INTRODUCTION TO LONG-TERM BIOLOGICAL EFFECTS OF NUCLEAR WAR

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INTRODUCTION TO LONG-TERM BIOLOGICAL EFFECTS OF NUCLEAR WAR

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Background

A rigorous assessment of the biological and ecological effects of a nuclear war would require more knowledge about the world than is now available. Yet, once it is conceded that certain basic information about nuclear weapon explosion phenomena, about the interaction between the explosion phenomena and units of the biota, and about biological systems is known, then it can be argued that this available information may be outlined and assessed with respect to at least the major effects of nuclear detonations on biological systems. Thus the purpose of the following discussion is to outline some of the major biological and ecological problems that could arise in a nuclear war, to summarize briefly some of the information (or lack of information) that has been found and reported regarding these problems, and to outline views and methods of treating these problems. In this presentation, only a minor fraction of the available and potentially useful data are included for illustrating relevant facts and concepts relating to the problem under discussion.

To focus the discussion on major effects and problems, some general definitions are made. Under the subject of biological effects, the major concern is on the direct effects of exposure to ionizing radiation of temporal units of the biota; the latter include cells, tissues, organs, organ systems, and organisms. Effects of thermal radiation and fire are not considered in this presentation; and blast effects are not considered as part of the longer term postattack biological effects. Under the subject of ecological effects, the major concern is on the secondary effects to functional units of the biosphere; the latter include populations, communities, and ecosystems. The secondary effects, in contrast to direct effects, are disturbances and damage that may be caused by the direct effects of explosion phenomena, but occur at a later time. Actually, the functional units of the biosphere would be disturbed by the direct effects of a nuclear attack but these disturbances generally would be considered a sum of the effects on the temporal units; for clarification, the ecological problems are separated from direct effect problems.

The characteristics of the biological functional units are closely associated with the climatic and other environmental features of the part of the earth at which the units exist. Thus the distribution of life over the earth attains familiar patterns in deserts, tundra, grasslands, and forests; areas in which human life predominates include farmlands and cities. Biological units in all these different areas over the earth usually have established integrated structure and function, a metabolism, and a capacity for repair of damage; units and areas that have well-integrated functional systems are called "ecosystems." Within the context of this study, three types of ecosystems are identified: (1) urban, (2) rural farmland, and (3) wild land. In this report, major emphasis is given to the rural farmland ecosystems.

In basic ecological studies (which are not the primary concern of this report), much consideration is given to the sources of energy on which ecosystems operate. The energy comes from two sources: (1) the sun and (2) fossil fuels. The concept of a capacity for repair of damage is always considered as a characteristic of any ecosystem. Those ecosystems that repair themselves using only solar energy are called homeostatic; these could include some wild land systems. The ecosystems that are maintained by man, using stored energy sources, are called nonhomeostatic; these include the rural farmlands and cities. However, since the advent of large-scale conservation programs, man has tended to increase his dominance over all the economically valuable ecosystems, including the wild land systems.

Pronounced opinions regarding the long-term ecological effects after a nuclear war range all the way from the pessimistic view that the direct damage of ecosystems would, in all cases, escalate toward the complete destruction of the systems, to the optimistic view that the inherent repair and recovery mechanisms available to ecosystems are sufficiently strong and would eventually prevail. The importance of biological and ecological damage from a nuclear war, in either case, centers on the premise that the recovery pattern of the industrial economy and the social institutions would be possible only if recovery of the biological economy is possible. Following this notion, the extreme positions with regard to biological recovery appear to be associated with divergent notions about the nature and degree of the direct damage to the various ecosystems as well as with divergent ideas about the repair and recovery mechanisms available to the various ecosystems (with and without influence of man).

Throughout history, ecosystems have been disturbed or damaged by fires, by floods, by predator invasion, and by many other means. Platt[1] reports a generalized view about the reaction of natural ecosystems to damage from past experience: "It is a well-established axiom in ecology that nature will reestablish disturbed or destroyed natural areas by its repair and recovery mechanisms. Equally well understood is that a great deal of time is required for these processes, the time being a function of the particular environment and the nature and severity of the disturbance." The degree of severity of disturbances in which repair and recovery of natural ecosystems have been effectively denied in past experience is usually associated with cases where the damage (or the effect causing the damage) is chronic or where the soil on which some of the ecosystem organisms grow is removed. Examples of these two cases are the Copperhill section of southeastern Tennessee where all the vegetation was destroyed because of the continuous release of sulfur dioxide fumes during copper smelting operations during the first part of this century (and the soil subsequently removed by erosion), and the Negev Desert where flourishing civilizations lived thousands of years ago when the climate and the topsoil supported vegetative growth.

Thus perhaps the major features of the long-term biological and ecological problems resulting from a nuclear war, with respect to severity of the disturbance and repair and recovery mechanisms, are (1) specification of the acute and chronic damage phenomena, (2) extent of the direct damage, (3) identification of repair and recovery mechanisms, (4) damage leading to floods and soil erosion, (5) loss of economically valuable resources, and (6) influence of man in ecosystem repair and recovery processes, including the establishment of both preattack preparations and postattack countermeasures.

In the following paragraphs, these six features are generally discussed in terms of the source of injury or damage (direct and secondary), the pattern of the damage and recovery phenomena, operational criteria (human), and general ecological considerations. The type of available information applicable to each with respect to the role of man, animals, plants, and insects is discussed.

Source of Radiological Injury or Damage

It is well known that, in a nuclear explosion, more than a hundred radioactive fission-product nuclides and many additional neutron-induced radionuclides are produced. This radioactive mixture initially consists of radionuclides with radioactivity decay half-life values that vary from a fraction of a second to many years. Most of these radionuclides emit both beta particles and gamma rays when they disintegrate, so that the presence of these two types of ionizing radiation in the environment would result in biological damage to living tissue. The presence of these radionuclides in an ecosystem thus would constitute a source of radiological hazard from fallout to ecosystem species. The major radiological hazard to man from fallout is known to be the external gamma radiation from deposited fallout; this fact requires special recognition in both damage assessment studies and in civil defense planning.

Fallout particles from land-surface detonations, as nuclear radiation sources, consist almost entirely of fused, sintered, and unchanged grains of soil minerals and other materials present at the point of detonation.[2] Also present in the fallout particles are inert materials from the weapon or warhead and radioactive elements from fission and neutron capture processes. Roughly, the relative amounts of soil minerals, bomb construction materials, and radioactive elements in fallout particles are, respectively, (1) 1 megaton of soil per megaton of total weapon yield; (2) the order of 1 ton of warhead materials per megaton of total weapon yield (but variable around this value); (3) about 0.06 ton (120 pounds) of fission products per megaton of fission yield (or 0.03 ton per megaton of total weapon yield which is 50 percent fission); and (4) about 0.05 to 0.1 ton of induced radioactive atoms per megaton of total yield (the yield of induced radioactive atoms would increase as the fraction of fission yield decreases).

Analyses of fallout particles from surface and near-surface detonations collected at weapons tests in both the Eniwetok Proving Ground and the Nevada Test Site show that the radioactive elements are either within the interior of fused and sintered particles or attached to the exterior layers of all three types of particles. It is known that larger fallout particles are not formed by the condensation of vaporized soil; rather, the larger fallout particles are individual or agglomerated particles that were formed from either single soil grains or a fused mass of liquid soil. These particles are drawn into the rising fireball and apparently serve as collectors for small vapor-condensed particles and as condensation centers for vaporized fission-product and radioactive neutron-induced atoms.

It is generally believed that the fallout formation process does not begin until the fireball temperature (or the temperature of the gaseous material) has decreased to about 3,000°K, because at higher temperatures all materials would tend to dissociate rather than condense. As the temperature decreases below about 3,000°K, vapor condensation processes should take place resulting in the initial formation of very small liquid particles. Such small particles are observed in worldwide fallout collections; they also have been observed as attached particles on unchanged coral grains in the fallout materials collected from weapons tests at the Eniwetok Proving Ground.

As the fireball rises and cools, and as the crater materials are drawn up into the fireball volume, the thermal action at the surfaces of entering (molten) particles should gradually change from a vaporization process to a condensation process in which the less volatile fission products condense onto and diffuse into the liquid phase of the particles. In addition, the larger molten soil particles, as they circulate through the fireball volume, would rapidly form agglomerates with a large fraction of the smaller (previously formed) vapor-condensed particles. Particles that enter the fireball volume at later times may be heated to sintering temperature or may be completely unaltered, thermally. When the temperature of the surface of the particles becomes lower, the rate of diffusion of the condensed radioactive atoms into the interiors of the particles should decrease so that the more volatile of the radioactive elements that can condense only at lower temperatures would collect, and be concentrated, on the exterior surface of the particles. Also, radioactive daughter atoms (even if not volatile) formed at later times from volatile parent nuclides (such as the rare gas elements) would be concentrated on the exteriors of the smaller particles. The degree of solubility and biological availability of Sr-89, Sr-90, and Cs-137 strongly support these views regarding the condensation process.

In general, two rather distinct periods of fallout formation by condensation processes have been postulated.[2] In the first period, the condensation of volatile radioelements is considered to occur by deposition onto and diffusion into large molten (soil) particles and by agglomeration with smaller particles. The radioelements thus condensed would become fused within the volumes of the molten particles when they cool and solidify. In the second period, the remaining volatile radioelements would then condense onto the surfaces of relatively cold solid particles (most of which are late-entering grains of soil).

Because of the differences in volatility among the various fission-product elements, fractional condensation would be expected to occur throughout the fallout formation process. The significant radiological property associated with the amount of a radioelement that condenses during the second period of formation is that the fraction condensed is considered to be potentially soluble and biologically available for assimilation by plants and animals. The more volatile radioelements in fallout, in fact, have been found to be most soluble and more biologically available than are the refractory elements. However, the fractional degree to which each element condenses in either period of condensation is expected to depend very much upon the temperature at which diffusion into the particle becomes limiting and the condensing radioelement is concentrated in the surface layer of the particle.

If all the materials that were produced in a land-surface nuclear detonation and all that entered the fireball volume remained together for the first 5 or 10 minutes after detonation, the radioactive compositions and the subsequent radioactive decay (and nuclide solubility) would be about the same for all fallout particles. However, it is known that all the entering particles do not remain together in the fireball and cloud for such periods of time. Immediately after the fireball expands to maximum size, it begins to rise in the air. The upward motion of the hot gases sets in motion a large-scale toroidal circulation because of the drag forces of the surrounding air. This toroidal motion, with circulation velocities in excess of 100 miles per hour, is probably responsible for pulling blast-loosened soil from the crater and crater lip into the rising fireball.

The circulation of the particles in the toroid should result in an earlier separation of the larger particles from the circulating volume(s) of condensing gases and should, by centrifugal forces, move them to the periphery of the toroid. When the circulating particles reach the periphery (or the bottom) of the cloud and the pull of gravity begins to exceed the upward drag forces of the air near the base of the rising cloud, the particles begin falling to earth. Other particles of the same size, not yet near the periphery of the toroid, may continue to circulate for a much longer time before they leave the base of the cloud. These views of particle circulation and formation are supported by (1) the relatively long period over which particles of a given size arrive on the ground, (2) the relatively early arrival times for close-in fallout, (3) the variation in composition of the radioelements on particles of different sizes, and (4) the variation in specific activity and radioelement composition among particles of a given size.

The concentration of the volatile radioelements in the radioactive compositions carried by the larger particles is generally found to be low. This lower relative concentration could occur only through the earlier ejection of the large particles from the volume of the fireball containing the radioelements (vapors plus small vapor-condensed particles). In addition, the large fallout particles from many low tower detonations do not contain or carry any soluble radioelements, and, therefore, these particles must have been ejected when their surfaces were still at a very high temperature. Thus the toroidal motion is considered to be partially responsible for the observed differences in the gross radioactive decay and biological availability of different radioelements carried by fallout particles with different diameters.

The toroidal motion which apparently causes early ejection (early with respect to fall from the stabilized cloud) of the larger particles also can cause prolonged apparent buoyancy of the smaller particles. The latter would circulate for longer times and, after cooling, would remain in the volume to collect the more volatile elements on their surfaces. Except for the fallout particles with diameters less than about 50 to 80 microns, all appear to leave the cloud volume under influence of circulation.

Observed data on the properties of fallout from detonations on soils similar to those of likely targets in a nuclear war are nonexistent. In fact, only a few detonations in both the Eniwetok Proving Ground and Nevada Test Site have provided useful data for the development of fallout models for land-surface detonations. The large yield devices were all detonated over water, on coral atolls, or in the air. No evidence exists today for proving that all types of information on fallout obtained from these few weapons tests are satisfactory for use in developing reliable models that are designed to give quantitative estimates of the properties of fallout (and its distribution) from assumed detonations of high yield weapons on targets in the continental United States. Perhaps continued theoretical developments and concurrent supporting high temperature experimental work are the only remaining methods for improving and evaluating the validity of some of the input data for currently available fallout models.

The radionuclides in worldwide fallout are generally found to be quite soluble, and all the radionuclides are, to a large degree, biologically available. However, a fairly large number of fused-type particles are formed from the warhead or bomb materials as identified in stratospheric collections of bomb debris.[3] A large fraction of the worldwide fallout from a large-yield nuclear air explosion appears to be formed in the stratosphere at some time after the detonation through processes of coagulation and coprecipitation of the radioactive atoms with the natural stratospheric aerosol particles. The latter, composed mainly of water-soluble ammonium sulfate compounds, then serve as carrier particles for returning the radioactive debris to earth.

In all types of detonation conditions, the form and properties of the produced fallout are determined during the cooling period of the fireball and cloud, as well as at later times for the decay products of gaseous radioelements and for many other radioelements in airbursts that produce the worldwide fallout. The materials that enter, or are in, the fireball at these times are important factors in determining the properties of the fallout particles. These formation processes set the stage for all subsequent radiological interactions between the fallout materials and the biological and ecological environment in which the materials are deposited.

One of the chief difficulties in the prediction or computation of levels of fallout at a given location, in addition to the problems of defining the fallout particle cloud source discussed above, is the analysis and prediction of the wind structure as the major influence in distributing the fallout particles over the earth's surface. Other major factors for which very little accurate data exist, especially for fallout from large yield detonations over silicate soils, include (1) the variation of the specific activity with particle size and (2) the influence of the environmental material (soils and other likely target materials) on the gross particle-size distribution of the fallout (i.e., by particle number, mass, or radioactivity content).

A comparison of several currently used fallout models (or fallout pattern scaling systems) is shown by the relative areas within stated fallout radiation rate contours in Table 1. The differences in the areas enclosed by stated standard intensity contours among the various computing systems for the two weapon yields and wind conditions are generally not small. Assumptions regarding the fraction of the gross fallout activity on particles of a given diameter and the locations of the particles in the initial cloud source are likely major causes of the differences among the models.[2] The integrated activity in the fallout patterns within the 1 r/hr at 1 hr contour, for the two cases of Table 1, gives the following values for the radiation rate conversion factor (in r/hr at 1 hr per KT/sq mi):

Case A: WSEG-RM10 - 1,500
ENW - 1,460
Anderson - 1,550
SFSS - 1,430

Case B: WSEG-RM10 - 2,500
AFCIN - 800
WB - 2,000 (approximately)
WSEG-NAS - 2,400

For Case B, the theoretical value of the conversion factor for unfractionated fission products is 3,600.[2] The parameters and data relating to the evaluation of the conversion factor from measured quantities on the fallout from Shot Small Boy in Operation SUN BEAM are discussed in Reference 8.

Four additional types of radiological hazards to biological species, in addition to the more general external hazards from gamma radiation, are known. These are (1) the contact hazard, (2) the inhalation hazard, (3) the beta-field hazard, and (4) the internal hazard from ingested radionuclides.

Table 1

RATIO OF AREAS WITHIN STATED STANDARD INTENSITY CONTOURS FOR FALLOUT PATTERNS COMPUTED FROM VARIOUS MODELS RELATIVE TO THOSE FROM THE WSEG-RM10 MODEL.[a,b]

Model Designation	Standard Intensity (r/hr at 1 hr) 1	10	100	1,000
	Case A. 10-MT yield, 15 mph wind speed (100 percent fission)			
ENW (1957)[5]	8.66	1.86	0.70	0.62
Anderson[6]	1.40	1.14	1.00	0.96
Simple Fallout Scaling System[2]	0.67	0.71	0.83	1.10
	Case B. 1-MT yield, 25 mph wind speed, 0.2 knots/10^3-ft vertical shear (100 percent fission)			
AFCIN[7]	0.15	0.18	0.26	0.57
WB (1962 ENW)[7]	2.16	1.18	0.67	0.40
WSEG-NAS[7]	1.96	1.36	0.87	0.60

a Standard intensities calculated from WSEG-RM10 Model were first multiplied by 0.56 to account for terrain shielding and instrument response for the 10-MT-yield weapon fallout pattern

b From Reference 4

The contact hazard (sometimes called the beta contact hazard) could develop in situations where fresh fallout particles remain in contact with the skin of humans, animals, insects, and plants for some period of time. For humans, this type of exposure could be avoided easily by wiping or brushing fallout particles from exposed skin. This hazard would develop only during fallout deposition and shortly thereafter; at times after attack longer than several days, the fallout particles would no longer have the radioactive content necessary to cause serious damage to skin tissues. Some data have been reported on the retention of particles by humans.[9,10] Some data have been obtained on skin doses to animals;[11] however, no reliable correlations of such data with fallout deposition levels have yet been made, although unverified relationships between the two have been proposed.[12] No computations or experimental measurements have been made of the contact dose to plants, although data on the retention of fallout particles by the foliage of many different types of plants have been obtained and reported.[9,10]

The inhalation hazard is associated with the inhalation and deposition in the respiratory system of small fallout particles of a narrow size-range. All the available data on exposure of animals in fallout areas at weapons tests and in laboratories, on air filter samples in various fallout environments, and on fallout particle resuspension in air give negligible results for the inhalation hazard. Therefore, the inhalation hazard is considered to be a minor one relative to other possible radiological hazards.

The beta-field hazard (sometimes called the "beta-bath" hazard) could occur in certain confined radiation source geometries for humans. The beta-field hazard, however, would be expected to be severe for small plants, small animals, and insects whose habitats become covered with the deposited fallout particles. In such geometries, the beta-to-gamma ratio (i.e., the rad-to-roentgen ratio) would generally be between 30 and 100 for fallout radiation compositions similar to those of past weapons tests. No mathematical models on the beta-field hazard to small plants and animals or insects have been reported, and none are known to exist for use in damage assessment studies of nuclear war. However, some related work on this hazard has been reported.[13,14] The combined radiological hazards, the external gamma, the contact, and the beta-field, for plants, animals, and insects should be considered in future research investigations.

Contamination Phenomena

Certain types of information on the contamination of various kinds of exposed environmental materials, objects, and biological materials are needed in the description of a radiological environment. Some of these types of information on contamination phenomena and their relative availability are summarized below.

Structure Contamination

Essentially no data are available on the contamination of urban-type structures and urban geometries by real fallout; some related data were obtained in Costa Rica where the retention of volcanic particles on roofs was observed.[9,15]

The influence of urban area geometries on fallout deposition is not well known. However, from observations in Costa Rica, it is expected that sloped roofs would not retain large particles for any long period of time if they are deposited in a dry state when the surface wind speed is more than 5 miles per hour. Under damp conditions and low wind speeds, the retention would be expected to be relatively high. Eave troughs, the lee side of roof peaks, crevices in the roof surface, and any roof areas protected from wind are locations where the deposited particles would tend to accumulate.

The effect of fallout deposition patterns (roof versus ground) on building shielding factors is not known or generally considered in the computation of radiation protection factors.

The effect of natural processes of roof decontamination, due to wind and rain, on building shielding factors and the surrounding radiation fields is not well known, quantitatively. For flat built-up roofs of tar and gravel, however, the effect of moderate wind speeds in accomplishing roof decontamination has been found to be small.[2]

Paved Area Contamination

Essentially no data are available on the decontamination of streets and roads by rain. However, it is expected that light rains would facilitate the leaching of soluble radionuclides from deposited fallout particles and the transport of these radionuclides to pavement surfaces where they could be chemisorbed; heavy rains would be expected to wash many fallout particles from sloped surfaces, as was observed in Costa Rica.[16]

Winds, with speeds in excess of 10 miles per hour, move particles with diameters between about 100 and 300 microns more effectively than they do other larger or smaller particles.[17]

A few data on the effect of wind erosion have been obtained. Radiation fie., reductions of a factor of 2 have been observed.[2] In Costa Rica, the wind and traffic tended to move the volcanic particles to the gutters along the street or to the edge of parking lots where the particles accumulated in the grass, weeds, or gravel.

Land Area and Soil Contamination

Fallout particles deposited on open land areas and on bare soils are not found to be moved significantly by winds.

Larger fallout particles are not expected to be moved by rain except where the soil itself is washed away, as in heavy rains; the larger particles, after several years on undisturbed land, probably never penetrate more than 1/4 to 1/2 inch into the soil. Soluble radioelements that leach from the fallout particles from land-surface detonations or that are deposited as worldwide fallout from high altitude detonations do penetrate into the soil to some degree (see Table 2).

The average reduction in radiation intensity, owing to the surface roughness of the terrain in certain open areas of the weapons test site in Nevada, is about 0.68.[18]

The rate of penetration of Sr-90 into soils is reported[19] to be so slow that no evidence was found to show significant vertical movement of the Sr-90 after initial deposition over a period of 8 years.

About 85 to 90 percent of Cs-137 in worldwide fallout is reported to remain in the top 2 inches of soil.[20]

The shallow penetration of soluble nuclides into the upper layers of undisturbed soil is expected to reduce and delay the assimilation of radionuclides in deep-rooted perennial plants and their fruits.

The deposition of worldwide (and, perhaps, local) fallout in heavy rain results in fractional runoff of soluble radionuclides. However, the available data on this loss from land masses in drainage systems are scarce; some reported data are shown in Table 3 for various environmental conditions.

The radioelement, Cs-137, absorbs on soil much more strongly than does Sr-90.

Water Contamination

Analysis of river waters and of the deposition of Sr-90 in worldwide fallout for the Ohio River basin indicates that between 4 and 12 percent of the Sr-90 deposited in 1959 was carried into river waters.[22] Observed concentrations of Sr-90 and Cs-137 from worldwide fallout in lake and river waters (up to about 1961) are reported[23] as being 0.1 to 1.0 picocuries per liter for Sr-90 and 0.05 to 0.2 picocuries per liter for Cs-137, with a yield ratio of 1.7; the concentrations of Cs-137 are thus lower than those of Sr-90 by factors of 7 to 15.

