chronic exposures of ionizing radiation. Japan. J. Genetics 40: 12-37.

29. Sparrow, A. H., R. C. Sparrow, K. H. Thompson and L. A. Schairer. 1965. The use of nuclear and chromosomal variables in determining and predicting radiosensitivities. Rad. Bot. 5: 101-132.

30. U. S. Dept. of Agr. 1963. Radiological Monitoring Handbook. ARS-USDA Agricultural Handbook 246.

31. U. S. Dept. of Agr. 1966. Agricultural statistics. U. S. Govt. Printing Office, Washington, D. C.

32. Ward, G. M., and J. E. Johnson. 1966. A study of cesium-137 passage from precipitation to milk. Fourth Annual AEC Project Report. Colo. State Univ., Fort Collins, Colo. 59 p.

33. Woodwell, G. M. 1967. Radiation and the patterns of nature. Science 156: 461-470.

34. Yamakawa, K., and A. H. Sparrow. 1965. Correlation of interphase chromosome volume and reduction of viable seed set by chronic irradiation of 21 cultivated plants during reproductive stages. Rad. Bot. 5: 557-566.

35. Yamashita, A. 1964. Some aspects of radiosensitivity of crop plants under chronic exposure. In Gamma Field Symposia No. 3, "Mutations in Quantitative Traits". Institute of Radiation Breeding, M.A.F., Ibaraki-ken, Japan. p. 91-110.

TABLE 1. U. S. Consumption of Major Foods and Nutrients Supplied in 1965*

Item	Pounds per capita	Percentage supplied Energy	Protein	Calcium
Meat and Fish**	203	19.2	38.6	3.3
Eggs	39	2.2	5.8	2.4
Dairy products	364	12.6	23.8	76.7
Fats and oils	51	16.4	.1	.4
Citrus and other fruits	158	3.3	1.1	2.0
Potatoes and sweet potato	101	2.8	2.4	.9
Vegetables	196	2.6	3.6	6.3
Dry beans and peas, nuts, soya flour	16	2.9	5.1	2.6
Flour and cereal	145	20.9	19.0	3.3
Sugars, sweeteners	112	16.3	---	1.0
Coffee, cocoa	15	.8	.5	1.1
Total animal products	629	40.5	68.2	82.6
Total crop products	787	59.5	31.8	17.4

* U.S. Department of Agriculture. Agricultural Statistics 1966. U.S. Govt. Printing Office, Washington, D. C. pp. 581, 583.

** Retail equivalent pounds: Beef 88; pork 52; poultry 41; fish 14; veal 5; and lamb and mutton 3.

TABLE 2. U.S. Livestock Statistical Data*

Species	Number in millions	Total value $ billions	Usual market weight lbs.	Usual market age months	Annual No. offspring per female	Reproduc. age months
Cattle	108	16.2	950	18	0.8	24
Swine	51	1.7	200	6	14.0	12
Sheep	24	0.5	90	9	1.2	12
Poultry	428	0.5	3.5	3	200.0	6

* Bell, M. C. 1967 ORNL Civil Defense Research Project Annual Report.

TABLE 3. Million Tons of Feed Consumed by Livestock in 1964*

Item	Dairy cattle	Beef cattle	Swine	Poultry
Roughage	64.4	119.0	2.4	0.7
Feed grain	25.7	25.0	46.7	25.0
Protein supplement	4.8	6.4	7.0	11.2

* Bell, 1966a.