Estimates of the yearly worldwide fallout deposit that eventually finds its way to the sea through runoff waters have been reported to be

Table 2

PENETRATION OF SR-90 IN NEW YORK AREA SOILS IN 1958[a]

Layer Depth (inches)	Fraction of Radioactivity in Soil Layer				
	Dark Loamy Gravel-Sand	Yellow Coarse Sand	Yellow Sandy Loam	Pale Brown Silty Loam	Pink Sandy Loam
0-1	0.33	0.49	0.62	0.73	0.71
1-2	0.24	0.23	0.14	0.13	0.18
2-3	0.13	0.09	0.06	0.06	0.05
3-4	0.16	0.07	0.05	0.03	0.03
4-5	0.05	0.05	0.03	0.02	0.01
5-6	0.01	0.04	0.02	0.00	0.01
6-12	0.03	0.04	0.04	0.01	0.00
12-18	0.03	0.03	0.02	0.01	0.01
18-24	0.02	0.02	0.02	0.01	0.00
Depth for 0.5 of Total Activity (inches)	1.7	1.0	0.7	0.5	0.5

a From Reference 19

Table 3

FRACTION OF SR-90 IN THE RUNOFF WATER FROM CROP LAND[a]

Crop	Fraction of Deposited Sr-90 in the Runoff Water	Fraction in the Runoff Water per Inch of Rainfall	Runoff Water (inches)
	LaCrosse, Wisconsin; 16 percent slope; March-August 1957; Fayette silt loam		
Corn	0.045	0.0020	0.93
Oat	0.041	0.0018	1.25
Clover[b]	0.0035	0.00016	0.15
	Tifton, Georgia; 3 percent slope; March-December 1957; Tifton loamy sand		
Corn	0.014	0.00034	1.32
Oat[b]	0.0044	0.00011	0.37
Peanut	0.014	0.00035	1.20

a From Reference 21

b Ground cover established before the measurements were started between 1 to 10 percent for Sr-90 and 2 to 6 percent for Cs-137.[23] The amount of local fallout in the runoff water would be expected to be less than these percentages.

The ratio of Sr-90 concentrations in well water to those in surface waters (from worldwide fallout) has been reported to be about 0.03.[23,24] However, the supply of data is meager for this ratio; the ratio may be inaccurate because the sources of the concentrations are not known.

The larger fallout particles in local fallout will fall to the bottom of exposed water supplies. Small particles may be suspended; the soluble nuclides would be expected to be dissolved initially into the water. Very few data are available on the contamination of real water sources by local fallout.

No data are reported on the amount and rates of depletion of radionuclides in fallout from water due to adsorption by bottom materials, assimilation by aquatic plants, or dilution by rain.

Data on the movement of radionuclides in streams are extremely scarce.

Plant Contamination

Some fragmentary data on the external and internal contamination of plants by worldwide fallout are summarized in Reference 23. Available data on the external contamination of plant foliage obtained at field tests and in Costa Rica are summarized in References 9 and 10.

Animal Contamination

Cattle were contaminated with fallout from Shot Trinity (1945) resulting in an estimated skin dose of 39,000 rads in 2 weeks.[11] Data on other such events are not generally available.

No reliable method exists for estimating the degree of the contact hazard for animals exposed to fallout during deposition.

Internal contamination data from worldwide fallout are illustrated by the summaries in Tables 4 and 5.

A summary of some available data and the discussion of that data in terms of animal assimilation model(s) are given in the second section of this report.

Human Contamination

The contamination of humans by fallout from nuclear explosions is a possibility that often has been overemphasized in past civil defense

Table 4

DERIVED VALUES OF CONSTANTS A_i^o AND B_i^o FOR WORLDWIDE FALLOUT SR-90 CONTAMINATION OF MEAT, POULTRY, AND EGGS[a]

Food	A_i^o [b] $\left(\frac{\text{atoms/gm}}{\text{atoms/sq ft-month}}\right)$	B_i^o $\left(\frac{\text{atoms/gm}}{\text{atoms/sq ft}}\right)$
Beef and pork	2.8×10^{-5}	0.31×10^{-6}
Poultry	5.9×10^{-5}	0.47×10^{-6}
Eggs	4.3×10^{-5}	1.8×10^{-6}

a From Reference 23

b These values are six times the 6-month average values; A_i^o was determined by taking A_i^o/B_i^o equal to 15 for beef and pork and 20 for poultry, as based on the 6-month ratio averages for many of the food sources of these animals. The constants are for the relationship

$$C_i^o \text{ (atoms/gm)} = A_i^o N_i(t) + B_i^o N_i^o$$

where $N_i(t)$ is the average number of atoms/sq ft deposited per month and N_i^o is the total number of atoms/sq ft deposited up to July of the year.

Table 5

SUMMARY OF DERIVED VALUES OF A_i^o AND B_i^o
FOR WORLDWIDE FALLOUT SR-90 AND CS-137 CONCENTRATIONS IN MILK

Reference	A_i^o $\left(\frac{\text{atoms/liter}}{\text{atoms/sq ft-month}}\right)$	B_i^o $\left(\frac{\text{atoms/liter}}{\text{atoms/sq ft}}\right)$
	Sr-90	
USA selections[26]	0.12[a]	0.0037
USA selections[26]	0.073	0.0032
New York[26]	0.14	0.0022
San Francisco[26]	0.14	0.0012
Average[23]	0.16	0.0034
	Cs-137	
Midwest USA[26]	0.42[b]	~0

a Six-month rate times six; see Table 4 for definition of A_i^o and B_i^o
b Assume Cs-137/Sr-90 = 1.7

and other weapons effects literature relative to the early-time external gamma hazard. A small amount of data on the contamination of hair, hands, and clothes by airborne particles was obtained in Costa Rica.[9,10,25]

The major historical reference incident in which the effects of the contact hazard were evidenced is the exposure of the Marshallese in 1954.[27] It is expected that this hazard would be much less severe in western countries where the dress habits and personal hygiene habits are different.

No reliable method exists at the present time for estimating skin contact hazards in various nuclear war conditions of fallout; the estimating procedures for computing contact doses for fallout situations suggested in Reference 12 are probably not suitable for fallout conditions.

The data on the assimilation of radionuclides by humans are discussed in all sections of this report; both the accuracy of the data and their interpretation regarding consequences are subjects for further study, research, and analysis.

The OR values (i.e., the ratio of the relative concentrations of Sr-90 and Ca in tissue to that in the diet) for uptake of Sr-90 in humans from food source contamination by worldwide fallout have been evaluated.[23] The OR values are as follows: (1) 0.3 for whole body/diet; (2) 0.5 (0.44 to 0.54) for blood/diet; (3) 0.22 (0.16 to 0.29) for bone/diet; (4) 0.1 for milk/diet; and (5) 0.6 for fetus/mother.

Patterns of Damage and Recovery Phenomena

External Gamma Radiation

The delivery of the external gamma radiation exposure dose to biological species at given locations in a fallout field is generally in the form of an acute or short-term damage phenomenon. For example, at many locations in the country that would receive heavy fallout deposits following a nuclear attack, about 70 percent of the exposure dose would be delivered in 1 week, and over 80 percent would be delivered the first month after the attack.[2] In 1 year, the gamma radiation from the fission products is about 6×10^{-5} of the standard intensity (r/hr at 1 hr); thus, for very high fallout levels (order of 10^5 r/hr at 1 hr), the chronic exposure dose rate would be between 1 and 6 r/hr at 1 year unless appreciable decontamination by weathering or by humans occurred.

Although small areas of the country that received heavy fallout deposits in an attack may have appreciable levels of chronic radiation rates after a year's time, the major damaging effects on biological systems would be caused by the high exposure dose delivered during the first month or so after an attack. Therefore, in terms of an ecosystem time-scale, the injury is primarily the result of an acute assault rather than a chronic one. However, this use of the term "acute" is not precisely the same as is used for experimentally determined acute exposure dose effects on a single biological species. In the latter usage of the two terms, the real pattern of the accumulation of external dose from fallout radiation is neither acute nor chronic; further, in most experimental evaluations, the biological response to chronic exposures is usually determined for a constant exposure rate.

The usual pattern of dose delivery in experimental evaluations of biological responses to radiation exposures is not similar to the pattern of dose delivery from radiation exposures in fallout. Because a given biological response is obtained in experiments from widely differing total exposure doses, depending on whether the pattern of delivery is acute (very short) or chronic, the response data from these experiments are not readily applicable to the pattern of dose delivery from fallout radiation. Because of these differences, many questions arise about the application of currently available biological response to exposure doses from fallout radiation; although this difficulty has been recognized for a long time, appropriate attention to it has not yet been reflected in the data output of experimental programs. Experimental biological response data for the exposure pattern from fallout radiation are therefore still required for evaluating the radiological consequences from nuclear attacks.

Other areas of biological response to radiation exposures that need experimental attention appear to be (1) biological response to variable intermittent exposures; (2) biological functional responses (i.e., work efficiency, general health, susceptibility to other diseases, etc.) to long-term exposures to low-level radiation; and (3) increased efforts on basic experimental programs for determining and evaluating biological repair and recovery mechanisms. These general data needs apply to all important biological species (humans, animals, plants, and insects).

The current state of knowledge on the short- and long-term effects of radiation on humans has been summarized;[5,23] these subjects are not discussed further in this report. The use of the effective residual dose, ERD,[12] in damage assessment studies is discussed below.

The radiation sensitivity of several higher vertebrate animals is summarized in Table 6 in terms of the LD_{50} (50 percent deaths) in 30 days for a brief exposure to gamma rays. Although it is assumed that the data apply to a multilateral radiation source in which the whole body of the animal is exposed to radiation, this exposure geometry is not specified in the referenced reports. For unilateral or beam radiation sources, the value of the LD_{50}/30 days would be higher than for a large area source of radiation. Also, the mean photon energy of the radiation sources used to obtain the data is not specified; the data probably consist mainly of results of experiments using Cs-137 (0.7 Mev/photon) and Co-60 (1.25 Mev/photon) sources.

When a biological response is expressed in terms of dose, such as the LD_{50}, and also in terms of the time required for the response to

Table 6

RESPONSE OF ANIMALS TO BRIEF EXPOSURES IN EXTERNAL GAMMA RADIATION FIELDS IN TERMS OF THE LD_{50} IN 30 DAYS[a]

Species	$LD_{50}/30$ (roentgens)
Dog	280
Guinea pig	340
Goat	350
Mouse	440
Swine	510
Sheep	520
Cattle	540
Rat	640
Burro	650
Monkey	760
Rabbit	800
Poultry	900

a From References 11, 28, 29, and 30: the listed $LD_{50}/30$ values were used in the calculations described in this report. Other $LD_{50}/30$ values, differing from those listed by as much as a factor of 2, are reported in References 93, 94, and 95. Some of these are: dog, 319; sheep, 360; burro, 375; swine, 390; rat, 936; and mouse, 940. The basic causes of these differences remain to be clarified.

occur (i.e., LD_{50} in 30 days), the value of the dose is increased for an equivalent response in a shorter period. Thus the value of an LD_{50} in 10 days is generally much larger than the value of an LD_{50} in 30 days. Also, if the exposure is at a lower dose rate, the exposure dose giving an indicated response is larger than for the brief, or acute, exposure as mentioned above. For example, where the LD_{50} for the burro for a single exposure is 780 roentgens, the value of the burro LD_{50} at a constant dose rate of about 50 roentgens per day is 1,500 roentgens; for the pig, the two LD_{50} values are 610 roentgens per exposure and 8,500 roentgens at 50 roentgens per day, respectively.[11]

Mortality-exposure dose relationships are usually derived from biological response data using standard error curves; the latter are then used to determine the LD_{50} values (or other responses); the dose is expressed either directly in roentgens or as logarithmic units of the dose. For most animals, the mortality-dose distributions are very narrow;[29] thus the dose at which 100 percent mortality occurs is only a relatively small increase in dose over the threshold dose for mortality. Thus, in damage assessment studies, the LD_{50} for such species can be used as a step function separating the survivors (including those receiving sickness doses) and those killed. However, for the pattern of exposure dose accumulation for the gamma radiation from fallout mentioned above, no reliable guidance is available on the time limit (say, in excess of 2 to 4 days) on the computed exposure doses that can be used to make reliable comparisons with the reported biological response (such as the LD_{50}) for a brief dose. In addition, the extension of laboratory data to operational situations (even for animals) requires information about variabilities in responses due to the differences in age, state of health, and other such factors for application to a heterogeneous population.

The dependence of the LD_{50} and other biological responses of animals during and after exposures to ionizing radiations on the energy of the radiation, rate of dose accumulation, time of exposure, and other factors is reviewed in detail by Trum;[30] data are cited to illustrate the influence of type and quantity (i.e., energy) of radiation, total dose, dose rate, dose fractionation, relative biological effectiveness, animal species, and animal age on the response (especially) of the mammalian animals to radiation. Physiological factors are also involved in the response but, as mentioned above, their nature and effect on the response are not known.

A few 50 percent mortality values for brief exposures of fish and shell animals are given in Table 7. Although it is unlikely that sea-water fish would receive lethal doses from fallout in a nuclear war, further analysis should be done to verify that lethal exposures to fresh-water fish (or aquatic animals that live on harbor or beach bottom) would also be an unlikely occurrence.

A few data representing the mortality response of insects to gamma radiation are given in References 5, 14, and 31. For insects, it is especially important that the radiosensitivity and response be known

Table 7

LD_{50}/30-DAY DOSES FOR BRIEF EXPOSURES OF FISH AND SHELL ANIMALS[a]

Species	LD_{50}/30 Days (rads)
Adult fish	1,000- 2,000
Crustacean	800-100,000
Mollusc	4,000-500,000

a From Reference 11

for their whole life cycle, so that the effect of exposure to nuclear radiation on the whole population can be evaluated. With insects, this requirement is more important than for other species because of the rapidity of the reproductive process and of the extreme range in radiosensitivity of some species over their life cycle. Thus, for parts of this segment of the biosphere, the "acute" time pattern of the radiation injury (i.e., about 2 to 4 weeks) could be, in effect, similar to a chronic, or long-term, injury for other biological species.

Data on the response of insects to beta radiation are needed because of the proximity of many of the insect species in their habitats on the ground or on low vegetation where the fallout particles would deposit. Since rad-to-roentgen (at 3 feet above a plane source of emitters) ratios of 10 to 100 are possible for the radiation source geometries in which many insects live and eat, their beta doses could be very large compared with those for the larger animals. Although the beta particles would not penetrate the shells of many insect species, not all insects are completely surrounded with thick-shelled exteriors, and, even so, the soft photon and bremsstrahlung intensities also would be increased manyfold at close range from the fallout particles.

The reported biological response of insects, mainly for X rays, is very limited in scope. It is quite likely, moreover, that the available reported data are not applicable to gamma radiation from fallout; the reported data, as mentioned above, are definitely not applicable to those species where the combined beta-gamma radiation should be considered. No biological response data appear to be available on the radiosensitivity of several important ubiquitous insects. Research on the biological response to radiation for these units of the biosystem are needed to evaluate the role of insects in the postattack repair and recovery of rural and wild land ecosystems.

The response of plants to nuclear radiations (especially external gamma radiation), called radiosensitivity, is manifested in several ways.[32] These include (1) genetic effects that may be recognized only in subsequent generations, (2) inhibition (and, occasionally, stimulation) of growth, (3) reduction of reproductive capability, and (4) death. That is, ionizing radiation of appropriate exposure doses and exposure patterns can increase, slow down, stop, or alter the subsequent patterns of plant growth. Some of the specific known factors involved include (1) the exposure schedule (acute, chronic, or fractionated), (2) the plant part exposed and the geometry of exposure, (3) the plant species, (4) the stage of plant development, (5) the physiological condition of the plant, and (6) the climate and other environmental conditions (soil, fertility, etc.).

Needless to say, very little quantitative data on the basic relationships among these six factors on plant radiosensitivity have been studied and reported. Sufficient data are available for identifying the more radiosensitive plant species and the characteristics of each that influence its response to radiation.

Some of the easily observable biological responses of plant parts (all parts exhibit response) are: (1) roots--reduction of growth and inhibition of new root formation; (2) stems--dwarfing, excessive branching, local swelling, fasciation, formation of adventitious roots, and tumor growth; (3) leaves--reduced blade development, dwarfing (asymmetrical blades), abnormal veination, decrease in chlorophyll (discoloration), and change in texture (older leaves become dry, brittle, and coarse and young leaves thicken and become leathery); and (4) buds and flowers--retarded formation, reversion to vegetative growth, fasciation, and changes in color and form.

Notable changes in plant growth habits after exposure to critical doses of radiation include the early dropping of leaves (deciduous trees) and the retardation of bud and new-shoot formation. The reduction in reproductive capability after exposure is related to the effect on vegetative growth (plant vigor), the retardation of flowering, and the direct damage to the parts of the cells that participate in the reproductive cycles of the plant.[32] The extreme combination of all the various radiation damage manifestations results in death of the plant.

The relative radiosensitivity of plants ranges over a factor of at least 5,000 from algae and bacteria, which are the most resistant or least affected by radiation, to the gymnosperms, which are among the most radiosensitive of the plants. Among the higher plants, the range in chronic, or protracted, doses to produce a similar biological response is the order of a factor of 500.

The reduction of vegetative growth of plants after exposure to nuclear radiation is apparently caused mainly by a reduced rate of cell division; since reduced growth is usually the first gross observed effect of the exposure, it is believed that the apical meristem regions are highly radiosensitive.[32] The radiosensitivity of young growing plants is probably highest.[33] Growth retardation appears to have a threshold dose; much of the plant growth retardation data can be represented by a function of the form

$$G = G_o \exp\left[-k_D(D - D_o)\right] \tag{1}$$

where G is the growth characteristic for an exposure dose of D roentgens, G_o is the characteristic for the controls (zero dose), D_o is the threshold dose, and k_D is a growth retardation coefficient. Some values of k_D and D_o for different plant species, as derived from reported data, are shown in Table 8.

Basic relationships between plant cell nucleus characteristics and radiosensitivity recently have been derived by Sparrow and Woodwell[32] from correlations between these characteristics and data on the response of plants to external gamma radiation. The cell nucleus variables include (1) cell nucleus or chromosome volume, (2) cell nucleus DNA content,

Table 8

ESTIMATED PLANT RETARDATION THRESHOLDS AND GROWTH RETARDATION COEFFICIENTS FOR SOME PLANTS EXPOSED TO GAMMA (AND X) RADIATION[a]

Species	Response	k_D (roentgens^{-1})	D_o (roentgens)	Time of Total Exposure
Pinus strobus (seedlings)	Leader length growth	4.6×10^{-4}	910	15 months
Taxus med. cv. hatfieldii	Number of growth buds	1.3×10^{-3}	850	12 months
Quercus alba	Number of leaves	2.3×10^{-4}	5,500[b]	6 months
Pinus regida	Terminal growth	-	360	6 months
Quercus alba	Terminal growth	-	1,800	6 months
Wheat (seedlings)	Growth[c]	-	250[c]	acute dose

a From References 32, 33, 34, and 35

b Cs-137 source; unmarked numbers are for Co-60 source

c Maximum growth retardation occurred for exposures at 2 days after germination; X-radiation

(3) chromosome number and ploidy, and (4) other cytological characteristics such as the number and position of centromeres in the chromosome and the amount and distribution of heterochromatin. These and other factors that affect the reproductive capability of plant populations after exposure to gamma radiation are discussed in detail in Reference 32. Empirical correlations of the relative amounts of chronic exposure dose that cause different types of biological response in herbaceous annuals are given in Table 9; such correlations are useful for estimating the exposure doses for different plant responses (during the period of active growth, meiosis, and seed set) from information on the exposure dose for any one type of response.

Low levels of radiation are often observed to cause growth stimulation but no proposed mechanism for this stimulation was found reported. Also, low-level radiation of seeds is often found to result in an increase in crop production. The quantitative aspects of these biologically favorable responses were not investigated during this study.

In general, the currently available reported data on the radiosensitivity of plants provide much useful basic information regarding the relationships among plant responses to radiation and their cell nucleus characteristics. The quantitative response data, however, do not apply either to the dose rate variations with time that would be characteristic of fallout from nuclear weapons or to the duration of the external gamma hazard from fallout. Also, the effects of beta radiation on growing plants have not been determined. While it may be appropriate to neglect the consideration of beta radiation effects on the larger plants, the same is not true for smaller plants. The proximity of fallout particles to sprouting cereals, grasses, and other small plants with thin-shelled stems would certainly cause these plants to be affected by the short-range beta particles. On the other hand, many data on the response of plants to gamma radiations have been obtained on the more sensitive seedling plants. Even with gamma radiation studies, relatively little or no work has been reported on the effects of radiation on the productivity and properties of standard food crops under field conditions; however, work has recently been initiated to study such effects.[36] More realistic representation of exposure patterns that could result in fallout environments and emphasis on economically valuable plants are needed in future research programs on the radiosensitivity of plants.

To be useful in damage assessment studies, the sensitivity data on plants should include (1) exposure dose rates that decrease with time in the same way that the dose rates from fallout decrease, (2) the employment of exposure schedules that are initiated at various stages of plant growth, (3) the use of multilateral exposure configurations (fallout geometry), (4) the use of exposures starting at different seasons or times of the year (as in 2), and (5) beta plus gamma radiation exposures on selected plants.

Many environmental factors can affect the response of plants to ionizing radiation. These include (1) the geometry of the radiation

Table 9

PLANT RESPONSE RELATIVE TO MORTALITY (LD_{100}) OF HERBACEOUS ANNUALS FOR CO-60 GAMMA RADIATION[a]
(Exposure Times from 8 to 12 Weeks)

Response	Fraction of LD_{100} Dose Rate
Normal appearance	0.11
10 percent growth reduction	0.26 ± 0.02
Failure to set seed	0.31 ± 0.06
50 percent growth reduction	0.34 ± 0.04
Pollen sterility (100 percent)	0.41 ± 0.04
Floral inhibition or abortion	0.44 ± 0.04
Growth inhibition (severe)	0.58 ± 0.03
LD_{50}	0.75 ± 0.02
LD_{100}	1.00

a From Reference 32

field; (2) the location of the more radiosensitive plant parts (the meristems) with respect to natural shielding (roots are shielded by the earth over them); (3) shielding by snow or other denser vegetation (such as large trees), the general density of plant growth, and the height of the plant tops; (4) the type of ionizing radiation and its energy; (5) the growth rate or rate of cell division; (6) climatic stresses (drought, heat, cold, etc.); and (7) insect and disease attack.

These factors should also be considered in future experimental programs to some degree. All are difficult to evaluate individually and without experimental data; some information on each factor is needed to make crude estimates of the fate of plant populations in possible nuclear war fallout environments.

In summary, the current information on plant radiosensitivity indicates that correlations of the responses of plants to external radiation with plant cell nuclei characteristics have successfully revealed methods for estimating the response of other plants from their cellular characteristics, at least under certain types of protracted exposure conditions. On the negative side, correlations and data for describing the response of plants (especially food crop plants) to short exposures and variable dose rates similar to those from fallout radiation dose rates are relatively scarce. Rough comparisons of the plant radiosensitivity data with the pattern of exposure doses from fallout radiation indicate that the severe plant growth inhibition in the more radiosensitive plants would begin at levels of about 1,000 r/hr at 1 hr and, for the more radioresistant species, at levels of about 500,000 r/hr at 1 hr. However, germinated seedlings (small young plants) appear to be most radiosensitive a few days after germination; for these young plants, severe growth inhibition effects are observed to begin at doses of a few hundred roentgens. In older plants, the most radiosensitive tissue is that in the new young growth of the plant.

Because of the variability in radiosensitivity of plants with species, age of plant, and period between growth and reproduction cycles, the gross effects in plant population from exposure to gamma radiation would depend a great deal on the time of year, and, perhaps, of month, when the attack occurred. It would also depend on the targeting for many agricultural areas; the midwestern state areas, for example, could receive high levels of fallout from surface detonations on missile sites in neighboring states and in the Rocky Mountain area.

Internal Radiation

The pattern of radiation exposures of humans, animals, plants, and insects after a nuclear war would depend mainly on the uptake and assimilation of biologically available (soluble) radionuclides by the various species. The various processes involved in the entry of the radionuclides into food chains (or webs) and the data available for evaluating the process mechanisms are discussed in the second section of this report.

The general assessment of the available input data is that, in spite of all the published work, the available data are generally fragmentary, incomplete with respect to continuity of processes, incomplete with respect to radionuclide coverage for the economically important biological species, and incomplete in many cases with respect to the measurement and reporting of obvious important control variables. The specific weaknesses in the currently available input data for developing the uptake models, as well as examples of the excellent reported work and applicable data, are noted in the following sections of this report, in part, by the assumptions used to complete the models, by the types of methods used in the data analysis and correlation, and by the data used in the model development.

The internal radiation hazard from fallout is characterized mainly by the fact that, at least in humans and other large vertebrate animals, most of the radiation sources (e.g., radioactive atoms) tend to concentrate in specific body organs and that the assimilation occurs according to the biochemical properties of specific radionuclides. Thus, in assimilation processes, it is not appropriate to consider the fission product elements as a single source of internal radiation; evaluation of the internal hazard must consider the behavior patterns of each individual radioelement in the fallout.

In terms of possible injury to various species in the biosphere, the internal radiation may be both acute and chronic. For the larger animals, two factors would tend to limit the significance of acute injury from internal radiation. First, in areas of heavy fallout, the injury from external gamma radiation would precede internal radiation injury because the latter requires time to build up in the food chain; death due to exposure doses from external radiation would limit further uptake by the animals so exposed. Second, the rates of assimilation are controlled by the rate of buildup of the radionuclide concentrations in plant and animal foods and by the rate of food ingestion. Thus the pattern of internal ingestion and radiation is one in which the concentrations of the radioelements increase with time, reach a maximum, and then decrease or remain essentially constant, depending on the ingestion rates, the biological elimination rates, and the radioactive decay rates for the radioelement and body organs and food sources involved in the process.

Few data that describe the biological response of animals to ingested internal emitters are reported. For example, the following data are given as part of the text in Reference 11; these data can be used to estimate, roughly, the lethal or near-lethal internal body concentrations of some larger animals:

1. A dose of 50,000 rads or more (brief period) to the thyroid of sheep from assimilated I-131 is required for ablation; if the thyroid dose is 100,000 to 150,000 rads over a period of about a month, sheep will show some evidence of the total-body radiation syndrome. (A similar response is likely for other animals with the same body burden of I-131 per unit weight of total body.)

2. The lethal dose from a single ingestion of Sr-90 in swine results if the body burden exceeds about 1.3×10^{16} atoms of Sr-90/kg of body weight.

3. For goats, a lethal dose results if the body burden exceeds 6.1×10^{16} atoms of Sr-90/kg of body weight.

4. For most animals, it is expected that a lethal dose results if the body burden exceeds 6×10^{16} atoms of Sr-90/kg of body weight.

5. If the body burden of Cs-137 in cows and sheep (and perhaps other animals) exceeds about 5×10^{16} atoms/kg of total body weight, the animal will probably show evidence of the total-body radiation syndrome.

The type of data needed for evaluation of biological response to internal ingestion of radionuclides for adult sheep is illustrated in Table 10.

The uptake, elimination, and absorbed doses of humans from radionuclides in fallout will depend on the degree of contamination of crops, the uptake in edible parts of animals, and on the distribution of these foods in the diet. The earliest internal hazard after a nuclear war probably would arise from the consumption of contaminated water, fresh milk, and fresh green vegetables. For an attack during the growing season, radionuclides such as I-131, Sr-89, and Ba-140 in these foods would contribute most to the absorbed dose of various body organs. For an attack during the fall or winter, the Sr-89 would most likely be the predominant contributor in these same food sources from the spring peak of worldwide fallout. The longer-lived radionuclides from both foliage contamination and root uptake processes in foods would be Ru-106, Sr-90, Cs-137, C-14, and K-40, and possibly other long-lived neutron-induced radionuclides in the fallout.

The data on absorbed doses from ingestion of radionuclides by adult humans have been developed in a significant research effort conducted by K. Z. Morgan and co-workers[37] over the past 10 years. Similar sets of data for the absorbed doses for young people during their growing years have not been developed. A bone model was developed by Kulp et al[19] for the uptake of Sr-90 in worldwide fallout. Models for estimating the absorbed dose from assimilation of radionuclides in organs of humans have recently been developed;[38] applications of these models in this study for estimating absorbed doses for human organs are given in the third section of this report.

Operational Recovery Criteria

The repair and recovery, or healing, after injury appears to be a generally recognized persistent and characteristic phenomenon of biological

Table 10

SINGLE ORAL INGESTION LEVEL OF SEVERAL RADIONUCLIDES BY ADULT SHEEP CAUSING SERIOUS INJURY OR DEATH[a]

Radionuclide	Ingestion Level (atoms ingested/kg body weight) Serious Injury[b]	Lethal ($LD_{50}/30$)
Sr-90	4.7×10^{16}	4.7×10^{17}
I-131	7.4×10^{12}	5.6×10^{14}
Cs-137	2.5×10^{16}	2.5×10^{17}

a From Reference 11
b Type of injury not specified

systems. Thus, when it is observed that the response both of plants and animals (including humans) to radiation exposures is less if the time period of delivery of a given total dose is longer, biological recovery of the injury with time is inferred. While the phenomenon of biological recovery appears to be generally recognized, the quantitative nature of the recovery processes and the use of the concept of biological recovery in operations planning are not agreed upon by radiobiologists (regarding the representation of the recovery process) and by operations analysts and planners (regarding the use of the criteria derived from the representation).

The following discussion of the biological recovery process for radiation injury, and of one of the proposed representations of the recovery process for humans, emphasizes the use of a representation of the recovery process in damage assessment studies and in criteria for operational recovery. The technical data and technical aspects of repair and recovery in humans are described in Reference 39; here the recommendations of Reference 12 are assumed to be a reasonable representation of the recovery process in humans (i.e., that the biological repair or recovery rate is 2.5 percent per day of 90 percent of the exposure dose and that 10 percent of the exposure dose is not repaired). The biological recovery formula gives what is called the effective residual dose (ERD).

One fundamental aspect of biological repair and recovery is that biological systems that receive damage or injury greater than a certain level will not recover. Thus an upper limit of exposure dose exists for which biological recovery can be considered; by definition, this upper limit of exposure dose must be less than the dose that results in death. In other words, it is not appropriate to apply biological recovery criteria to a response such as death. This rather simple interpretation of what is meant by biological recovery is neglected in many damage assessment studies where the ERD (usually in the form of its maximum value) is used incorrectly to compute the number of people killed by radiation from fallout.

The second point of misuse of the ERD formula in damage assessments is that its definition is given in terms of a constant rate of chronic exposure, whereas in the damage assessment models the exposure rate is always defined to decrease with time according to $t^{-1.2}$ or other similar function of time. This misuse, however, does not receive much criticism and probably is not important because it tends to limit the time over which the largest fraction of the dose is received and thus to reduce any error due to inaccuracies in the recovery formula.

Most of the currently used fallout models include methods for estimating the potential ERD or total exposure dose (i.e., the outdoor doses) by assuming or computing an "effective" fallout arrival time at which the fallout is all deposited instantaneously. However, none of the reported computational methods that use this approximation for calculating the ERD or exposure dose during fallout arrival cite data for the reliability of the dose estimates from use of the "effective" arrival time as a mathematical technique. Additional complications in dose estimating arise owing to the fact that people may move about within and out of sheltered locations with different shielding attenuation factors. In such situations, the problem of estimating the individual ERD or exposure dose of people (or even the distribution of doses among the people) to a given degree of accuracy is impossible without specifying, ahead of time, what the movements of each individual will be. The normal procedure in estimating doses is to make rough estimates of the fraction of the time that people spend, on the average, in various types of sheltered and unsheltered locations. However, in all such cases, the computation of the ERD is more complicated than that of the exposure dose.

Another difficulty in the current applications of the ERD formulation is that it cannot be measured and used directly in postattack operations. The dose and dose rates are physical quantities obtained from radiation detection instruments without compensation for biological recovery factors.

While the problems in interpretation and use of the ERD representation appear to be numerous, some clarification can be made. In the first place, use of ERD in computations and in protective system design criteria is to be made only in reference to exposures of people and animals (and plants) that do not become casualties. Another way of stating this is that the ERD (and the implied biological recovery) applies only to those biological units that are able, after radiation exposure injury, to carry out normal functions. Thus, for humans, the recommended maximum dose is 200 roentgens ERD.[12,39] In terms of postattack recovery assessments, the interpretation regarding the operational implications is that all persons that receive about 200 roentgens ERD, or less, are counted as not being injured by the dose to the extent that they could not be part of the normal work force. The people in this injury category (i.e., those receiving between 0 and 200 roentgens ERD) therefore would be expected to recover and carry out normal functions.

Persons that receive larger exposure doses than those resulting in 200 roentgens ERD would sustain increasing biological injury resulting in serious sickness and, eventually, death. The expected 100 percent mortality dose for a prompt exposure of humans is reported to be from 600 to 1,00C roentgens.[5] If this range of exposure dose represents certain mortality for a prompt exposure, then it is reasonable to conclude that the fraction of mortalities of persons receiving 600 roentgens in 4 days or 1,000 roentgens in a month (from a rapidly decaying radiation source such as that of the radioactivity in fallout) would be very high.

The above information can be utilized in damage assessment studies in the following way: (1) the number of people expected to be uninjured or to recover would be computed on the basis of the 200 roentgen ERD limit; (2) the number of people expected to die are those computed to receive 600 roentgens in 4 days or 1,000 roentgens in a month; and (3) the number of people counted as casualties are those not otherwise accounted for; some of these will die; the remainder will recover. Without further definition of the dose distributions among those in this latter group, the median outcome might be that 50 percent of them recover.

The medical burden on the healthy survivors in the postattack period (considering only radiation injury) would be determined by the number of people in the third injury category (the casualties); the treatment and care of this group would be one factor in determining how many of them recovered, how many died, and how many were permanently disabled. Future research should be concerned with the fate of people in the third category (also for animals and other biological species for which a similar set of categories of radiation effects can be established).

One representation of the three radiation injury categories for humans is shown in Figure 1. In the figure, the effective standard intensity, I_1RN, is plotted against the time after detonation, t_e, of entry into an area covered with fallout. The RN term is the inverse of an effective protection factor, so that the boundary standard intensity between two of the three categories is directly proportional to the protection factor. The time, t_e, may represent the effective (instantaneous) arrival time of fallout, the time of entry into an area covered with fallout, or the time of exit from a perfect shelter.

The decay curve from which the 200 roentgens ERD and the other exposure doses shown in Figure 1 were obtained was taken from Reference 2. The selected exposure dose criteria that approximate the 200 roentgen ERD max criteria are 190 roentgens per week, 270 roentgens per month, and 700 roentgens per year, assuming an effective fallout arrival time of 1 hour after detonation. The latter definitions would vary depending on the decay rate of the fallout radiation and the time of arrival of fallout (from a surface detonation).

The curves to the left in Figure 1 define the upper limit criteria for civil defense protective systems (not for just a single component of the system such as a shelter). However, the protective components are evaluated from the figure in order of use so that the shelter protection factor is considered first. It can be seen from the insert curve in Figure 1 that the minimum shelter requirements for people in the first category, where the fallout arrives at 1 hour after detonation, are given by

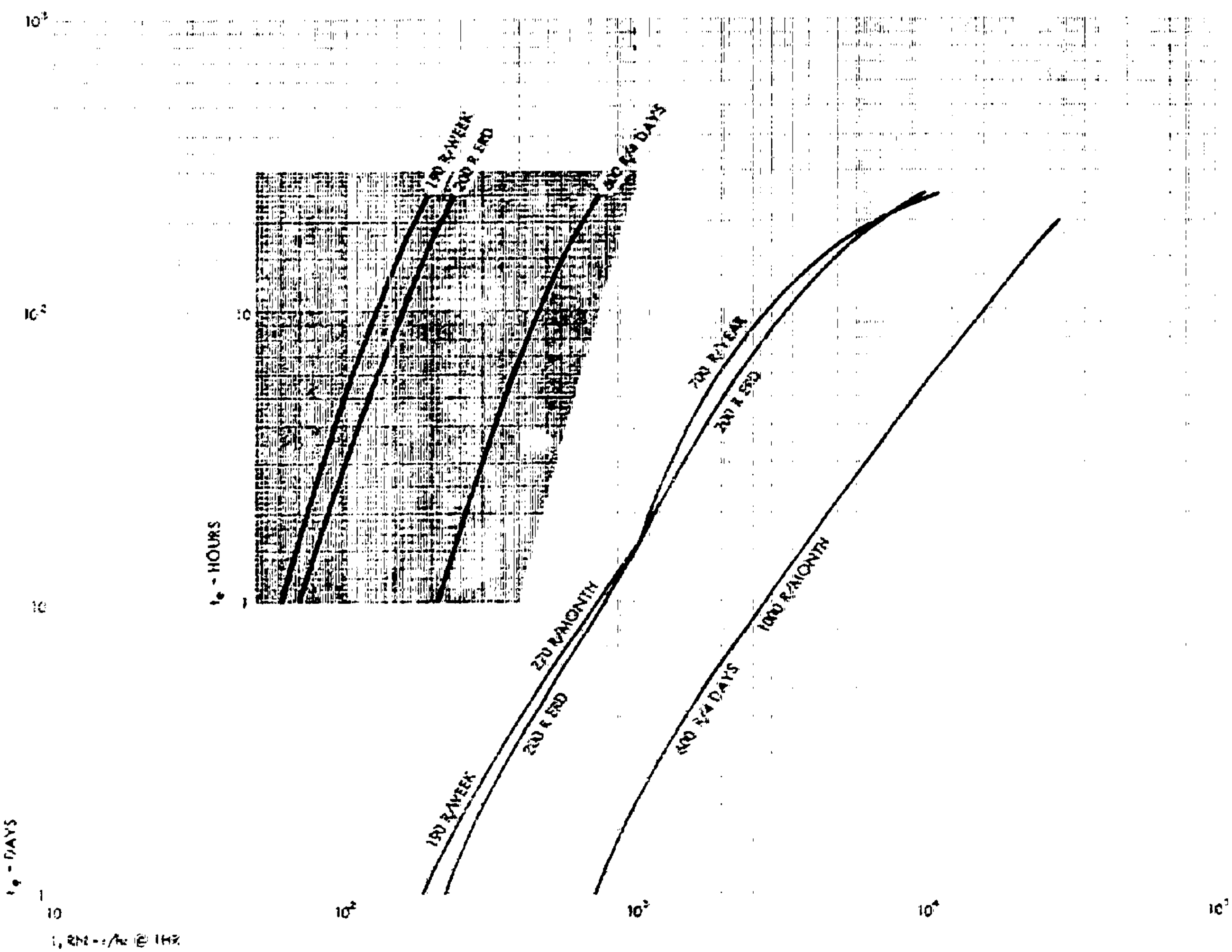
$$\frac{I_1}{PF_1} = I_1 RN_1 \approx 62.5 \tag{2}$$

where I_1 is the fallout standard intensity in r/hr at 1 hr, PF_1 is the shelter protection factor, and RN_1 is the shelter residual number. Thus the criteria for minimum adequate shelter for people in the first injury category is defined by

$$I_1 \leq 62.5 \ PF_1 \tag{3}$$

Figure 1

EXPOSURE DOSE CRITERIA OF THREE RADIATION INJURY CATEGORIES FOR HUMANS



For people in the second injury category,

$$I_1 \geq 215\ PF_1 \tag{4}$$

and for people in the third injury category,

$$62.5\ PF_1 \leq I_1 \leq 215\ PF_1 \tag{5}$$

Equations 2 through 5 give the shielding requirements for only the protective shelter without consideration of limiting the stay time in the shelter or for any out-of-shelter exposures. The representation of the exposure dose limitation (as a planning dose because operational requirements may indicate the necessity of exposure doses greater than an arbitrarily selected limit) is given, in general, by

$$D^* \geq RN_1D_1 + RN_2D_2 + RN_3D_3 \tag{6}$$

where D* is the planning exposure dose, D_1 is the out-of-shelter or outside exposure dose for the shelter stay time, RN_1 is the effective residual number for the shelter, D_2 is the exposure dose for crews or people that may be used for special operations outside of shelter, RN_2 is the effective residual number out of shelter, D_3 is the dose after permanent exit from shelter to 2.5 years (or infinity), and RN_3 is the average residual number for the third period. For people that stay in shelter until the permanent exit time, RN_2D_2 is 0. Discussion of these criteria and their relation to civil defense operations is given in Reference 40.

The types of simplified civil defense system routines described in Reference 40, together with operational planning dose criteria, can generally be used to develop design requirements for radiological defense system components and operations. The representations of the exposure criteria can be used to determine, for a given civil defense system, which routines are feasible and, in many cases, which of those feasible would be the optimum routine for meeting national postattack recovery objectives. Up to the time of this study, little evidence exists to indicate that the above-described criteria are being applied in damage assessment studies or in civil defense operations planning. The operational problems and supporting data for the detailed planning of decontamination operations are given in Volume II of Reference 2 and in References 41 and 42.

Ecological Considerations

The general ecological consequences following a nuclear war are not yet well defined but, in the main, appear to center on the chain of events that would retard or inhibit the natural recovery processes and that would lead to permanent denudation of the landscape, to erosion which would remove the fertile soil layers, and to floods which would disrupt the function of other ecosystems as well as pollute the water sources of farmland and urban (human) ecosystems. The consequences of such events on the national economy and on the population would include, first, the loss of the existing and future capital biological resources and, second, the possible continued degradation of living standards in the long term.

As previously mentioned, the major primary radiological hazards that would be most important in causing damage to the wild land and farmland ecosystems are external gamma and beta radiation and internal beta radiation from assimilation of radionuclides. It is significant, for the biological repair and recovery processes, that the injury sustained from the external hazards would be more like an acute assault than a chronic assault. The assimilation of radionuclides would be mainly a chronic exposure; the general effect of radionuclide cycling in species of ecosystems, from all available data, appears to be mainly in the class of a long-term public health problem rather than a cause of injury leading to the death of biological species.

The primary effects on ecosystems, from the two major damage phenomena of chief concern for nuclear war considerations, are those responses leading to the death or weakening of a species. Secondary effects, which may follow because of these primary effects, include a variety of further disturbances in ecosystems. For example, if an area were sufficiently contaminated so that the exposure dose from fallout killed all the trees in a young pine forest in the state of Washington or all the sprouting wheat seedlings in the state of South Dakota, the land would be bare for a period of time. Then, if heavy rains occurred prior to revegetation by weeds, pine seedlings, or annual grains, and if the terrain were hilly, severe erosion of the surface soil could occur. Less severe secondary effects include changes in relative numbers and vigor of plants in a mixed plant population and the retardation of growth of the more sensitive plants during one growing season.

The response of ecosystems, as well as an member species thereof, to external radiation would be evaluated in terms of the three categories of injury discussed above, if the data were available to do so. Such analyses would be expected to show that, after a hypothetical attack on the country, the landscapes in many areas would be the same as they were before attack; that, in other areas, all the vegetation and animals would gradually die, leaving terrestrial islands without life for some period of time; and that, in a band around the killed areas, areas would be found where the more sensitive species were killed or severely affected, and the more resistant species would remain. The relative size of these three general postattack environments and their eventual recovery would (at the least) be dependent on the size of the attack, the distribution of the burst points, the distribution of weapon yields and mix of ground and air bursts, the time of year, the weather during attack, and the composition of the ecosystems affected. Perhaps the first major ecological question is whether the killed areas would continue to grow in size or would decrease by invasion of surrounding species; the second question is what the rates of each process might be and what the more important factors that effect these rates might be

The major consequence of the cycling of the radioelements in the farmland ecosystems would be to provide paths for the entry and continued flow of these elements in the food chains of all biological species or, otherwise, paths for exit of these radioelements by concentration and retention in soils (e.g., Cs-137) or final dilution in the sea along with runoff water (e.g., Sr-90).

The more subtle secondary ecological effects include the possibilities of increased attack by predators, such as insects, on weakened species, long-term genetic effects, decreased attack on species by predators more radiosensitive than the species, further destruction by secondary fires in radiation-killed forest lands, and general changes in the relative abundance of species in a given ecosystem.