TABLE 4. Production Data for Principal Food Crops in United States, 1965

Item	Harvested acreage million acres	Yield bu/acre	Production million bu.	Production million tons
Wheat				
Winter	37.5	27.3	1,025	30.8
Spring	11.5	26.3	302	9.1
Total	49.0	27.0	1,327	39.9
Corn				
Grain	57.0	73.0	4,171	116.8
Silage	7.9	--	--	--
Oats	19.1	50.2	959	15.3
Barley	9.5	43.5	412	9.9
Sorghum				
Grain	13.3	50.0	666	18.6
Silage	2.3	--	--	--
Forage	1.2	--	--	--
Soybeans	34.5	24.4	844	25.3
Potatoes	1.4	--	--	14.4
Sugarbeets	1.3	--	--	20.9
Sugarcane	0.6	--	--	23.0

TABLE 5. Predicted Acute Exposures Required to Produce a Slight Effect on Vegetative Growth and Lethality for 13 Vegetable Crops and 12 Field Crops (Sparrow et al., 1965).

Common name	Est. interphase chromosome vol. (μ^3 ± S.E.)	Slight effect* (rads)	Lethal (rads)
Vegetable Crops			
Onion	39.3 ± 2.3	380	1,500
Broadbean	32.0 ± 1.6	460	1,800
Corn	14.0 ± 0.6	1,060	4,200
Peas	12.8 ± 0.7	1,200	4,600
Lettuce	8.2 ± 0.4	1,800	7,100
Asparagus	6.8 ± 0.2	2,200	8,600
Cabbage	4.8 ± 0.2	3,100	12,300
Tomato	4.7 ± 0.2	3,140	12,400
Radish	4.7 ± 0.2	3,200	12,600
Potato	4.6 ± 0.3	3,200	12,600
Winter squash	4.4 ± 0.2	3,400	13,500
Swiss chard	3.9 ± 0.2	3,700	14,800
Okra	1.6 ± 0.1	9,200	36,500
Field Crops			
Broadbean	32.0 ± 1.6	460	1,800
Oats	15.3 ± 0.7	960	3,800
Wheat	14.6 ± 1.1	1,000	4,000
Barley	13.5 ± 0.8	1,100	4,350
Sorghum	7.7 ± 0.3	1,900	7,600
Cotton	5.8 ± 0.3	2,600	10,100
Sugar beet	4.4 ± 0.2	3,400	13,400
Soybean	4.1 ± 0.2	3,600	14,200
Sweet potato	3.2 ± 0.2	4,700	18,600
Rice	3.0 ± 0.1	5,000	19,700
Flax	2.8 ± 0.1	5,200	20,700
Kidney bean	1.6 ± 0.1	9,100	36,100

* A slight vegetative effect was defined as a 15 percent reduction from controls. Seed yields are considerably more reduced.