The most significant factor in determining the nature of the long-term ecological effects and the rate of recovery of the farmland ecosystems after a nuclear war would be the capability of the farmers to maintain control of these ecosystems as is currently done or, if control is temporarily lost in an area because of the presence of high levels of gamma radiation, the capability of the survivors to reestablish a desired level of control of the farmland ecosystems within a reasonably short period of time.

Wild land ecosystems are becoming under increased control by man through forest management practices, fire prevention and control, flood control, and other natural resource conservation programs. Thus, as for the farmlands, one of the more important factors in determining the degree of the long-term effects of exposure to nuclear radiation from fallout under nuclear war conditions on the wild land ecosystems would be the capability of man to reestablish needed control programs in the more seriously damaged areas.

Considerations of likely nuclear war targets and their distribution over the country and the currently available protection systems for humans lead to the conclusion that, for both the wild land and farmland ecosystems, larger areas would be damaged by external radiation from fallout than from fires. However, the time of the year of attack and the type of weather preceding and during attack would be important factors in the extent of the areas damaged by both phenomena. Especially in the areas affected by high levels of fallout, the lack of adequate protection for humans could result both in lethal doses to area occupants and extended periods of area denial for entry from other areas; thus ecological control by man could be lost for several seasons if the manpower and supporting facilities were not available to carry out needed corrective measures.

No previous studies have been reported in which specific effort has been expended to organize the data base necessary for making quantitative estimates and assessments of the ecological effects that may follow a nuclear war. An outline of some of the major factors in ecological sequelae, including data summaries on plant and animal diseases, pest and insect behavior, and other information, has been compiled by Ayres[31] in a study for the Office of Civil Defense. Other applicable data, not yet organized for use in assessment of nuclear war effects, include work in many biological laboratories (private, government, and at universities). A number of ecological research programs have been carried out in Atomic Energy Commission (and Atomic Energy Commission supported) installations including the Puerto Rico Nuclear Center, Savannah River Plant, Argonne National Laboratory, Emory University, Oak Ridge National Laboratory, Battelle-Northwest, Nuclear Test Site at Nevada (including U.S. Public Health Service), University of California at Los Angeles, and others; these programs and their data also have not yet been organized within the scope of this discussion.

Plant Radioecology

Terrestrial ecosystem structures are dominated by plants but, because of soil and climatic factors (mainly), the plant compositions vary geographically. The geographic pattern of the natural ecosystems in North America includes tundra, boreal and coniferous forests, montane coniferous forests, Eastern deciduous forests, grasslands, Pacific Northwest coastal coniferous forests, deserts, and Mediterranean vegetation in California. These long-term developed (climax) systems, in some regions, have been altered by man and converted to farmland (temporal) ecosystems. Both types of ecosystems now exist.

Recent research,[32,35] mentioned previously, has shown that variations of more than a factor of 100 in the sensitivity to damage from external gamma radiation occur. Two major practical kinds of effects on both individual plants and ecosystems occur: (1) the production of mutations and (2) the reduction of vigor.

The repair and recovery from the genetic damage (the latter being defined as an increase in the frequency of deleterious genes) involves the tendency for elimination of the deleterious genes after a few generations and for the gene frequency to return to the predamaged equilibrium. After two or three generations, populations exposed to natural selection would be expected to have essentially eliminated, or recovered from, the genetic damage.[43]

The principal effect on natural ecosystems in the third category of radiation injury, as found in both small-scale experiments and in field experiments of irradiated ecosystems, is the simplification of the ecosystem by selective mortality or growth inhibition of sensitive species. These changes in plant populations would be expected to cause changes in insect populations since the latter would be expected to be sensitive to the abundance of food supplies. In these damaged ecosystems, the capacity of the ecosystem · recover should remain intact, at least initially, but rapid changes in plant species composition and in number of plants during the first few years after injury would be expected to occur. Reduction in competition, appropriate radiation exposures, and other factors would result in stimulated growth patterns of some species and retarded growth for others (depending on the number and kind of original species present).

Lowland deciduous forests would be expected to be much less sensitive to damage than would montane coniferous forests because the deciduous trees themselves are less sensitive than are the gymnospermae and also because the lowland forests usually contain a greater diversity of species and are less prone to sustain erosion damage. Areas with the larger diversity of species generally would be expected to recover and stabilize more rapidly and at higher fallout levels than would areas with fewer species.

In areas where complete destruction of aboveground vegetation would occur, the rate of recovery would depend on whether underground shielded seeds, tubers, and bulbs were present for revegetation and whether other plants would revegetate from roots and stems. Another factor is the area size of such a devastated region; recolonization from surrounding areas would be slower if the destroyed area is large (large in width as well as in length).

Some estimated radiation exposures for likely ecosystem recovery, based on currently available data extrapolations, are listed in Table 11. In the use of the last column of the table for mature forests, the listed exposure dose should be corrected to the standard 3-foot dose computed for fallout on a level open field. A factor of 2 is suggested to account for tree height and shielding. Also, a 2-week exposure is suggested so that, for an effective arrival time of 1 hour, the calculated standard intensities for which the recovery of coniferous forests would be expected to occur are those less than 1,200 r/hr at 1 hr; for deciduous forests, the calculated intensities for recovery in 2 years or less are those less than about 6,000 r/hr at 1 hr; higher levels of fallout would be required for the same effect at later fallout arrival times. These dose levels, similar to the 200 roentgen ERD for humans, are indicators of the maximum fallout intensities and doses for which recovery would appear to be nearly certain. At higher levels, the chances of recovery would decrease; the levels at which recovery would not be possible (without assistance from man) have not yet been specified.

Further specific studies of ecosystems of different composition are needed for evaluations of the upper limits of possible ecosystem recovery and for further verification and extensions of the data needed to develop criteria such as those of Table 11. However, complete organization of currently available data on ecosystem components needs to be accomplished before an adequate assessment of the available data can be made. The duration of this study was too short for accomplishing this needed organization of the data.

Table 11

ESTIMATED RADIATION EXPOSURES
FOR LIKELY RECOVERY OF TYPICAL ECOSYSTEMS[a]

Major Ecosystem	Exposure Dose for No Significant Effect (roentgens)	Exposure Dose for Likely Recovery (roentgens)	Exposure Dose for Likely Recovery in about 2 Years (roentgens)
Typical farmland	200	200	-
Coniferous forest	200	200 - 2,000	2,000
Deciduous forest	200	200 - 10,000	10,000
Grassland	2,000	2,000 - 20,000	20,000
Herbaceous successional	4,000	4,000 - 70,000	70,000

a From Reference 43

Role of Insects

The concern about the role of insects in damaged ecosystems after a nuclear war appears to be associated with (1) the relatively high resistance to radiation of insects compared with other species (vertebrate predators, food plants, etc.), (2) the potentially high reproductive capability of insects, (3) the added insult to otherwise weakened species by insects, and (4) the reduced ability of the human survivors to maintain, or achieve, effective chemical controls.

A lack of data on the radiosensitivities of insects exists; of the existing data, it is known that the sensitivity varies by as much as a factor of 100 over the insect life cycle. No data on the beta sensitivity of insects were found during this study. The exposure doses in normal habitat geometries are needed if the role of insects in ecological recovery is to be evaluated.

It appears that many available data on the reproductive and other behavior patterns of many insects exist which could be organized for use in evaluating the role of insects (neglecting, however, the radiation effects). A review of pertinent subjects by Jenkins[44] lists the following types of information and studies for forest and orchard insects, crop insects, social insects, pests, and parasites and predators: (1) longevity; (2) flight ranges, dispersal rates, and migration; (3) breeding habits and reproduction rates; (4) feeding rates and habits and nourishment requirements; (5) mixture in colonies and competition; (6) colony growth rates and population behavior and size; (7) epidemiological roles, transmission of diseases, and vector ability; (8) host exchange; (9) pathogenic-parasite relationships; (10) mortality rates, self-destruction, and sterility; and (11) effect of insecticides and herbicides on population control.

Other factors include the causes of population eruptions (or cycles) and their relation to food supply, climate (time of year), disease, predators, and other possible stresses.

At this time, none of the above available data and factors have been correlated or analyzed with respect to the role of insects in postattack environments, although some data compilations have been initiated.[31]

DESCRIPTION OF MODELS AND ATTACK ASSUMPTIONS

Format of Computations

In this section, the model system developed for radiological systems is described along with the appropriate input data and assumptions regarding a set of attacks that was used in a set of model calculations. Those portions of the model that have been described in previously issued reports are referenced. A schematic diagram of the Stanford Research Institute radiological assessment system, designed for application to civil defense problems, is shown in Figure 2. The general assumptions involved in the development of the models, the data sources, and the concepts involved are briefly described in Reference 45.

Two assumed nuclear attacks were used in the following described computations. One was a counterforce city-avoidance type of attack with a total yield of 5,900 megatons (MC), and the other was a mixed military-city attack with a total yield of 11,900 megatons (HM).

Two types of detonations are considered in the assumed attacks. These are surface detonations which produce local fallout, and air bursts which produce only worldwide fallout.

Local Fallout Model

The model for estimating the local fallout deposit levels is described in detail in Volume I of Reference 2; some of the revisions to the model are reported in References 46 and 47. The model was developed and used as a fallout deposition scaling system rather than as a dynamic model of the fallout formation and distribution processes, to facilitate its application to the study of radiological effects from large-scale nuclear attacks. No scaling system or model has yet been applied to the estimation of fallout deposition levels from intermediate burst heights in damage assessment studies. The general effect of burst height on some of the properties of fallout are discussed in Reference 2.

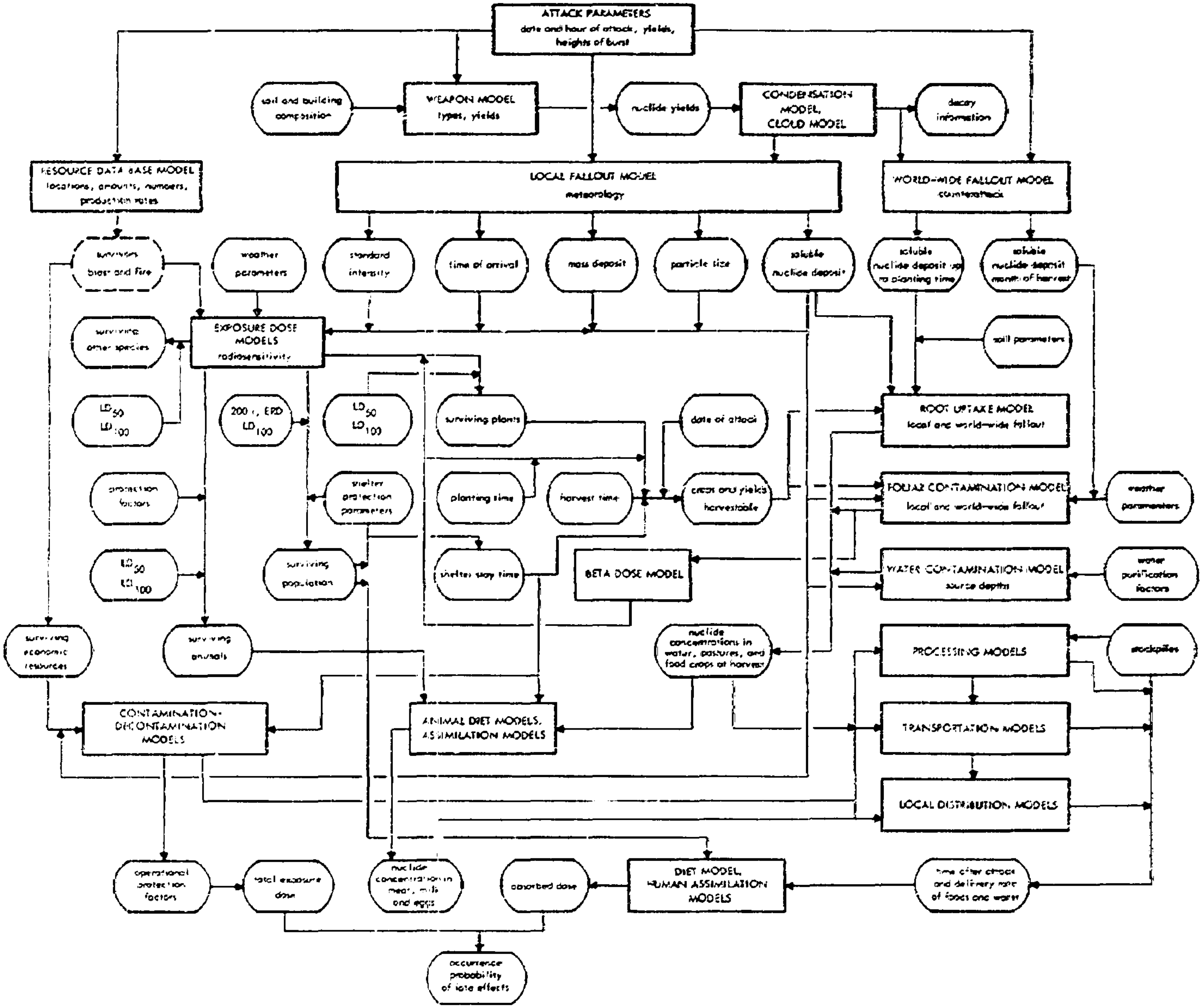
To estimate the radiological hazard as well as the radiobiological effects from fallout, the fallout model must provide estimates of (1) the magnitude of the radiation level at a given location, (2) the variation of the air ionization rate with time (i.e., the decay) for the mixture of radionuclides deposited at the location, (3) the time after detonation that the fallout arrives, and (4) the potential solubility, or biological availability, of the important radioelements in the fallout at the location.

Weapon Model

In this study, no particular weapon design or designs were selected, except that the yield of the land-surface detonations was assumed to be 37.5 percent fission. The $t^{-1.2}$ function was used to estimate external

Figure 2

SCHEMATIC OUTLINE OF MODEL SYSTEMS FOR ESTIMATING RADIOLOGICAL EFFECTS



gamma doses; its use to represent the decrease in radiation intensity with time for computing exposure doses automatically implies a weapon design that would yield almost 1 atom of neutron-induced Np-239 for every fission event. This relative amount of Np-239 would increase the standard intensities (i.e., the r/hr at 1 hr) by about 2 percent; however, at about 4 days after detonation, the radiation rate from the Np-239 would be about equal to the total radiation rate from all the fission products. Such a contribution from the Np-239 is about enough additional radiation in the period from 3 to 10 days after fission to produce a gross decay curve that is better approximated by the $t^{-1.2}$ function than is the decay from the fission products above. The decay curves for more accurate estimates of the decrease in radiation rate from the radionuclides in fallout at longer times after detonation are discussed in Reference 2.

Radionuclide Solubility Model

The model used for estimating the potential solubility or potential biological availability was generally based on the fallout formation model in References 2 and 47; however, for this study, extensive revisions were made on the thermodynamic data used in the calculations, and new methods for estimating the average solubility as a function of particle size for the six major biologically important radioelements were developed.

Worldwide Fallout Model

The worldwide fallout model used in these calculations is described in References 45 and 48.

Water Decontamination Model

The water supply of the United States is generally obtained either from ground sources or surface sources.[49] Ground-source water includes that from wells, springs, and infiltration galleries. Surface sources are lakes, reservoirs, and streams. Water from ground sources, especially at early times after an attack, would be virtually free from contamination because the fallout deposited upon ground surface areas would initially be precluded from the ground water supply by an earth mantle. The penetration of this mantle by the soluble fractions of fallout and its subsequent movement through the earth to the location of withdrawal is a very slow process.

Although ground water may be free from contamination, since it is pumped from wells, it may still become contaminated prior to consumption. For instance, if the water is first pumped to an open (unprotected) water storage reservoir or if the water is pumped to a contaminated distribution reservoir, the water would become contaminated. The estimation of the degree of contamination of clean water by these processes would require a detailed study of each water system. In this study, all communities partially or wholly supplied from ground sources were assumed to have clean relatively uncontaminated potable water available for use.

Surface waters, on the other hand, would be directly contaminated by the deposited fallout. The concentration of radionuclides would be proportional to the soluble amounts deposited per unit area upon the surface and inversely proportional to the average depth of the surface water supply. This definition of concentration is based upon the assumption that the soluble fractions of fallout isotopes would be uniformly mixed in the total volume of water; thus the water from shallow surface sources would be, at least initially, the most highly contaminated. The depths of reservoirs and especially streams vary widely throughout the time of year and from year to year. The depths of some streams during periods of heavy runoff may easily be a factor of 5 deeper than the near minimum values used in this study. The depths of reservoir water, on the other hand, are maximum values.

In this study, the calculated radionuclide concentrations of surface sources are for the fallout that fell directly into the surface waters. Fallout radionuclides deposited upon ground areas and subsequently carried by runoff into surface waters due to a period of heavy precipitation were not considered; dilution of the nuclides already in the water by rain or by adsorption on bottom materials also was not considered. Available data, that of measured concentrations of Sr-90 and gross beta activities in precipitation and in streams, show that, at least for worldwide fallout, only 1 to 10 percent of Sr-90 as well as gross beta activities deposited in watershed or drainage basin areas is carried with runoff to streams.[22] The available data do not provide any generalized evaluation of the migration dynamics of radionuclides through watersheds, so that the elapsed time between the times of fallout deposition and maximum stream contamination could not be determined; in general, it appears that, at least for the wet season, the elapsed time is less than 1 month.

Of the 16,747 communities in the United States served with public water supplies, 11,784 are partially or wholly supplied from ground sources. On the basis that those localities that are partially supplied by ground water sources would have sufficient water from these supplies for postattack emergency use (but requiring power for pumping), the source water for 70 percent of all communities would be relatively unaffected by fallout. However, of the 184 larger communities, representing a total of 71 million people, only 43.5 percent of the people have adequate public ground water sources. Although this percentage may be increased to 61 percent if both private industrial and public water supplies are considered available for public consumption (in the communities where they exist) during the postattack period, only the available public water sources were considered in the computation of the radionuclide contamination in water supplies for the proposed nuclear attacks upon the United States.

For any proposed attack, parts of water systems (especially the distribution systems) that are located near explosion points would be destroyed or damaged. Wherever this occurs, the water supply may be disrupted or completely lost until the damaged component is repaired or replaced. This aspect of the availability of water supplies for the survivors is not considered in this report; the discussion here is limited to the possible levels of water contamination.

The complete destruction of a water source, on the other hand, would not be readily achieved by explosion phenomena. Water in lakes, streams, and diversion reservoirs is not normally very vulnerable to blast damage, and some water loss would be expected if the source was located within the region of the crater. The same general low damage vulnerability would hold for ground sources; an exception would be a direct hit on a small well-field or on a rather small stream. In such a case, the well-field could be destroyed, and the lip of the crater could divert the water off stream and render it unusable. Also, a direct hit upon the dam of an impoundment reservoir would certainly cause the loss of the water from the reservoir. On the other hand, most large communities have one or more alternative water supply sources.

The water contamination data for the 184 large communities in this study were used as a "sample" of the available water for the entire (urban) population of the United States. The selected sample should tend to give a nuclide concentration distribution that is somewhat higher than the national distribution because the communities not in the sample generally have more well-water sources. Although the contamination in the water from streams normally depends upon the amount and rate of fallout at upstream locations, and the radionuclide concentration in the water when drawn would depend upon when it was drawn and the rate of stream flow, in this study the concentration computations were simplified by treating these waters as though they were from a stationary source.

Errors introduced by this computational treatment would be largest for communities that use water from exceptionally long streams where the water from one geographical location is transported to another distant location and the amount of fallout deposited at the two locations is grossly different. For example, the calculated radionuclide concentrations in the water for a community such as New Orleans, Louisiana, may underestimate the real concentrations for that city if the heavier fallout deposits in the upstream parts of the Mississippi River (and Ohio River, etc.) were actually carried as far as New Orleans.

The direct contamination of exposed surface waters by fallout particles landing on the water may include (1) the suspension of small insoluble particles and (2) soluble radioelements that dissolve when the carrier particle lands in the water. The larger fallout particles will settle rapidly to the bottom of still water. The only important group of elements, for potable water sources, are the soluble elements.

External Contamination of Plants

The external contamination of plants by local fallout particles is discussed in detail in References 9 and 10. The major portion of the currently available data on the subject was obtained in the Costa Rican experiments; however, in this described study, which was initiated prior to the Costa Rican work, the plant contamination factors that were used were those derived from the field test data, as shown in Figure 3. In the model, the average effect of weathering on the foliar deposits was assumed to be represented by

$$a_L = a_L^o e^{-0.05(t-\bar{t}_a)} \tag{7}$$

where a_L is the contamination factor in terms of the ratio of the activity or weight concentration of the fallout on the foliage to the surface density of the fallout, and $\bar{t}_a$ is the average time of arrival of fallout. The factor, 0.05, corresponds to a weathering half-life of 14 days, as discussed in References 9 and 50. Newer data on the effect of wind and rain on foliar contamination indicate that weathering effects, in general, do not correspond to that given by Equation 7; however, the computations of this study were made using Equation 7 and therefore underestimate, to some degree, the contamination levels on most food crops due to the contamination of the foliage by local fallout. The initial values of the contamination factors, $a_L^L (\approx a_L^o)$, used in the calculations are summarized in Table 12.

Entry of radioactivity from worldwide fallout into plants is made via two major routes: (1) direct foliar absorption of radionuclides in solution in rain and (2) root uptake from the accumulated nuclides in the soil. Measurements of the total specific activity of the edible parts of plants therefore represent the sum of both odes of entry, and the problem becomes one of separating the total int parts. There are many data available on root uptake from pot experiments so that it would appear that a reliable approach would be to subtract that amount of activity due to root uptake from the soil. The usual result, however, is that all or more of the observed activity is accounted for by root uptake alone. It would therefore appear that the uptake of crops grown in the field is different from that of crops grown in pot experiments.