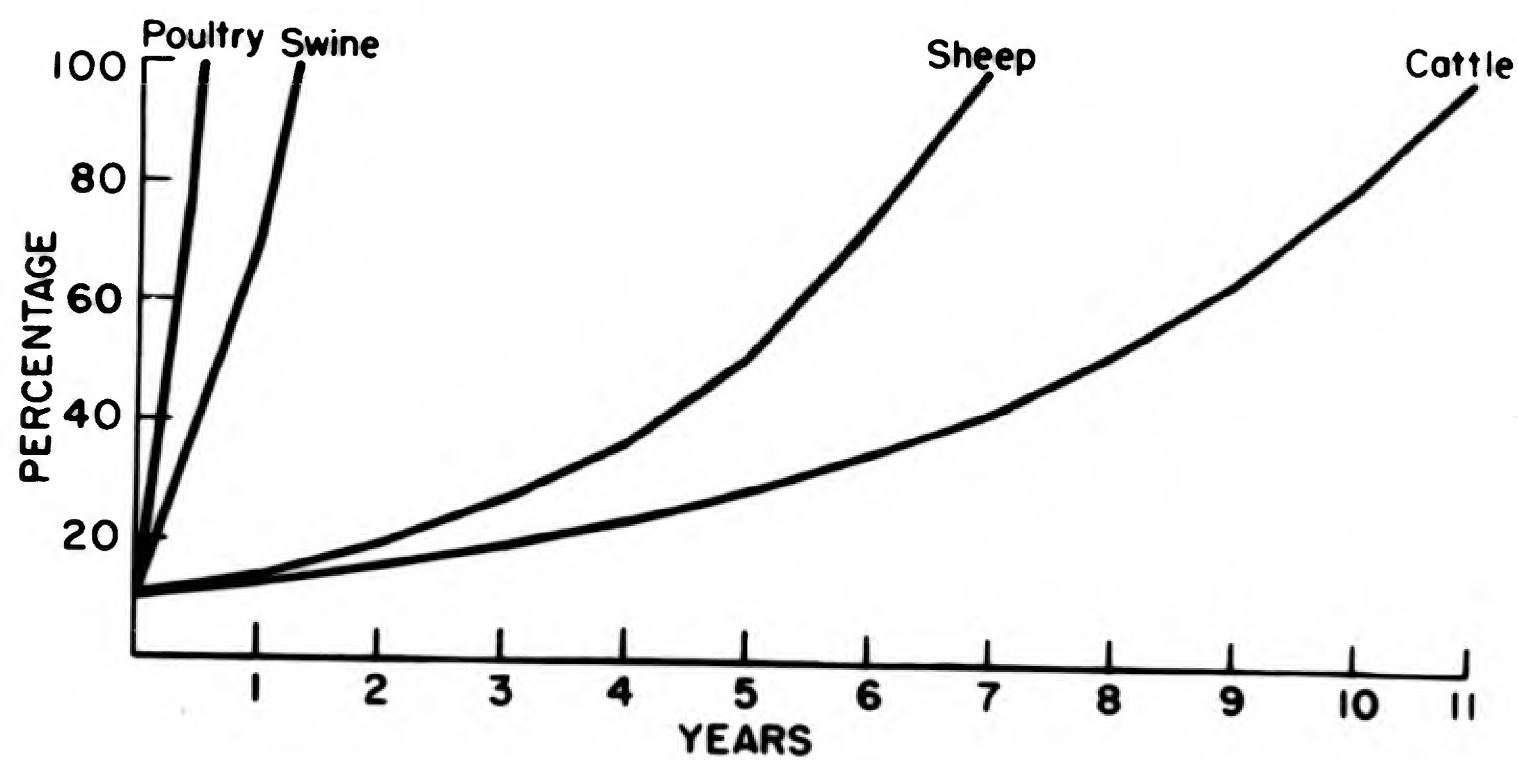

Figure 1. Years Required to Rebuild after 90% Loss of Female Breeding Stock.