Among the reasons for such differences, aside from the usual uncertainty in the number of atoms (such as Sr-90) per unit area of soil, are the effects of distribution in depth in relation to root habit and the long-term availability of the nuclide in question. The method usually followed in assessing foliar and root uptake from worldwide fallout is to set up an equation with two unknowns and solve these over successive years.[51,52] This method, for any nuclide, is represented by

Figure 3

EXPERIMENTAL VALUES OF a_L

AS A FUNCTION OF a_o FOR A 15 MPH WIND SPEED

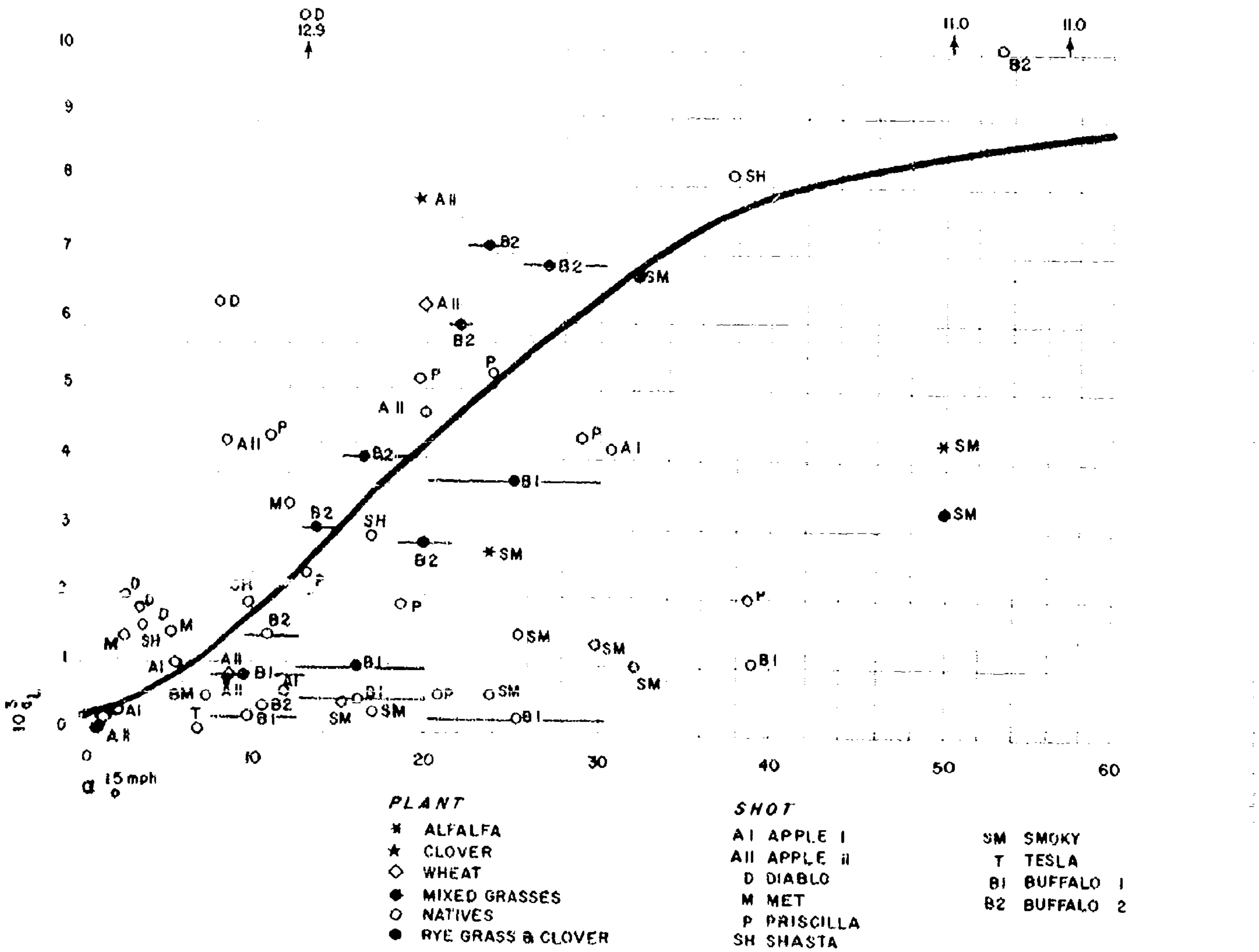


Table 12

FOLIAR CONTAMINATION FACTOR VERSUS α_o^{15}
AND RELATED PARAMETERS

α_o^{15}	Particle Falling Velocity v_f^o (mph)	Particle Diameter d (microns)	Foliar Contamination Factor a_L^L (sq ft/gm)
0.15	100	8,000	0.000200
0.50	30.0	1,170	0.000225
1	15.0	500	0.000250
5	3.00	120	0.000750
6	2.50		0.000930
10	1.50	75	0.00170
15	1.00		0.00300
20	0.75	50	0.00425
25	0.60		0.00535
30	0.50	40	0.00635
35	0.4286		0.00720
45	0.3333		0.00815
75	0.2000	25	0.00912
100	0.1500		0.00945
150	0.1000		0.00975
300	0.0500	13	0.00997
400	0.0375		0.0100
↓	↓		↓
∞	0	0	0.0100

Source: Derived by Stanford Research Institute

$$N_f = A^O N^O(t) + B^O N^O(T) \text{ atoms/gm} \quad (8)$$

where $N^O(t)$ is the fallout deposit in a time interval designated by t and $N^O(T)$ is the total fallout deposited up to the time of sampling, both in atoms/sq ft.

A set of A^O and B^O values is given in Reference 52 for Sr-90 in which the $N^O(t)$ values used were monthly values (averaged over a 6-month period) as taken from an averaged accumulation curve of $N^O(T)$; the $N^O(T)$ values at July 1 of each year were used.

The derived values of a_L^W, in atoms/gm dry weight per atoms/sq ft, for Sr-89, Sr-90, Zr-95, Ru-106, Cs-137, and Ce-144 are listed in Table 13. The root crops were assigned very small values; that is, except for Cs-137, the radioelements are not considered to translocate from foliage to roots to any appreciable extent. The a_L^W values for sorghum and oat were made equal to that for wheat. As suggested in Reference 53, the Sr-90 in lucerne (alfalfa) was mainly attributed to direct contamination; the a_L^W value was accordingly chosen to account for 80 percent of the observed lucerne contamination. A similar assignment was made to clover. It should be noted that dry weights are specified in the table, consistent with the a_L^L values presented earlier but differing from the common practice of reporting worldwide food contamination in terms of fresh or market weight.

In summary, a single a_L^W value was assigned to each crop for contamination from worldwide fallout, assuming that superficial activity was removed by normal washing or preparation and that the levels reported reflected true tissue absorption. The absorbed number of atoms of the ith kind at zero time in the edible plant tissue is

$$C_i = a_L^W N_i^O(t) \text{ atoms/gm dry weight} \quad (9)$$

where $N_i^O(t)$ is the zero-time number of atoms of the ith kind per square foot of soil deposited in the last month before harvest.

Estimates of $N_i^O(t)$ are available for eight different nuclides from the worldwide fallout model discussed earlier. It is assumed that all worldwide fallout is soluble and hence available for absorption.

The complete expression for the number of zero-time atoms incorporated into the edible parts of a crop planted subsequent to a nuclear attack is

$$C_{if} = \frac{a_{SU}}{\rho D}\left[N_i^O + \sum_{o}^{p} N_i^O(t)\right] + a_L^W \sum_{h-1}^{h} N_i^O(t) \text{ atoms/gm dry weight} \quad (10)$$

Table 13

ESTIMATED VALUES OF a_L^w FOR SELECTED CROPS AND RADIONUCLIDES

Crop	a_L^w $\left(10^{-5}\ \frac{\text{atoms/gm dry weight}}{\text{atoms/sq ft soil}}\right)$			
	Sr-89, Sr-90	Zr-95, Ce-144	Ru-106	Cs-137
Corn	90	0.1	0.3	40
Sorghum	90	9.0	27	450
Wheat	90	9.0	27	425
Oat	90	9.0	27	450
Barley	30	3.0	9.0	180
Dry bean	20	2.0	6.0	800
Soy bean	20	2.0	6.0	240
Alfalfa	600	600	600	600
Clover	700	700	700	700
Potato	1	0.1	0.3	100
Green pea	6	0.6	1.8	18
Sugar beet	1	0.1	0.3	100
Tomato	500	500	500	1,750
Snap bean	20	2.0	6.0	60
Cabbage	300	300	300	1,050
Dry Onion	1	0.1	0.3	100
Carrot	1	0.1	0.3	100
Lettuce	500	500	500	1,750
Apple	50	5.0	15	150
Peach	300	30	90	900
Orange	50	5.0	15	150

Source: Stanford Research Institute

where

a_{SU} is the soil uptake factor, $\frac{\text{atoms/gm plant}}{\text{atoms/gm soil}}$

ρD is the soil density-depth or mixing factor

N_i^o is the number of available ith atoms/sq ft of soil from previous local fallout

$N_i^o(t)$ is the number of available ith atoms/sq ft deposited as worldwide fallout. The summation from o to p (i.e., from attack to planting) is the cumulative amount available for root uptake; the summation from h-1 to h (i.e., over the last month before harvest) is the amount responsible for foliar contamination

Internal Contamination of Plants

The uptake of radionuclides from fallout by plants through their root system would be the major path of food contamination in the long-term period after a nuclear war.

The major factors that influence the uptake of radionuclides by plants through their root system are (1) physiochemical properties of the radioelement, (2) plant species, (3) soil type, and (4) soil management practices.

The assimilation of nutrients, or inorganic ions, by the roots of plants usually involves soluble exchangeable ions in the soil. When new ions, from a mineral fertilizer or from fallout particles, are introduced into the soil, they compete with and replace other ions on exchange sites in the soil. In some reactions with the soil, the new ions become non-exchangeable, and, to the extent that these reactions occur in a soil, some portion of the radioelement becomes unavailable for uptake. Thus the types of interactions that occur between the soluble radionuclide and the soil constituents determine the availability of the radionuclide for uptake from the soil. The model for this mode of food contamination is discussed in detail in References 52 and 54.

General Model for the Internal Contamination of Animals, Fowl, and Fish

Estimates of the amount of radionuclides in meat and eggs were made by means of a simplified assimilation model. The major simplifying assumption for the model is that the nuclide is assimilated by a body organ at the time of ingestion. Also, in the model, it is assumed that a constant fraction, f_{ik}, of the nuclide ingested enters the kth organ and that, except for assigned decay processes, the ingestion rate, U_{if}^o, of the fth food is constant. The rate of change in N_{ik}, the number of atoms of the ith nuclide in the kth organ (i.e., soft tissue such as muscle), is then represented by

$$dN_{ik}/dt = f_{ik}U_i^o - \lambda_{ik}N_{ik} \text{ atoms/day} \quad (11)$$

in which

$$U_i^o = \sum_f U_{if}^o \text{ atoms/day} \quad (12)$$

and where λ_{ik} is the biological elimination rate constant for the organ and radionuclide of interest. Integration of Equation 11, under the condition that N_{ik} is zero at t_o (the time after attack at which ingestion is started), gives

$$N_{ik} = \frac{f_{ik}U_i^o}{\lambda_{ik}}\left[1 - e^{-\lambda_{ik}(t - t_o)}\right] \quad (13)$$

When radioactive decay is included in the ingestion rate, Equation 13 becomes

$$N_{ik} = \frac{f_{ik}U_i^o e^{-\lambda_i t}}{\lambda_{ik}}\left[1 - e^{-\lambda_{ik}(t - t_o)}\right] \quad (14)$$

where λ_i is the radioactive decay rate constant of nuclide i and t is the time after detonation.

For green leafy foods (such as pasture grasses) where weathering and growth effects cause a decrease in foliar contamination, it was assumed that the ingestion rate would be represented by

$$U_{if} = U_{if}^o e^{-\lambda_i \bar{t}_a} e^{-(\lambda_i + k_w)(t - \bar{t}_a)} \quad (15)$$

where $\bar{t}_a$ is the median or average time of fallout arrival and k_w is an empirical decay rate constant.* The value of N_{ik} for these foods is

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* This formulation applies to the assumption that all the radioactivity is removed by weathering effects with a given half-life, usually taken to be 14 days (prior to the Costa Rican experience).

$$N_{ik} = \frac{f_{ik} U_i^0 e^{-k_w (t_0 - \bar{t}_0) - \lambda_i t}}{(\lambda_{ik} - k_w)} \left[e^{-k_w (t - t_0)} - e^{-\lambda_{ik} (t - t_0)} \right] \tag{16}$$

The chief use of Equation 13 is for analyzing data to determine the values of f_{ik} and λ_{ik} for various radionuclides and tissues of different animals. Equation 14 applies to stored foods for a single crop, such as grains and hay, and perhaps to water from exposed sources; the value of U_i^0 depends on location and crop and thus is adjusted at least on a yearly basis. Equation 16 was restricted to foliar contamination in the calculations and thus applies only to field crops that are standing at the time of an attack, for local fallout deposition, and during the following growing seasons, for worldwide fallout deposition.

The concentration of the radionuclide in an organ or soft tissue at the time, t, after detonation, in the case where the tissue is used as a human food, is given by

$$C_{ik} = \frac{N_{ik}}{m_k} \text{ atoms/gm} \tag{17}$$

where m_k is the mass of the tissue that contains the N_{ik} atoms.

For food products that are produced by an animal at an average (daily) rate in which the concentration of the nuclide in the product (milk from cows and eggs from chickens, for example) is controlled mainly by the elimination of the nuclide from one (or more) body organs or tissues, the rate of change of the number of atoms in the secreted product is represented by

$$dN_{if}/dt = f_{if} \lambda_{ik} N_{ik} \text{ atoms/day} \tag{18}$$

where f_{if} is the fraction of the amount eliminated from organ k that enters the food product.

Internal Contamination of Animals (Meat and Milk)

The analysis of data for determining f_{ik} and λ_{ik} from experiments in which a single ingestion (i.e., dose) is administered to animals was carried out using the following model equations. The number of atoms at any time in an organ in the simplified model for the single ingestion case (not accounting for radioactive decay) is represented by

$$N_{ik} = f_{ik}U_i^{oo}e^{-\lambda_{ik}(t - t_o)} \quad (19)$$

where U_i^{oo} is the number of atoms ingested and f_{ik} is the fraction that is assimilated (instantaneously) by the kth organ. The number of atoms eliminated from a body organ in a secreted product (for example, in all the eggs produced by a chicken) between t_o and t is then

$$N_{if} = f_{if}f_{ik}U_i^{oo}\left[1 - e^{-\lambda_{ik}(t - t_o)}\right] \quad (20)$$

where f_{if} is the fraction of the nuclide, eliminated from organ k, that is incorporated into the secreted product.

For atoms that are eliminated from a body organ in a secreted product (such as milk), the rate of change of the concentration in the product (as a food) is given by

$$dC_{if}/dt = \frac{f_{if}f_{ik}U_i^{oo}\lambda_{ik}}{m_f} e^{-\lambda_{ik}(t - t_o)} \quad (21)$$

in which m_f is the mass of the product. Muscle, or meat, however, is treated as one body organ (occasionally even as whole body) so that the concentration of a nuclide in meat is derived directly from Equation 19 by

$$C_{if} = \frac{f_{ik}U_i^{oo}}{m_k} e^{-\lambda_{ik}(t - t_o)} \quad (22)$$

where m_k is the total weight (wet basis) of the muscle (or whole body).

Much of the available data on the assimilation of radionuclides by animals and fowl is reported in terms of the fraction of the dose (i.e., amount of the nuclide ingested), or fraction of the dose per unit weight of tissue, absorbed for a single ingestion and the fraction of the daily dose, or fraction of the daily dose per unit weight of tissue, for a chronic ingestion. Therefore, the above equations are converted, for convenience, to the fractional notations. For the single ingestion, F_{ik} and F_{if} are designated as the fraction of the dose assimilated; these fractions, from Equations 19 and 20, are

$$F_{ik} = N_{ik}/U_i^{oo} = f_{ik}e^{-\lambda_{ik}(t - t_o)} \quad (23)$$

and

$$F_{if} = N_{if}/U_i^{oo} = f_{if}f_{ik}\left[1 - e^{-\lambda_{ik}(t - t_o)}\right] \qquad (24)$$

The fractions of the dose per unit weight of tissue are, respectively,

$$F'_{ik} = C_{ik}/U_i^{oo} = f_{ik}/m_k, \text{ at } t = t_o \qquad (25)$$

and

$$F'_{if} = C_{if}/U_i^{oo} = f_{if}f_{ik}/m_k, \text{ at } t >> t_o \qquad (26)$$

Thus the intercept of Equation 21 for C_{if}/U_i^{oo} at $t = t_o$ is $f_{if}f_{ik}\lambda_{ik}/m_k$; for most data, only the value of the product, $f_{if}f_{ik}$, can be evaluated.

The fraction of the daily dose from continuous ingestion experimental data, using Equations 13 and 18, at steady state, are

$$F_{ik} = f_{ik}/\lambda_{ik} \qquad (27)$$

and

$$F_{if} = f_{if}f_{ik} \qquad (28)$$

Certain basic relationships between animal food ingestion (or intake) rates and their body or muscle weights can occasionally be used to estimate values of f_{ik}, $f_{if}f_{ik}$, or λ_{ik} if the value of one of the constants is known and if the steady-state concentrations of a nuclide in both the ingested food and the organ are known. This ingestion-rate dependence on muscle weight is described indirectly in Reference 11; to illustrate, let

$$\dot{m}_f = K_{fk}m_k \qquad (29)$$

where $\dot{m}_f$ is the dry food intake rate, m_k is the muscle weight, and K_{fk} is a constant for an animal. Also,

$$U_i^o = C_{if}\dot{m}_f \qquad (30)$$

and

$$N_{ik} = C_{ik} m_k \tag{31}$$

The value of f_{ik}/λ_{ik} from Equations 29, 30, and 31 is given by

$$\frac{f_{ik}}{\lambda_{ik}} = \frac{C_{ik}}{C_{if} K_{fk}} \tag{32}$$

Values of λ_{ik} and f_{ik} for muscle tissue (meat) that were derived from various data sources using the above-described equations are summarized in Table 14. In spite of all the published data on Sr-90 and its accumulation in bones, practically no experimental data have been reported on its behavior in the other (more edible) tissues of animals. The average values of m_k, $\dot{m}_f$, and K_{fk} for the muscle of several fullgrown animals are given in Table 15.

Internal Contamination of Fowl (Eggs and Meat)

The concentration of a nuclide in eggs is given by

$$C_{if} = \frac{dN_{if}/dt}{m_f \dot{e}} \text{ atoms/gm} \tag{33}$$

in which m_f is the average weight of an egg and $\dot{e}$ is the average production rate in number of eggs per day. However, the whole egg is not used as food; only the yolk and egg white (albumen) are eaten. However, the yolk and albumen have slightly different assimilation patterns for radionuclides such as Sr-90, Ca-45, and I-131.[61-65] Therefore, if the yolk and albumen are taken together, the average concentration of a nuclide in the two parts of the egg for a single ingestion is given by

$$C^o_{if} = \frac{U^o_i}{m_f \dot{e}} \left\{ F_{ie} \left[1 - e^{-\lambda_{ik}(t - t_o)} \right] + F'_{ie} \left[1 - e^{-\lambda'_{ik}(t - t_o)} \right] \right\} \tag{34}$$

or

$$C_{if} = \frac{U^o_i e^{-\lambda_i t}}{m_f \dot{e}} \left\{ F_{ie} \left[1 - e^{-\lambda_{ik}(t - t_o)} \right] + F'_{ie} \left[1 - e^{-\lambda'_{ik}(t - t_o)} \right] \right\} \tag{35}$$

Table 14

SUMMARY OF DERIVED ASSIMILATION MODEL EQUATION CONSTANT VALUES FOR THE MUSCLE TISSUE OF MEAT ANIMALS

Nuclide	Animal	C_{ik}	C_{if}	λ_{ik} (day^{-1})	f_{ik}	Reference
Cs-137	Cattle	-	-	0.045	0.38	11
	Caribou[a]	20 pc/gm	20 pc/gm	(0.03)[b]	0.5	55
	Caribou[a]	3 pc/gm	10 pc/gm	(0.03)	0.15	55
	Caribou[a]	30 pc/gm	20 pc/gm	(0.03)	0.75	55
	Reindeer[a]	35 pc/gm	36 pc/gm	(0.03)	0.49	56
	Swine	-	-	0.023	0.49	11
	Swine	0.134 mc/gm	0.116 mc/gm	(0.02)	0.49	57
	Sheep	-	-	(0.03)	(0.5)[b]	
K	Swine	2.6×10^{-3} gm/gm	5.0×10^{-3} gm/gm	(0.02)	0.22	57
I-131	Cattle	-	-	(0.05)	0.090	11
	Sheep[c]	1.8×10^{3} pc/gm	2.3×10^{4} pc/gm	0.051	0.049	11, 58, 59
	Swine	-	-	(0.05)	(0.07)	
Sr-90 (Sr-89)	Cattle	-	-	(0.35)	0.053	11
	Sheep	-	-	0.35	(0.06)	60
	Swine	-	-	(0.35)	(0.06)	

a Assumed $K_{fk} = 0.06$ day^{-1}

b Values in parentheses are estimated

c Concentration of I-131 in meat assumed to be equal to its concentration in blood, as suggested in Reference 11

Table 15

MUSCLE WEIGHTS AND FOOD INTAKE RATES OF SEVERAL ANIMALS[a]

Animal	m_k (gm)	$\dot{m}_f$ (gm/day)[b]	K_{fk} (day^{-1})
Beef cattle	1.8×10^5	8×10^3	0.045
Dairy cattle	1.6×10^5	9×10^3	0.056
Sheep	2.4×10^4	2×10^3	0.083
Swine	8.5×10^4	4×10^3	0.047

a From Reference 11
b Dry weight basis

or

$$C_{if} = \frac{U_i^o e^{-k_w(t_o - \bar{t}_a)} e^{-\lambda_i t}}{m_f' \acute{e}} \left\{ \frac{\lambda_{ik} F_{ie}}{(\lambda_{ik} - k_w)} \left[1 - e^{-\lambda_{ik}(t - t_o)} \right] + \frac{\lambda_{ik}' F_{ie}'}{(\lambda_{ik}' - k_w)} \left[1 - e^{-\lambda_{ik}'(t - t_o)} \right] \right\} \tag{36}$$

in which

$$F_{ie} = f_{if} f_{ik} \tag{37}$$

and

$$F_{ie}' = f_{if}' f_{ik} \tag{38}$$

Also, λ_{ik} and f_{if} are for the yolk, λ_{ik}' and f_{if}' are for the albumen, and m_f' is the average weight of the yolk and albumen. The weights (wet basis) of the three parts of an egg from a mature hen are as follows: yolk--15 to 17 grams; albumen--24 to 27 grams; and shell--6 to 7 grams. The average value of m_f' for use in the above equations is 41 grams. The value of $\acute{e}$ for laying hens may range from less than 0.5 to almost 1.0 egg per day; an average of 0.6 egg per day is suggested. This production rate may be somewhat less than that achieved in a well managed poultry farm but it also may be somewhat higher than would be obtained in the postattack period of a nuclear war.

The general findings and conclusions from the data on the assimilation of radionuclides by fowl (mainly chickens) and the accumulation of the nuclides in eggs are as follows:

1. The pattern of elimination of strontium and calcium from the hen in eggs is about the same (see Figures 4 and 5); however, in some data,[66] discrimination between the two elements is shown.

2. For both strontium and calcium, about 30 percent of the amount ingested is concentrated in the shell of the first egg produced following the ingestion. About 50 percent of the ingested amount of these two elements is excreted (in eggs and feces) within about 48 hours.

3. The concentration of all radionuclides (for which data are available) in the egg yolk increases slowly after the start of ingestion; for a single ingestion, a maximum concentration occurs at about 4 days after the ingestion for cationic elements. For

Figure 4

FRACTION OF DOSE ELIMINATED IN EGGS AFTER A SINGLE INGESTION OF SR-90 AND CA-45[62]

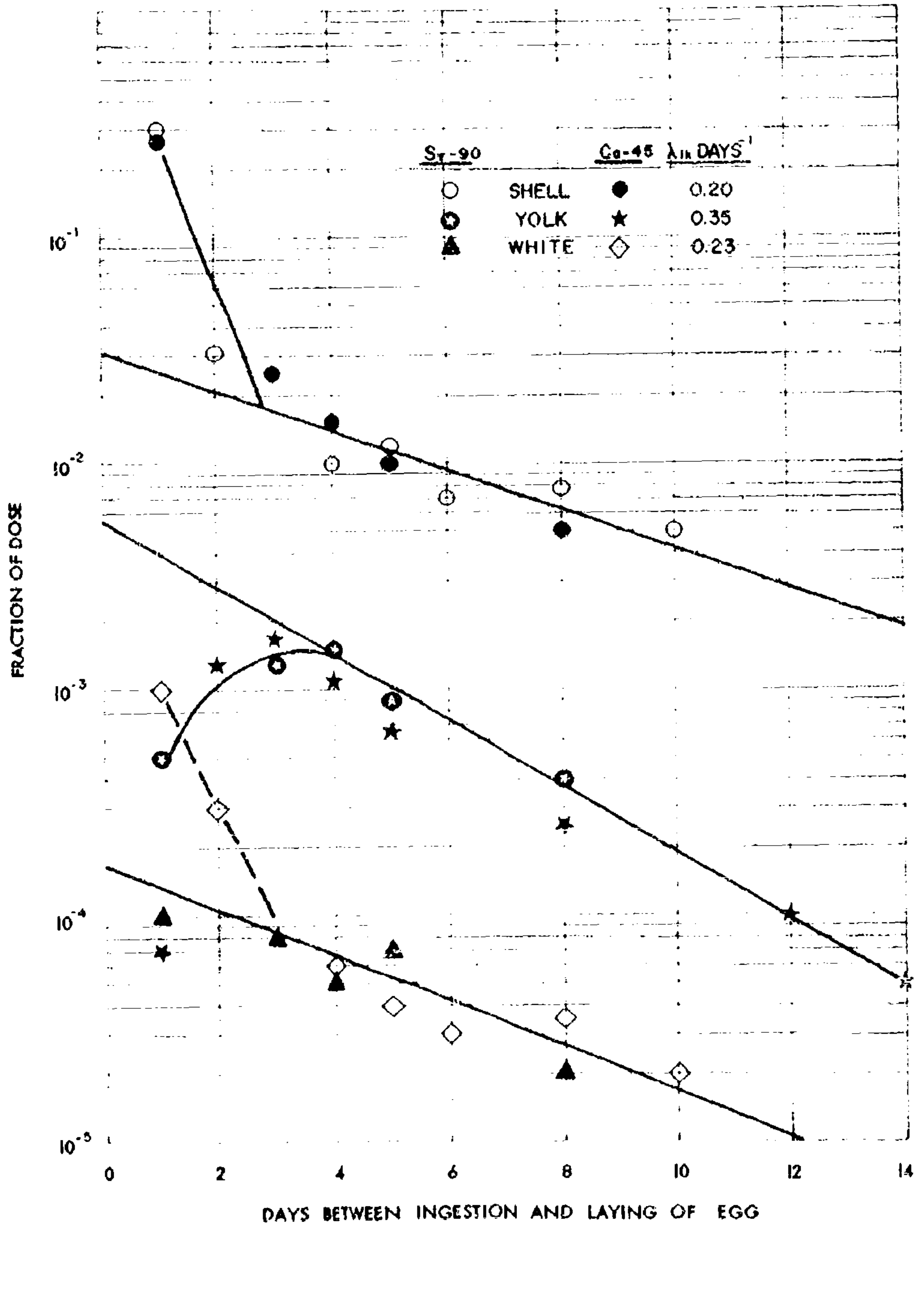
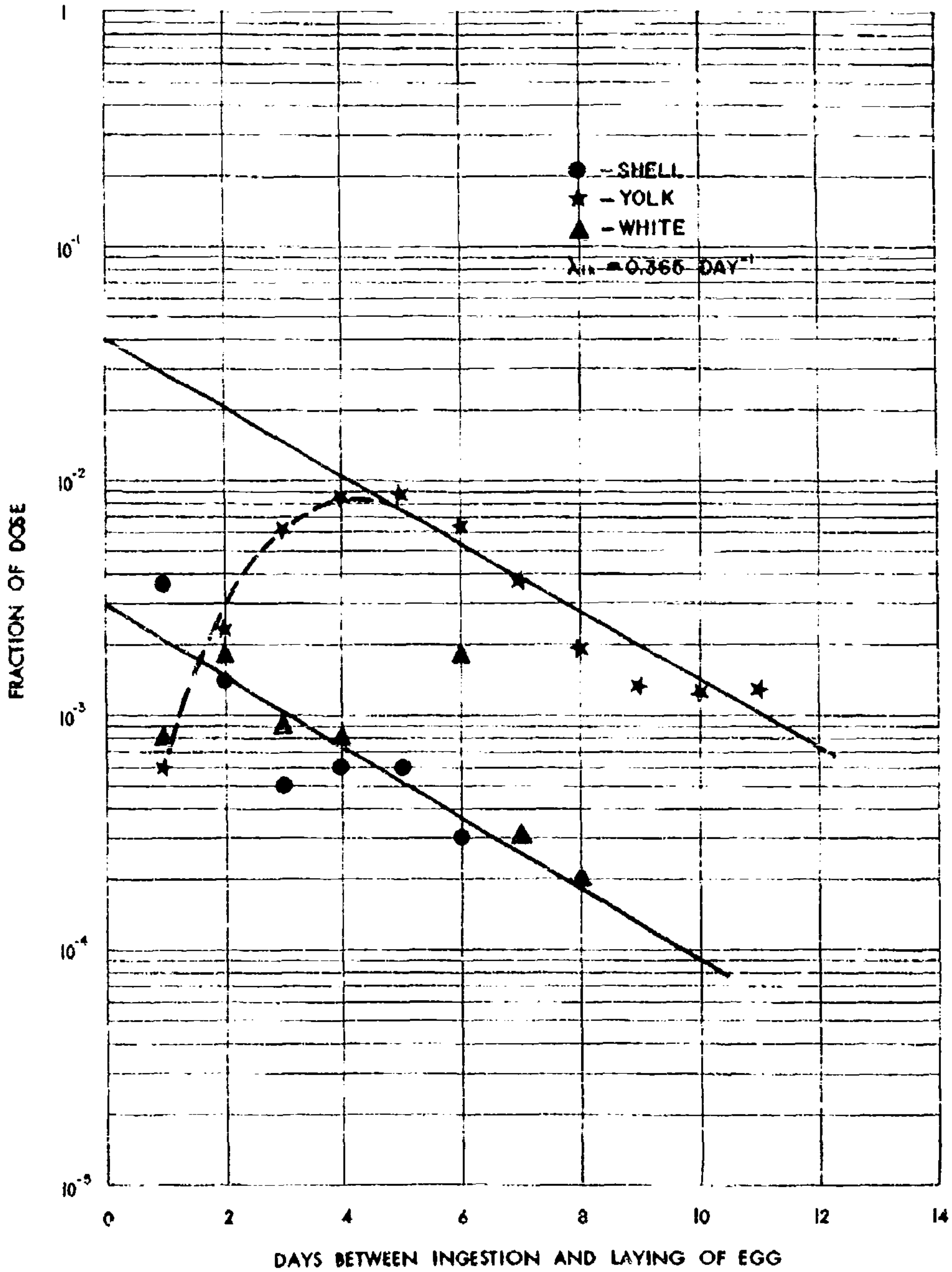


Figure 5

FRACTION OF DOSE ELIMINATED IN EGGS AFTER A SINGLE INGESTION OF P-32[66]



I-131, the maximum concentration in the yolk occurs at 6 days after ingestion.[63] The concentration of all elements in the shell and in the albumen is highest in the first egg and is less in succeeding eggs. Some data (on single ingestions) suggest that the concentrations of strontium and calcium in the egg become constant (or decrease very slowly) after about 3 weeks. No experimental work has yet been carried out long enough to establish whether the concentrations do level off. If this occurred, the concentrations in eggs for a continuous ingestion of radioactively contaminated food would increase for a long period of time. The simplified radionuclide assimilation model then would not be applicable for describing the situation.

The model equations do not represent the described buildup of the concentration of strontium and calcium in the egg yolk. The slow buildup of the concentration in the yolk, compared with the rapid assimilation in the eggshell, suggests that a two-stage exchange process occurs in the hen as the yolk forms. That is, the release of the elements utilized in the formation of the yolk is controlled by other body organs (which had previously assimilated them). A more complicated mathematical model is required to describe such a process; this type of process has been represented by model equations for the concentrations of radionuclides in milk from the cow;[67] a similar derivation could be made for egg production.

A summary of some derived assimilation model equation constant values for poultry and eggs is given in Table 16. While the use of the derived values of the equation constants in the equations should reproduce the data from which the equation constants were derived, the poor quality and limited scope of the original data limit the extrapolation of the data (through the model equations) to order-of-magnitude estimates for the concentrations of the listed radionuclides in the edible parts of poultry and eggs.

Internal Contamination of Fish and Other Aquatic Organisms (Meat)

The assimilation of radionuclides by fish is complicated by the fact that the fish would live in contaminated water as well as ingest contaminated foods. Also, other forms of aquatic organisms in the water and the material containing the water (soil minerals, rock, etc.) will assimilate or adsorb otherwise soluble radioelements from the water in competition with each other. Since, in most data, the two uptake processes (absorption and adsorption) are not separated, the gross assimilation of a radionuclide is given in terms of a concentration factor or uptake contamination factor. It is designated as a_{WU} and is the ratio of the amount of a radioelement in atoms (or as activity) assimilated per gram of muscle (or other body part) to the concentration of the radioelement in atoms (or as activity) per milliliter of water at equilibrium. However, it may be noted that very few of the reported investigations actually show the necessary data to establish the fact of equilibrium for a given particular experiment. Thus some variation in the derived a_{WU} values is due to measurements of non-equilibrium systems.

Table 16

SUMMARY OF DERIVED ASSIMILATION MODEL EQUATION CONSTANT VALUES FOR POULTRY AND EGGS

Radionuclide	Meat		Egg Yolk[a]		Egg Albumen[a]		Reference
	f_{ik}	λ_{ik} (day^{-1})	F_{ie}	λ_{ik} (day^{-1})	F'_{ie}	λ'_{ik} (day^{-1})	
P-32	-	-	0.11	0.36	0.0083	0.36	65
Ca-45	0.015[b]	0.35	0.017	0.35	0.00074	0.23	61, 62, 66
Sr-90 (Sr-89)	0.012[b]	0.35	0.017	0.35	0.00074	0.23	64, 66
Ru-106	0.04	0.2	(0.04)[c]	(0.2)[c]	(0.002)[c]	(0.2)[c]	68
I-131	0.11[b,d]	0.16[d]	0.073	0.82	0.0016	0.53	63
K-42	0.17[b]	0.012[e]	-	-	-	-	66
Cs-137	0.057[b]	0.010[e]	(0.03)	(0.46)	(0.06)	(0.46)	66

a Combined yolk and albumen weights, m'_f = 41 gm/egg; $\dot{e}$ = 0.8 egg/day

b From fraction of daily dose assimilation/gm of muscle; assumed m_k = 600 gm for the average weight of meat for the whole chicken; for Ca and Sr, the concentrations in meat (muscle) and blood are assumed to be equal

c Values in parentheses are estimated

d From data on whole body retention (muscle plus fatty tissue)

e Assumed same exchange rate as for an adult human

Because of the complexity of natural food chains or food webs within an aquatic environment, the observed values of the uptake contamination factor for such systems are restricted to the type of environment for which they were observed.

The concentration of a nuclide in the fish, or organism, as a food is given by

$$C_{if} = a_{WU}(i)C_{iw} \tag{39}$$

where C_{iw} is the concentration of the nuclide in the water at a steady state (or equilibrium) and a_{WU} is in ml/gm (usually wet weight basis).

Values of a_{WU} of Cs-137 for plant and animal organisms in an artificial freshwater pond, as reported by Pendleton and Hanson,[69] are given in Tables 17 and 18, respectively. It may be noted that the a_{WU} values for the two herbivorous fish are very high. In the reported experiment, only 5 percent of the injected Cs-137 remained in the water at 5 hours after addition, and at 5 days, only 1 percent remained in the water. The a_{WU} values of the algae, snails, and tadpoles were in excess of 100 within 2 hours after injection of the Cs-137. The a_{WU} values of Table 17 are generally higher than most other reported values.

Values of a_{WU} of Sr-90 for freshwater organisms in Perch Lake, Ontario, Canada, as reported by Ophel[70] are listed in Table 19.

The contamination factors of aquatic plants, in a more detailed study of the food-web system in Doe Run Creek, Meade County, Kentucky, as reported by Minckeley et al,[71] are given in Table 20, for gross beta measurements, and Table 21, for Sr-90 and Cs-137 measurements. In this study, the plants and animals are listed respectively as producers and consumers in order of their major position in the food chain. The fish, cottus carolinae, is carnivorous, and therefore its a_{WU} value is much lower than the herbivorous first consumers. The second consumers may eat both producers and first consumers (but at least partially feed on the latter). It is seen that the contamination factor values for the first consumers are as large as those of the producers but that the values tend to decrease for the second and third consumers.

Contamination factors for several nuclides and marine microorganisms in fresh water and seawater are given in Table 22. Two points of notice are: (1) the contamination factors for the rare earth elements, Y-91 and Nb-95, are much higher than those for Cs-137 and Sr-90; and (2) the contamination factors are much lower in seawater than in fresh water. Contamination factors of Sr-89, Sr-90, and Ca-45, as reported by Townsley,[72] for a small fish exposed to contaminated fresh water and seawater are shown in Table 23; in these reported experiments, only the tank water was contaminated. Although the experiments were carried out for three weeks, equilibrium assimilation apparently was not achieved for the whole fish

Table 17

CONTAMINATION FACTORS OF CS-137 FOR FRESHWATER PLANT ORGANISMS IN AN ARTIFICIAL POND[a]

Plant Organism	[a]WU (ml/gm)
Net plankton	1,000 - 25,000
Green algae	
Rhizoclonium and oedogonium	1,500 - 4,000
Spirogyra	400
Submerged vascular plants	
Elodea	1,000
Ceratophyllium	400
Potamogeton	700
Floating plants	
Lemna	500
Azolla	250
Emergent plants	
Scirpus	
Culms	50 - 90
Seeds	300 - 400
Typha	
Leaves	200
Seeds	100
Polygonum	
Leaves	600
Seeds	400

a From Reference 69

Table 18

CONTAMINATION FACTORS OF CS-137 FOR FRESHWATER ANIMAL ORGANISMS IN AN ARTIFICIAL POND[a]

Species	[a]W/U (ml/gm)
Snails (radix)	600[b]
Arthropods	
Amphipod	11,000
Damselfly nymph	800
Dragonfly nymph	800
Amphibians	
Bullfrog	
Tadpole flesh	1,000
Adult flesh	8,000
Fish	
Carp muscle	3,000
Sunfish muscle	9,500

a From Reference 69

b $\lambda_{ik} \sim 0.05\ \text{day}^{-1}$

Table 19

CONTAMINATION FACTORS OF SR-90 FOR FRESHWATER ORGANISMS IN PERCH LAKE, ONTARIO, CANADA[a]

Species	a_{WU} (ml/gm)[b]
Aquatic plants	280
Bottom sediment (1-inch layer)	180
Clams (soft tissue)	730
Minnows (whole body)	950

a From Reference 70
b Wet weight basis

Table 20

GROSS CONTAMINATION FACTORS FOR FRESHWATER PLANTS AND ANIMALS IN DOE RUN SPRING STREAM IN MEADE COUNTY, KENTUCKY[a]

Species	a_{wu} (ml/gm) Station I[b]	Station IV[b]
Producers		
Cyanophyta (phormidium and oscillatoria)	1,400	950
Rhodophyta (batrachosperum)	170	-
Chrysophyta (diatoms)	1,300-2,700	850
Chrysophyta (vaucheria)	860	880
Chlorophyta (dichotomosiphon, etc.)	1,000	950
Bryophyta (fissidens)	980	-
Marl and contained algae	-	400
First consumers		
Amphipoda	540	2,000
Isopoda	2,600	2,100
Tipulidae	590	290
Chironomidae	-	1,500
Trichoptera	2,000	600
Ephemeroptera	-	1,600
Oligochaeta	-	small
Goniobasis	220	360
Second consumers		
Plecoptera	-	1,900
Megaloptera	-	1,300
Notropsis spilopterus	-	160
Etheostoma flabellare	-	270
Third consumers		
Cottus carolinae	130	110

a In terms of gross beta activity, which was mainly Bi-214; from Reference 71

b Station I is at the creek source; Station IV is about 5 miles downstream from Station I

Table 21

CONTAMINATION FACTORS FOR THE ASSIMILATION OF SR-90 AND CS-137
IN FRESHWATER ANIMALS
IN DOE RUN SPRING STREAM IN MEADE COUNTY, KENTUCKY[a]

Species	a_{WU} (ml/gm) Sr-90	Cs-137
First consumers		
Amphipoda (gammarus)	30	440
Isopoda (asellus)	1,100	1,200
Tipulidae	3,300	1,000
Trichoptera	1,200	920
Ephemeroptera	1,500	720
Oronectus rusticus (crayfish)	570	290
Second consumers		
Plecoptera	1,000	780
Etheostoma flabellare (fish)	-	560
Cambarus bartoni (crayfish)	130	67
Third consumers		
Cottus carolinae	130	67

a From Reference 71

Table 22

CONTAMINATION FACTORS OF SEVERAL RADIONUCLIDES FOR MICROORGANISMS IN AQUATIC ENVIRONMENTS

Organism	Nuclide	a_{WU} (ml/gm)[a]	Reference
Fresh water			
Bacteria	Cs-137	15-26	75
Chlamydomonas sp.	Cs-137	28	
Platymonas elliptica	Cs-137	50	
	Y-91	53,800	
Nitzchita sp.	Cs-137	100	
Ochromonas sp.	Cs-137	980	
	Y-91	46,600	
	Nb-95	83,700	
Seawater			
Bacillariacae	Cs-137	1.2-1.7	76
	Sr-90	17	
	Ce-144	2,000	
Chlorophyceae	Cs-137	1.3-3.1	
	Ce-144	2,400	
Rhodophyceae	Cs-137	1.3	
Open sea phytoplankton			77
G. simplex (48 hour)	Sr-90	19	
	Y-90	360	
K. rotundata (48 hour)	Sr-90	380	
	Y-90	~ 0	

a Wet weight basis

Table 23

EFFECT OF ASSIMILATION TIME AND WATER ENVIRONMENT ON THE CONTAMINATION FACTOR OF FISH[a]

Time of Contact (days)	a_{WU} (ml/gm) Fresh Water Sr-89	Sr-90	Ca-45	Seawater Sr-89	Sr-90	Ca-45
1	9	-	-	0.8	-	-
2	9	-	-	0.3	-	-
4	18	-	-	0.7	-	-
7	-	24	29	-	0.8	1.4
8	22	-	-	1.0	-	-
14	-	44	78	-	1.5	3.0
16	49	-	-	2.0	-	-
21	-	67	106	-	2.7	4.4

Fresh Water

Sr-89 and Sr-90: $a_{WU} = 3.1\ t,\ t = 0 \text{ to } 21 \text{ days}$

Ca-45: $a_{WU} = 5.1\ t,\ t = 0 \text{ to } 21 \text{ days}$

$$OR = a_{WU}(Sr)/a_{WU}(Ca) = 0.62$$

Seawater

Sr-89 and Sr-90: $a_{WU} = 0.13\ t,\ t = 0 \text{ to } 21 \text{ days}$

Ca-45: $a_{WU} = 0.21\ t,\ t = 0 \text{ to } 21 \text{ days}$

$$OR = a_{WU}(Sr)/a_{WU}(Ca) = 0.62$$

Both Elements, a_{WU} (fresh water)/a_{WU} (seawater) = 24

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a Tilapia mossambica; from Reference 72

because the a_{WU} values increased throughout the course of the experiment. However, at all times, the contamination factor for the fish in fresh water was about 24 times larger than for the fish in seawater.

The contamination factors for several marine animals in seawater, with and without contact with clay materials, are given in Table 24, as reported by Duke et al.[73] Because of the short exposures (24 hours) no assurance is given that the a_{WU} are equilibrium values.

Experiments on the force-feeding of growing rainbow trout with Sr-90-contaminated feed for 21 days, as reported by Nakatani and Foster,[74] result in the following average concentration intake-rate ratios:

$$C_{90}\ (\text{whole body})/U^{o}_{90} = 0.097 \pm 0.010 \text{ days/gm of fish} \tag{40}$$

and

$$C_{90}\ (\text{muscle})/U^{o}_{90} = 0.0055 \pm 0.0020 \text{ days/gm of muscle} \tag{41}$$

In the same experiments, data were obtained on the lethal uptake concentrations; at a feeding rate of 0.75 mc of Sr-90/day, the following killing rate (in excess of normal) was observed: 20 percent dead in 17 days, 50 percent dead in 21 days, and 100 percent dead in 25 days.