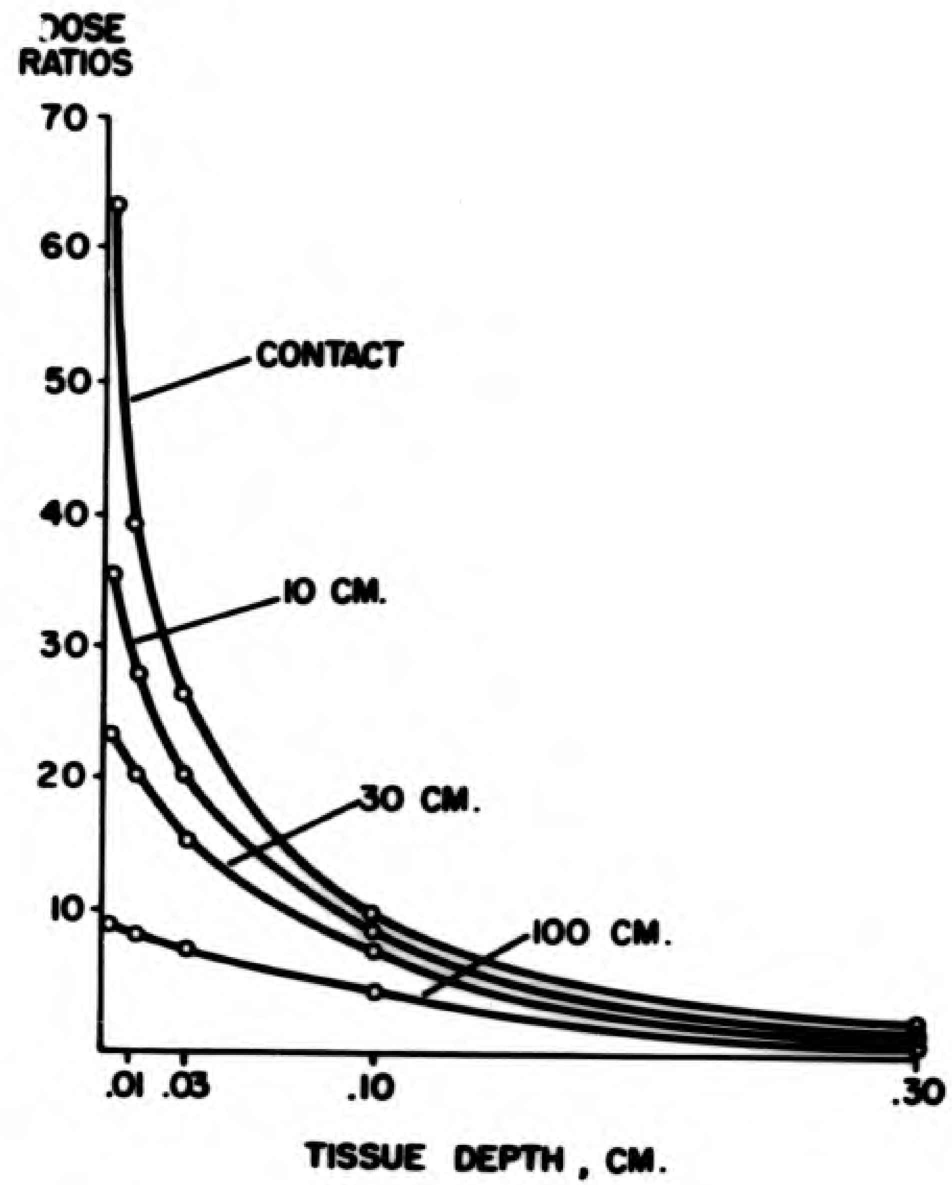

Figure 2. Beta/Gamma Dose Ratios.

Title: Vulnerability of Food Crop and Livestock Production to Fallout Radiation

Authors: M. C. Bell and C. V. Cole

SUMMARY

In this report, a review has been made of the effects of radiation on food crops and livestock in order to properly evaluate the vulnerability of food production to fallout radiation. Food supplies and food production have always played important roles in recovery from major disasters. In political and military diplomacy at the international level, the mere presence or absence of food reserves, primarily grain and livestock, has served as a major strategic deterrent to aggressive action. Much more information is needed on the radiation sensitivity at different stages of growth for the principal food crops to gamma and beta radiation. Direct retention of fallout data are needed for plants and animals along with gastrointestinal sensitivity data for grazing livestock. Cattle are one of our main food reserves valued at $16 billion and data are needed on interaction of radiation insults to these livestock which have little protection from fallout. The interaction of radiation insults needs to be investigated since under heavy fallout conditions grazing livestock would be simultaneously exposed to internal and external irradiation which would be a combination of beta and gamma insults. Valid data are available on whole-body gamma irradiation of cattle, but no data were found on lethal gastrointestinal exposures.

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13. ABSTRACT

In this report, a review has been made of the effects of radiation on food crops and livestock in order to properly evaluate the vulnerability of food pr duction to fallout radiation. Food supplies and food production have always played important roles in recovery from major disasters. Much more information is needed on the radiation sensitivity at different stages of growth for the principal food crops to gamma and beta radiation. Direct retention of fallout data are needed for plants and animals along with gastrointestinal sensitivity data for grazing livestock. Cattle are one of our main food reserves valued at $16 billion and data are needed on interaction of radiation insults to these livestock which have little protection from fallout.

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