Although the reported data reviewed to date on the assimilation of radionuclides are entirely unsuitable, from both a coverage and a measurement accuracy point of view, for the evaluation of assimilation models, the following a_{WU} values are tentatively selected for use in estimating the contamination levels of fish food, given the concentration of a nuclide in the water:

Species	a_{WU} $\left(\frac{\text{atoms/gm muscle}}{\text{atoms/ml water}}\right)$ Cs-137	Sr-90
Fresh Water		
Fish (herbivorous)	1,000	100
Fish (carnivorous)	70	8
Clam	2,000	700
Seawater		
Fish (herbivorous)	2	4
Fish (carnivorous)	0.5	0.3
Shrimp	2	5
Oyster	2	5

Table 24

CONTAMINATION FACTORS FOR SEAWATER MARINE ANIMALS[a]

Animal	Nuclide	^{a}WU (ml/gm)[b]	Animal Part
Feed only (force-fed)			
Fish (Fundulus similis)	Cs-137	0.38(s)[c]	Body
Contaminated environment (24 hours)			
Fish (Fundulus similis)	Cs-137	0.19(s)	Body
	Cs-137	0.50	Body
Shrimp (Palaemonetes pugio)	Cs-137	1.87(s)	Body
	Cs-137	1.93	Body
	Ca-45	6.13(s)[d]	Body
	Ca-45	4.42	Body
Oyster (Crassostrea virginica)	Cs-137	1.80(s)	Soft tissue
	Cs-137	1.56	Soft tissue

a From Reference 73
b Wet weight basis; 24-hour exposures
c (s) indicates contact with clay
d λ_{ik} = 2.5 day^{-1} (gross elimination rate into clean seawater)

It is expected that these a_{WU} values, based on partial analysis of incomplete data, could be revised as the data summaries and analyses become more complete. Also, the model for estimating the uptake is not fully developed conceptually. Additional data on relative populations of producers and consumers in selected environments are still needed. For example, if the fish population were n_v fish/ml and there were no other competitors present for taking up the radioactive atoms, the average whole-body concentration would be given by

$$C_{ik} = \frac{a_{WU} C^o_{iw}}{1 + m_{ik} n_v a_{WU}} \tag{42}$$

where C^o_{iw} is the initial concentration of the water, as computed from the fallout deposition model, and m_{ik} is the average weight of the fish. It can be seen that the distribution of the C^o_{iw} atoms deposited in a real marine environment is a complicated function of the biological community, including the dietary habits and the reproduction and growth patterns of each member.

Absorbed Dose for Humans

Once estimates have been made of the human ingestion rates, U_i, of each radionuclide, i, to be considered, it is possible to generate reasonably reliable estimates of the dose to any organ, k, from each nuclide. These estimates are based on simplified representations of the human ingestion, organ assimilation, and body elimination processes. These representations are much the same as those postulated by the International Committee on Radiation Protection,[37] and much of the data on the model parameters is taken from their report.

There are two major divisions of the absorbed dose model. The first deals only with those organs in the gastrointestinal tract. The assumptions of this model, as given in a separate Stanford Research Institute report,[38] are:

1. The absorbed dose (in rads or rems) of each gastrointestinal (GI) tract organ is equal to one-half of the absorbed dose calculated for the contents of that organ.

2. No radioactive atoms pass across, or through, the wall of the stomach and large intestine.

3. A given fraction of some of the soluble radioactive elements passes across, or through, the wall of the small intestine as long as the contaminated food (or water) remains in this organ.

4. The contents of the digestive tract move continuously from one organ to the next at rates (and in amounts) determined by the intake rate assumptions of the model.

5. The radioactive atoms are uniformly distributed among the organ's contents as soon as they enter that organ.

6. The steady-state concentration of a radionuclide in the contents of a given GI tract organ is reached, after first entry of the food (or the contents), in a time equal to the average time that the contents normally stay in the organ. This assumption is required to follow assumption No. 4 in order to adjust the concentration to the condition for a uniform rate of ingestion.

The second model deals with all of the remaining body organs, including the total body considered as one organ. Using the results of the gastrointestinal-tract model, it assumes, in addition, that a given fraction, f_{ik}, of the amount of radionuclide, i, entering the blood at any time is immediately taken up by organ k. Furthermore, it is assumed that the instantaneous rate of elimination of the nuclide is proportional to the amount of that nuclide present in the organ at any time. The proportionality constant is λ_{ik}, the biological exchange rate. However, in calculating the rate of absorption from the blood, only the material entering the blood from the small intestine is considered; no provision has been made to consider the possibility of the recycling of materials excreted from other organs into the blood.

With these assumptions, it is now possible to write down a simplified differential equation for the number, $N_{ik}(t)$, of atoms of a particular radionuclide, i, in an organ, k, at time t. This equation is

$$\frac{dN_{ik}(t)}{dt} = g(t) - \mu N_{ik}(t), \quad t_a \le t \le t_b \tag{43}$$

where g(t) is an uptake rate function whose form depends on the organ involved and the time period, t_a to t_b, for which it is valid. The equation also involves an elimination rate constant, μ, which is the sum of the radioactive decay constant, λ_i, and some number of biological or physical decay rates, any or all of which may also be zero. In order to solve Equation 43, it is also necessary to specify an initial condition, which is usually taken to be $N_{ik}(t_a)$. With this initial condition, the solution can be written in the completely general form,

$$N_{ik}(t) = \int_{t_a}^{t} g(t')e^{-\mu(t - t')}dt' + N_{ik}(t_a)e^{-\mu(t - t_a)}, \quad t_a \le t \le t_b \tag{44}$$

There are usually at least two time periods to be considered in the calculation of N_{ik}. The first begins when the first radioactive material reaches the organ (i.e., $N_{ik}(t_a) = 0$) and is called the buildup period. This period ends either (1) when the organ reaches a state where food and radioacitve elements leave the organ at the same rate they enter, as in the digestive tract, or (2) when the blood concentration has stabilized, except for radioactive decay, as for the remaining body organs. At that time, the uptake rate function, g(t), changes, and the steady-state period begins. The latter is usually of indefinite duration; i.e., it holds for all $t \geq t_b$, where t_b is the end of the buildup period.

As an example, consider the stomach as the organ of interest. A radionuclide, i, enters the stomach in food and water at a rate of U_i atoms per day. (In the simplest case, $U_i = U_i^o e^{-\lambda_i t}$, where U_i^o is a zero-time ingestion rate.) For this case, the rate of change of the number of atoms of nuclide i in the stomach is represented by

$$\frac{dN_{ik}}{dt} = U_i - \lambda_i N_{ik}, \quad t_0 \leq t \leq t_1 \tag{45}$$

By the second assumption, only radioactive decay depletes atoms in the stomach. The times, t_0 and t_1, are the time that ingestion of radioactive food begins and the time that the stomach begins to pass this food to the small intestine, respectively. The solution, in the simplest case, is

$$N_{ik} = U_i^o (t - t_0) e^{-\lambda_i t}, \quad t_0 \leq t \leq t_1 \tag{46}$$

in which $N_{ik}(t_0)$ has been set equal to zero.

In the steady-state peiod, as many nuclides leave the stomach and enter the small intestine as enter the stomach so that g(t) becomes zero and

$$\frac{dN_{ik}}{dt} = -\lambda_i N_{ik} \quad t \geq t_1 \tag{47}$$

Again, the simplest case has the solution

$$N_{ik} = U_i^o (t_1 - t_0) e^{-\lambda_i t}, \quad t \geq t_1 \tag{48}$$

in which $N_{ik}(t_1)$ has been set equal to $U_i^o(t_1 - t_0)e^{-\lambda_i t_1}$.

For solutions for other organs and for absorbed dose functions associated with the presence of the radionuclides in each organ, see Reference 38.

Long-Term Human Response to Ionizing Radiation Doses

The currently available estimates of the long-term biological response to ionizing radiation doses are summarized below as a function of the exposure and/or absorbed dose. It is not possible to specify the distribution of long-term doses in the population without detailed knowledge of the living routines and the environment of the population. However, it is possible to specify an upper limit for absorbed doses that should not be exceeded if people are to avoid early effects of radiation. An ERD(max) of 200 roentgens is generally considered to be the threshold for early effects of radiation. Unfortunately, the ERD is neither a measurable phenomenon nor very convenient to use in some applications. Hence, a consistent and convenient set of criteria, using measurable phenomena, was developed to approximate the 200 roentgen ERD(max). Using these criteria, civil defense programs would be designed to limit radiation exposures to 190 roentgens in 1 week, 270 roentgens in 1 month, and 700 roentgens in 1 year. Only people who reside in areas having very high levels of fallout, or who are required to operate vital systems in such areas, should approach these limits. The response data and estimates of the long-term effects at the threshold doses for short-term effects are given in the following summary (for each long-term response), as obtained from References 78 through 81.

Leukemia

$$\dot{n}_c = 1.2 \times 10^{-6}(D - 100)N_e \text{ cases/yr} \tag{49}$$

where D is the external dose in roentgens received by the number of people, N_e, so exposed over the time of 1 year.

$$\dot{n}_c^o = 5.0 \times 10^{-5}N_T \text{ cases/yr} \tag{50}$$

where $\dot{n}_c^o$ is the normal incidence rate and N_T is the total population; the rate doubling dose is about 150 roentgens.

$$\dot{n}_c' = 1.2 \times 10^{-6}(D_b - 1,000)N_e \text{ cases/yr} \tag{51}$$

where D_b is the absorbed dose in rem to the whole skeleton from radionuclides assimilated by the bone.

Exposure to 700 roentgens of external gamma radiation within 1 year would result in 720 additional cases of leukemia per year per million people exposed as compared with 50 cases per year per million people in the peacetime population.

Bone Tumors

$$\dot{n}_c = 2.0 \times 10^{-7}(D - 100)N_o \text{ cases/yr} \qquad (52)$$

$$\dot{n}_c' = 2.0 \times 10^{-7}(D_b - 1{,}500)N_o \text{ cases/yr} \qquad (53)$$

Exposure to 700 roentgens of external gamma radiation within 1 year would result in 120 additional cases of bone tumors per year per million people exposed.

Sterility and Fertility

Single Exposure Dose to Gonads[a] (roentgens)	Response
25	Threshold for detectable temporary tissue damage
100–200	Temporary subfertility
200–400[b]	Temporary sterility in most men and women for 1 to 2 years
400–600[b]	Permanent sterility in many people
≥ 800[b]	Permanent sterility in most people

a Response is more predominant at the lower dose when received at low dose rates over a long period of time.
b A whole-body dose of these amounts would be lethal.

Whole-body doses that would accompany a short-term dose of 200 roentgens to the gonads (threshold dose for temporary sterility) would exceed the exposure dose criterion of 190 roentgens in 1 week. Permanent sterility should not be expected in many healthy survivors as a result of external gamma radiation to the gonads resulting from radiological fallout since the threshold doses for this response are in the lethal range.

Radiation Cataracts

Exposure Dose (roentgens)	Response
200	Threshold dose for a single exposure
400	Threshold dose for exposures of 3 to 12 weeks duration
550	Threshold dose for exposures of more than 12 weeks duration
500[a]	Threshold for clinically significant cataracts, single exposure

a A whole-body dose of this amount would be lethal.

The threshold doses for radiation cataracts are comparable to the maximum permissible doses for emergency operations developed in this research. The threshold for clinically significant cataracts is comparable with the criteria for fatal radiation doses. Hence, although some development of radiation cataracts is to be expected, relatively few should be clinically significant.

Shortening of Life Span[a]

Brief doses:

$$-\Delta Y/Y = 8 \times 10^{-5} D; \quad D \leq 150 \tag{54}$$

where D is the exposure dose in roentgens and $-\Delta Y/Y$ is the fractional decrease in life span.

$$-\Delta Y/Y = 1.2 \times 10^{-3} \exp(0.0128\ D); \quad 150 \leq D \leq 500 \tag{55}$$

a $\Delta Y/Y$ is taken as the midrange value for those estimated as being applicable to a given exposure-dose range; in all cases, the spread in the reported $-\Delta Y/Y$ values is within $\pm$ 0.5 $\Delta Y/Y$ as calculated from the formula.

One-month doses (approximately):

$$-\Delta Y/Y = 8 \times 10^{-5} D; \; D \le 150 \tag{56}$$

$$-\Delta Y/Y = 3.4 \times 10^{-3} \exp(0.0057\ D); \; 150 \le D \le 1{,}000 \tag{57}$$

Protracted dose (many months):

$$-\Delta Y/Y = 8 \times 10^{-5} D; \; D \le 2{,}000 \tag{58}$$

Exposure to 190 roentgens in 1 week or 270 roentgens in 1 month would shorten the life span of individuals so exposed by 0.015 percent, or up to 1 year, depending on the age at the time of exposure. Exposure to 700 roentgens in 1 year would shorten the life span of individuals exposed by 0.056 percent, or up to 4 years, depending on the age at the time of exposure.

Genetic Effects[a]

Persons with impaired vigor or fertility:

$$n_a = 6 \times 10^{-3} N_a' D \text{ cases} \tag{59}$$

where D is the exposure dose in roentgens and N_a' is the number of productive parents that have received the exposure dose, D, up to the time of conception and that produce offspring at an average rate.

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a Values of n_x are for the number of cases over many succeeding generations where all original parents receive the dose, D; the equation constants were derived from midrange values of reported estimates of genetic effects, with the spread in the latter being within a factor of 2 of the midrange value. The upper limit value of D is not specified, but it is assumed to be equal to the threshold dose for lethality of the parents. To estimate the effects for the first generation, divide the calculated n_x values by 30.

Fetal or neonatal deaths:

$$n_b = 3 \times 10^{-3} N_b' D \text{ cases} \tag{60}$$

where N_b' is the number of conceptions for people having received the exposure dose, D (normal number is 0.1 N_b).

Stillbirths and early childhood deaths:

$$n_c = 1 \times 10^{-3} N_c' D \text{ cases} \tag{61}$$

where N_c' is the number of pregnancies for parents that have received the exposure dose, D (normal number is 0.05 N_c).

Infant mortality during first year of life:

$$n_d = 1.3 \times 10^{-4} N_d' D \text{ cases} \tag{62}$$

where N_d' is the number of parents that have received the dose, D (normal number is 0.026 N_d).

Major defects in newborn:

$$n_e = 3 \times 10^{-4} N_e' D \text{ cases} \tag{63}$$

where N_e' is the number of live births from parents that have received the exposure dose, D (normal number is 0.025 N_e).

Exposure of both parents to 700 roentgens would result in about 140,000 cases of impaired vigor or fertility per million parents in the first generation. If the entire population was exposed to 700 roentgens, a total of four additional offspring per originally exposed normally productive parent would have impaired vigor or fertility over many succeeding generations.

Exposure of both parents to 700 roentgens would result in increasing the fetal or neonatal death rate from the present 10 percent to 17 percent in the first postattack generation. If the entire population were exposed to 700 roentgens, a total of two additional fetal or neonatal deaths per conception by originally exposed parents could be expected over many generations.

Exposure of both parents to 700 roentgens would increase the stillbirths and early childhood deaths from the present 5 percent to 7 percent in the first generation. If the entire population was exposed to 700 roentgens, one additional stillbirth or early childhood death per conception by the originally exposed parents could be expected over many generations.

Infant mortality in the first year of life would increase from 26,000 to 29,000 per million parents in the first generation if both parents are exposed to 700 roentgens. If the entire population is exposed to 700 roentgens, infant deaths could be expected to increase by 91,000 per million originally exposed parents over many succeeding generations.

If both parents are exposed to 700 roentgens, major defects in newborn infants could be expected to increase from the present 2.5 percent to about 3.2 percent. If the entire population were exposed to 700 roentgens, 210,000 additional birth defects could be expected per million live births in the first generation. Unfortunately, no data are available for estimating the genetic effects that might result from mixed doses (e.g., one parent being exposed to 700 roentgens and the other having no exposure).

Gut Response, Internal Emitters

Absorbed Dose (rads)	Response
100	Threshold for nausea, vomiting
1,000	Threshold for tumor production
1,300	Threshold for acute radiation injury

In the cases considered in the third section of this report, the absorbed dose to the lower large intestine was well below the threshold for nausea and vomiting.

Thyroid Response, Internal Emitters[a]

Absorbed Dose (rads)	Response
10,000 ± 6,000	Threshold for hypothyroidism
80,000 ± 20,000	Central destruction of thyroid
150,000 ± 50,000	Complete destruction of thyroid

a For adult humans. Infant thyroids are more highly susceptible to damage; threshold exposure dose for carcinoma in the thyroid of children and young adults for a brief exposure is about 200 roentgens.

In the cases considered in the third section of this report, the absorbed doses for adult humans were less than the threshold for hypothyroidism. An external dose that would result in a brief exposure dose of 200 roentgens to the thyroid of children would exceed the selected whole-body exposure dose criterion. Larger brief-exposure doses would result in the whole-body syndrome.

Computer Program Data Base

Diets, Crop Yields, and Planting and Harvest Dates

In order to apply the derived contamination and other model equations to an attack on the United States, it was necessary to set up an agriculture and livestock data base. The county was chosen as the smallest geographical division, dictated by the data base in the U.S. Census of Agriculture for 1959.[82]

Accordingly, each of the 3,071 counties in the United States was assigned an identification number, and the centroid was located in both Universal Transverse Mercator and latitude and longitude coordinates. In the case of 90 large western U.S. counties, the agricultural centroid was chosen.

The following types of data were then recorded for each county: (1) acres to each of 48 crops; (2) plant-harvest dates for each crop; (3) acres to pasture; (4) mean annual rainfall; (5) exchangeable Ca^{++} in soil; and (6) number of cattle, milk cows, swine, sheep, and chickens.

Crops were included on the basis of importance in the 1955 U.S. diet[83] and importance as fodder. The major food items (of all kinds), abstracted from Reference 83, are shown in Table 25; the crops selected for this study are shown in Table 26, together with currently representative yields. For this study, "crop" means a particular planting of a given item (e.g., summer carrot is one crop and winter carrot is another). This was necessary in order to properly assign plant-harvest dates and acreage. For this reason, the 22 items listed in Table 26 multiply into 48 crops.

Planting and harvesting dates were necessary in order to determine (1) whether a crop was standing at the time of attack, (2) if the dose to farmers would have precluded harvesting, (3) if the land could have been entered at the next scheduled planting, and (4) the times over which worldwide fallout was to be integrated for root uptake and foliar contamination assessments. Those plants that stand all of the time (such as alfalfa, timothy, and the fruit trees) were assigned a "planting" date of 1 day after the harvest date.

Plant-harvest data were taken primarily from Reference 84, with supplemental information from References 85 through 90. Representative values of planting and harvesting dates by crop are shown in Table 27, although the particular values entered in the computer program actually varied considerably from one county to another.

Table 25

CONSUMPTION OF MAJOR FOODS PER PERSON
IN THE UNITED STATES
1955

Item	Consumption Rate (gm/day)[a]
Milk, all forms	633
Meat, poultry, and fish	233
Beef	81
Pork	74
Lamb and mutton	6
Poultry	46
Fish all kinds	26
Wheat	194
Potato	117
Sugar	81
Orange	64
Fat and oil	58
Egg	55
Tomato	43
Sweet corn	42
Bean	34
Apple	29
Grain other than wheat	28
Lettuce	23
Grapefruit	22
Melon	22
Cabbage	19
Peas	15
Onion	15
Peach	14
Carrot	13

a Table weight basis

Table 26

YIELDS OF SELECTED U.S. CROPS[a]
1962

Crop	Fresh Yield (tons/acre)	Notes
Leguminosae		
Pea (Pisum sativum)	1.0	seeds
	2.5	pod and seeds
Bean (Phaseolus vulgaris)	0.75	dry
	2.5	snap and wax
Soybean (Glycine max.)	0.75	seeds
	2.5	hay
White clover (Trifolium repens)	2.0	hay
Alfalfa (Medicago sativa)	2.3	hay
Gramineae		
Sorghum (Sorghum vulgare)	1.1	grain
	2.0	foliage
Corn (Zea mays)	1.4	grain
	1.75	ear
Oat (Avena sativa)	0.64	grain
	2.0	hay
Barley (Hordeum vulgare)	0.75	grain
Wheat (Triticum vulgare)	0.75	grain
Timothy (Phleum fratense)	2.0	hay
Chenopodiaceae		
Sugar beet (Beta vulgaris)	17	
Amaryllidaceae		
Onion (Allium cepa)	13	dry
Cruciferae		
Cabbage (Brassica capitata)	16	

a From Reference 85

Table 26 (concluded)

Crop	Fresh Yield (tons/acre)	Notes
Rosaceae		
Apple (Malus and mill.)	0.145 tons/tree	
Peach (Prunus persica)	0.048 tons/tree	
Rutacceae		
Orange (Citrus sinensis)	0.125 tons/tree	
Umbelliferae		
Carrot (Daucus carota)	8.6	
Solanaceae		
Potato (Solanum tuberosum)	9.6	
Tomato (Lycopersicon esculentum)	10	
Compositae		
Lettuce (Lactuca sativa)	8.5	

Table 27

AVERAGE PLANTING AND HARVEST DATES, BY CROP

Crop	Day of the Year Plant	Day of the Year Harvest
Corn	136	289
Sorghum	163	288
Wheat, winter	278	190
Wheat, spring	110	228
Oat, winter	281	163
Oat, spring	98	198
Barley, winter	278	173
Barley, spring	105	216
Dry bean	152	258
Soybean	147	285
Alfalfa	205	204
Clover and timothy	198	197
Oat and other hay	98	197
Potato	130	252
Green pea, spring	89	165
Green pea, summer	119	197
Sugar beet	112	289
Tomato, winter	349	60
Tomato, spring	50	150
Tomato, summer	135	224
Tomato, fall	156	252
Sweet corn, spring	46	144
Sweet corn, summer	136	232
Sweet corn, fall	232	316
Sweet corn, winter (Florida)	319	66
Snap bean, winter	362	45
Snap bean, spring	80	152
Snap bean, summer	145	223
Snap bean, fall	231	294
Cabbage, winter	308	43
Cabbage, spring	28	134
Cabbage, summer	135	230
Cabbage, fall	187	224
Dry onion	95	243
Carrot, winter	290	43
Carrot, spring	22	132
Carrot, summer	140	243
Carrot, fall	210	320
Lettuce, winter	286	24
Lettuce, spring	344	107
Lettuce, summer	125	200
Lettuce, fall	220	315

Table 27 (concluded)

Crop	Day of the Year	
	Plant	Harvest
Apple	251	250
Peach	222	221
Valencia orange (Arizona)	62	61
Valencia orange (California)	202	201
Valencia orange (Florida)	110	109
Navel orange (Arizona)	365	364
Navel orange (California)	46	45

Foliage Contamination and Crop Casualty Program (Local Fallout)

Using the inputs described, and the dose criteria established elsewhere in this report, the following computations were made for each crop-county combination:

1. Total acres devoted to crop.

2. Cumulative harvestable acres on which foliage was contaminated to a given level (atoms/gm) for each of six radionuclides. These were cumulated, by acres, for a selected series of contamination levels in atoms/gm.

3. Acres destroyed by direct external gamma radiation, using lethality criteria described elsewhere.

4. Unharvestable acres (acres, the harvesting of which, at the normal time, would have led to an ERD(max) greater than 200 roentgens, under the conditions described elsewhere).

5. Unplantable acres (acres, the planting of which, at the normal time for the next crop, would also have led to an ERD(max) greater than 200 roentgens).

6. Unplanted acres (acres of crop not yet planted at time of attack).

Results were printed out by crop-state, with national summaries for each crop. These were further summarized nationally for like crops, such as spring and winter wheat, labeled wheat.

As mentioned previously, foliar contamination, as computed, is the gross superficial number of atoms per gram of plant above ground. The corresponding quantity for the nonremovable and absorbed activity in the fruit or edible part is considerably lower. The fractions, f_p, by which the computed values are to be multiplied to obtain edible-part concentrations are given in Table 28. They were estimated from the following allowances:

Root vegetables:	No direct relation between top contamination and root content, but 0.1 of foliar contamination allowed for unavoidable contamination in harvesting and 0.1 for processing
Fruits, grains, and pod vegetables:	0.5 for growth of the plant (on the average) after contamination and 0.01 to 0.02 for absorption into tissue. Wheat flour/grain, 0.2[52]
Leafy vegetables:	0.5 for growth and 0.1 for processing
Hay:	0.5 for growth only

Table 28

FRACTION OF GROSS FOLIAR CONTAMINATION
FROM LOCAL FALLOUT ASSOCIATED WITH EDIBLE PLANT PARTS

Crop	f_p[a]
Sweet corn	0.005
Sorghum grain	0.005
Wheat	
Grain	0.005
Flour	0.001
Oat	
Hay	0.5
Grain	0.005
Barley	0.005
Dry bean	0.005
Soybean	0.005
Alfalfa	0.5
Clover, timothy, and other hay	0.5
Potato	0.01
Green pea	0.005
Sugar beet	0.01
Tomato	0.01
Snap bean	0.005
Cabbage	0.05
Dry onion	0.01
Carrot	0.01
Lettuce	0.05
Apple	0.01
Peach	0.06
Orange	0.01

a All nuclides

Milk Production Program

The effects of a nuclear strike on the cow population and milk production were assessed by calculating, on a county basis, the following:

1. Total cows.

2. Cows surviving direct gamma radiation. The exposure dose criteria for both the cow and the farmer, in terms of the limiting H + 1 intensities, are presented elsewhere.

3. Milk production, in liters per day, from cows surviving on pasture land contaminated to a given level (atoms/gm) for each of six radionuclides. These were cumulated in ten concentration ranges, one-half decade wide, extending from $< 5 \times 10^8$ to $< 10^{13}$ atoms/gm. As discussed elsewhere, the pasture grasses always survive if the cows survive.

The results were summarized by state and nation.

Postattack Crop Contamination Program

This program was concerned with the entry of radioactive atoms into the edible parts of the crops planted subsequent to a nuclear attack. In this study, only the first crop following the attack was considered. Computations were made for two mechanisms of nuclide entry into the food chain under the following conditions: (1) uptake, through the root system, of available nuclides deposited on the soil with local and worldwide fallout, the latter integrated up to planting time, and (2) fruit and edible-part contamination from worldwide fallout, integrated over the harvest month.

The areas identified as unplantable from the foliage contamination program were excluded from the calculations of the crop contamination levels. The results were again expressed as the number of cumulative acres on which plants were contaminated to a given level. Root uptake results were obtained for all six radionuclides but sufficient data for assessment of foliar contamination were available only for Sr-89 and Sr-90. State and national summations also were computed.

External Dose Criteria

Dose to Humans

The limiting external dose for farming operations was set at an ERD(max) of 200 roentgens. The external radiation dose received by the farmer depends on the general radiation environment and the available protection he has from this environment. In this study, the two conditions of protection afforded the farmer were (1) shelters with a protection factor (PF) of 10 and (2) shelters with a PF of 1,000.

The first condition was an assigned value that was considered representative of currently available shelters on farms. The shelter residual numbers, RN_1 (residual numbers are the inverse of the shelter PF's) consequently were 0.1 and 0.001, respectively. The selected maximum shelter stay time was 2 weeks. After the initial shelter period, the harvesting residual numbers (RN_3) assigned were 0.4 for the first condition and 0.3 for the second condition. The harvesting and planting periods were set at 1 week for all crops. While the farmer was not engaged in harvesting, a residual number (RN_2) equivalent to a living routine in which the farmer spent 1 hour each day outside of the shelter was also assigned to the second condition.

For the next planting, the case with the good shelter (PF = 1,000) assumed a routine in which the farmer spent half the time in the shelter and half the time outside, where the effective residual number is 0.3 for the times after the initial shelter stay time (i.e., up to planting time). Also, if the estimated initial shelter stay time exceeded 30 days, evacuation to a clean area at 2 weeks after attack was assumed. An 8-hour evacuation with an effective PF of 2 was also assumed. If area reentry (for continued stay thereafter) was possible for the assumed total dose limit by the time of planting, the crop was included in the calculation as being planted.

If the limiting ERD(max) were expressed in terms of an exposure dose, D*, for a specific period of time, then

$$D^* = I_1 (RN_1 DRM_1 + RN_2 DRM_2 + RN_3 DRM_3) \qquad (64)$$

where I_1 is the standard intensity and DRM is the dose rate multiplier for the specific time period (DRM_1 for shelter period, DRM_2 for an intermediate period, and DRM_3 for harvest or long-term period). Also, where harvesting or planting immediately follows the shelter period, $DRM_2 = 0$.

Limiting I_1 values were determined for various harvesting or planting entry times of D + 1 or later. Crops not destroyed by the attack and ready for harvest were considered either harvestable or lost, depending upon whether the existing fallout levels permitted or denied the farmer entry to harvest at harvest time. The following season's crops were also considered lost if the farmer (or other source of manpower) would be denied area entry to plant at planting time. The limiting I_1 values for various entry times for the two PF conditions are listed in Table 20.

In the case where PF = 10, I_1 values greater than 707 r/hr at 1 hr would give the farmer an ERD greater than 200 roentgens while still in shelter. Therefore, the farmer is considered incapacitated or unavailable for harvesting or planting if I_1 exceeds 707 r/hr at 1 hr.

Table 20

LIMITING I_1 VALUES FOR VARIOUS ENTRY TIMES

Entry Times (D + days)	I_1 (r/hr at 1 hr) Harvest of Standing Crops PF=10	PF=1,000	First Planting After Attack PF=10	PF=1,000
1	405	800	405	1,300
2	470	1,300	470	2,200
3	520	1,650	520	2,800
4	555	2,000	555	3,300
5	595	2,350	595	3,800
6	635	2,750	635	4,200
7	670	3,200	670	4,600
8	690	3,750	690	5,000
9	707	4,400	707	5,300
10		5,000		5,700
15		7,500		7,300
32		12,000		9,300
60		15,000		12,400
100		18,000		17,500
150		21,500		26,000
200		21,500		30,000

Dose to Farm Animals and Poultry

In order to assess and summarize biological damage to farm animals and poultry by residual gamma radiation from fallout from a nuclear attack on the United States, it is necessary to (1) define the fallout radiation intensity variation within the boundaries of the United States where the effects are to be assessed, (2) determine, from agricultural census data, the geographic distribution of the farm animals of interest, and (3) analyze data from 1 and 2 together with acceptable radiation dose criteria to determine the degree of biological damage within prescribed areas. Cumulative summaries of biological effects can then be obtained by state, region, or nation.

Two different nuclear attacks on the United States have been postulated for the present study. Each set of attack conditions has been used as input for a fallout model to predict radiation intensities that would occur at H + 1 hour at one point within each county in the United States. The county was chosen as the basic geographic unit because agricultural census data is compiled by county.

The agriculture census of 1959 was the source for information on the geographic distribution, by county, of farm animals and poultry. The data were adapted for computer manipulation by punching cards from published data or, in a few cases, by using county summary cards obtained from the Bureau of the Census. In all cases, counties reporting less than 1,000 animals or chickens were omitted (to reduce machine computation time) without seriously affecting the summarized results.

Table 30 presents the lethal dose values used for selected farm animals in the present computations to assess the biological effects of the two attacks. It is recognized that most of the $LD_{50}/30$ values were obtained experimentally under exposure conditions different from those that might be experienced after a nuclear attack. Many experimental exposures involve a monoenergetic radiation source (single radionuclide) which, for convenience, has a half-life that is long compared with the exposure period. Such a source does not simulate fission-product radiation either in the decay of dose rate or change of energy spectrum with time. Point radiation sources have been used experimentally and do not simulate either the plane source dose to animals outdoors or the complex exposures within barns or chicken houses. The values for $LD_{50}/30$ are estimates for nuclear attack exposures.

One point (usually the geographic center) of each county was taken as a point of interest where all farm animals in the county were assumed to be concentrated for assessment of biological effects of radiation intensities computed at the same point. Although variations in radiation intensity will occur within the county boundaries, the point of interest chosen represented the entire county because details of animal distribution within the county were not available.

Table 30

RESPONSE OF ANIMALS
TO BRIEF EXPOSURES IN EXTERNAL GAMMA RADIATION FIELDS
IN TERMS OF LD_{50} IN 30 DAYS

Species	$LD_{50}/30$ (roentgens)
Cattle and calf	540
Milk cow	540
Swine	510
Sheep and lamb	520
Chicken	900

The dose contribution from each weapon was computed for each county point by integrating a $t^{-1.2}$ dose rate decay curve from time of fallout arrival to 7 days later.

This procedure assumed that the $t^{-1.2}$ function closely matched the true fission product decay curve and that doses during fallout buildup between time of arrival and cessation were not a significant part of the total dose. The total 7-day dose used for each county point was the sum of the dose contributions from all weapons whose H + 1 intensity at the point was greater than 1 r/hr.

After the 7-day doses were computed for each county point, the $LD_{50}/30$ values from Table 30 were used as follows to determine if the livestock survived:

$$\sum D < LD_{50}/30 \qquad \text{All survived}$$

$$\sum D > LD_{50}/30 \qquad \text{All died}$$

Dose to Agricultural Crops

Table 31 presents the lethal dose values used for selected farm crops to assess the biological effects of the postulated nuclear attacks. Some values taken from Reference 91 may be inaccurate owing to uncertainties in translation from Russian. Comparable data are currently being obtained by A. H Sparrow at the Brookhaven National Laboratory; when these are available, they will be used to replace the doses in Table 31.

In the reported plant response dose data, some apparent discrepancies occur between the 24-hour dose, which produced severe damage, and the acute lethal dose, which had no dose rate specified. In some cases, the acute lethal dose could not have been administered within the crop growing period without exceeding the constant dose rate that would produce severe damage in the first 24 hours. Because of the uncertain relationship between dose rates producing severe damage and those producing lethality in 7 days, the report of acute lethal doses was cut in half to achieve closer correlation between the two dose rates.

Most of the experimental dose values were obtained under exposure conditions different from those postulated by a nuclear attack. Experimental procedures generally did not simulate radiation from actual fallout in either geometric configuration or change of dose rate and energy spectrum with time.

The above dose criteria were used in conjunction with radiation intensity data obtained from fallout model calculations for the postulated nuclear attacks and geographic crop distribution data from the agricultural census to determine whether or not an existing crop in a given county received a lethal dose. Further dose criteria relating to humans were

Table 31

GAMMA RADIATION SENSITIVITY OF PLANTS

Common Name	7-Day Lethal Dose (roentgens)
Grains	
Corn	7,500
Sorghum	(7,500)[a]
Wheat	10,000
Oat	25,000
Barley	(20,000)
Field Crops	
Dry field and seed beans	12,000
Soybean	12,000
Alfalfa	50,000
Clover and timothy	25,000
Irish potatoes	4,500
Tobacco	50,000
Green pea	10,000
Sugar beet	(12,000)
Tomato	3,000
Sweet corn	7,500
Snap bean	(5,000)
Cabbage	50,000
Dry onion	5,000
Carrot	(5,000)
Lettuce	12,000
Pasture	7,500
Trees	
Apple	(5,000)
Peach	(5,000)
Orange	(5,000)
Loblolly pine	7,500
White pine	7,500
Hickory	< 30,000
White oak	> 50,000
Black oak	> 50,000

a Values in parentheses are estimated values (also indicate plant species for which no response data have been reported); the estimates were made using the assumption that similar species have similar responses to a given radiation dose.

then applied; the latter govern what action (harvesting or planting) could be taken on existing and future crops, as previously described.

Damage to Forests

Under conditions where rather extensive areas of the United States would be subjected to heavy deposits of local fallout, the gamma radiation doses in some areas would be sufficient to damage or kill certain tree species in forests. Although these acute radiation doses would not be extensively damaging to the mature trees for use as lumber (at some later time when residual radiation dose rates have decayed to a level permitting normal logging operations), natural growth recovery of the trees within a short period of time would be doubtful above a given exposure, as discussed in the first section of this report. The time at which either artificial or natural reforestation may be initiated in a given area would depend on the magnitude of the radiation levels and exposure doses.

The evergreen coniferous forests which predominate in the western United States are less resistant to radiation damage than the deciduous hardwood forests of the eastern part of the country. The exposure dose criteria for recovery of forests, as given in the first section of this report, were utilized to delineate areas within which coniferous forests and deciduous forests may not recover within a period of 2 years. The fallout standard intensities at which forest survival would be expected are 1,200 r/hr at 1 hr, or less, for coniferous forests and 6,000 r/hr at 1 hr, or less, for deciduous forests.

During the time period of the study, it was not feasible to develop the data for estimating the amount of timber in the highly contaminated areas where many trees would likely be killed or the likely postattack times when it would be feasible to recover and stockpile lumber from the killed trees. (For the attack patterns assumed in the study, it was apparent that the total forest area affected by high fallout levels was much greater than that subjected to thermal phenomena from the nuclear explosions.)

ASSESSMENT OF BIOLOGICAL EFFECTS

Introduction

The assessment of the biological effects mainly consists of summaries of numerical results from computations using the various mathematical models and process representations described in the second section of this report as applied to the attacks assumed for the study.

The major portions of the model system (see Figure 2) not completed or incorporated during the study were (1) food processing industries, (2) transportation and food distribution systems, (3) external gamma-dose burdens of survivors, (4) derived diet model, and (5) ingestion-rate routines for all animals.

In this section, the estimated biological effects on humans are limited to the computation of the absorbed dose in several body organs from assimilation of several specific radionuclides in fallout. The assumptions for making these estimates, without the undeveloped model systems mentioned above, are given along with the numerical results in the following paragraphs.

The biological effects on plants and animals were limited to estimates of the number killed by exposure to external gamma radiation.

All data were computed on the basis of state and national summaries. Most are reported in terms of the national summaries; however, the more detailed state summaries were retained for further analysis as needed.

Time-span limits of 29 and 90 days duration were selected for an assumed constant consumption rate of water and food with a given radionuclide concentration. This arbitrary limitation was used mainly because the behavior patterns of the radionuclide concentrations have not yet been worked out for long periods of time. Questions regarding the change in the concentrations in the water supplies, as mentioned in the second section of this report, are not resolved. The lifetime of many fresh foods, for example, is shorter than 1 month and certainly no longer than 3 months (especially without refrigeration). Other foods, such as canned goods and fruits, have an average shelf-life of about 1 year.

Thus the selected time-span limits for the dose computations are a direct reflection of the end point of the current model system development at this time. The accuracy and reliability of the computations up to the cutoff points are separate subjects; although specification of the reliability of the numerical results is beyond the scope of this study in a statistical and mathematical sense, attempts were made to use average values of all input parameters that were derived from experimental measurements or from other considerations to eliminate, insofar as possible, consistent biases in the calculations.

Water Contamination

The concentrations of six radionuclides (Sr-89, Sr-90, Ru-106, I-131, Cs-137, and Ba-140) in exposed water systems were computed for both assumed attacks. No damage restraint for destruction of the water sources by ground shock or air-blast overpressure was included in the calculation to verify the survival of the source(s).

Table 32 gives, for the HM attack, the radionuclide concentrations in atoms per liter for five representative cities receiving different levels of fallout. Table 33 groups all of the water supplies of the 184 communities into concentration ranges for the six soluble radionuclides resulting from the HM attack and gives the percentage of the (preattack) population that would use these waters. The percentage of the population listed under zero atoms per liter is made up from communities that either did not receive significant fallout or had adequate well water for emergency use.

Table 34 gives, for the survivors in or near the five representative cities, the body and organ absorbed doses for the adult human, in rems, computed for the ingestion of their source water at the rate of 1 liter per day starting at 1 day and 7 days after attack. The water of the city of St. Louis had the highest radionuclide concentrations of all of the 184 communities considered. At that city, all six radionuclides had concentrations ranging from 10^{12} to 10^{13} atoms per liter. For comparative purposes, the water for Philadelphia had nuclide concentrations between 10^{11} and 10^{12} atoms per liter, that of Baltimore had between 10^{10} and 10^{11}, that of Boston had between 10^{9} and 10^{10}, and that of Tulsa had between 10^{8} and 10^{9} atoms per liter. The daily ingestion of 1 liter of the most contaminated water of all 184 communities in the study, from 1 to 91 days after attack, produced only a minimal total-body dose. The I-131 thyroid dose, on the other hand, was calculated at 9,550 rems for this period of ingestion. For infants drinking 1 liter per day, the thyroid dose would be about 96,000 rems in 91 days. If water was drunk nationwide during this period at the rate of 1 liter per day, no more than 5.6 percent of the population would have accumulated thyroid doses in excess of 1,530 rems. For the MC attack, no more than 2.5 percent of the population was calculated to receive a 1,530-rem thyroid dose.

Table 35 groups all of the water sources into concentration ranges for the six soluble radionuclides for the MC attack and gives the percentage of the population reliant upon water with the given ranges of radionuclide concentration.

Although the nationwide ingestion dosages have not been individually calculated for the 184 communities, the internal absorbed dosage to a given percentage of the population may be inferred for the two attacks by comparing the percentages listed for concentrations of radionuclides in Tables 33 and 35 with the concentrations shown in Table 32 and the calculated dosages listed in Table 34. Also, since the number of radionuclides did not vary radically from each other and usually are within an order of magnitude from each other for a particular water source,

Table 32

CONCENTRATIONS OF SOLUBLE NUCLIDES IN EXPOSED WATER SOURCES
FOR FIVE REPRESENTATIVE CITIES AFTER THE HM ATTACK
(In 10^{10} Zero-Time Atoms/Liter)

City	I_1 (r/hr at 1 hr)	Sr-89	Sr-90	Ru-106	I-131	Cs-137	Ba-140
St. Louis	16,820	418	652	284	624	665	723
Philadelphia	4,210	27.9	41.8	18.2	40.0	44.3	46.3
Baltimore	440	3.20	4.43	1.92	4.24	5.18	4.86
Boston	88	0.463	0.66	0.288	0.63	0.743	0.728
Tulsa	3	0.0447	0.0601	0.0262	0.0576	0.073	0.0661

Table 33

SOURCE WATER QUALITY AFTER HM ATTACK
IN SOLUBLE RADIONUCLIDE ATOMS PER LITER
AVAILABLE TO PERCENTAGE OF U.S. PREATTACK POPULATION[a]
(Percent of Population)

Radio-nuclide	Concentration Range (atoms/liter)[b]						
	0	$10^{5}-10^{8}$	$10^{8}-10^{9}$	$10^{9}-10^{10}$	$10^{10}-10^{11}$	$10^{11}-10^{12}$	$10^{12}-10^{13}$
Ba-140	50.0	1.4	1.7	5.3	20.0	15.8	6.0
Cs-137	50.0	1.5	1.7	6.4	18.7	16.7	5.2
I-131	50.0	1.4	1.7	5.2	20.8	15.4	5.6
Ru-106	50.0	1.4	2.1	13.9	17.2	13.1	2.3
Sr-90	50.0	1.4	1.7	5.3	20.6	15.5	5.6
Sr-89	50.0	1.4	2.0	10.9	18.6	12.2	4.9

a Assuming the same concentration distributions for the United States as for the 184 selected communities

b Number of atoms at the time of detonation

Table 34

BODY AND ORGAN DOSES IN REMS TO ADULT HUMANS
FOR INGESTION OF 1 LITER OF WATER PER DAY
FROM THE 1ST AND 7TH DAY TO THE 30TH AND 91ST DAY AFTER THE EW ATTACK
FOR FIVE REPRESENTATIVE CITIES[a]

City	t \ t_o [b]	Total Body		Bone[c]		Thyroid		Lower Large Intestine	
		1	7	1	7	1	7	1	7
St. Louis	30	5.41	2.95	21.8	16.1	6,950	3,440	88.1	60.5
	91	10.85	7.57	80.6	65.6	9,550	5,670	144	116
Philadelphia	30	0.348	0.190	1.41	0.971	445	220	5.71	3.9
	91	0.701	0.490	5.11	4.11	611	364	9.34	7.56
Baltimore	30	0.0373	0.0205	0.155	0.108	47.3	23.4	0.612	0.420
	91	0.0767	0.0539	0.574	0.463	64.9	38.6	1.009	0.815
Boston	30	0.00553	0.00869	0.0228	0.0157	7.03	3.47	0.0911	0.0641
	91	0.01129	0.00792	0.0856	0.0691	9.64	5.74	0.151	0.122
Tulsa	30	0.000509	0.00028	0.00214	0.00149	0.642	0.418	0.0084	0.00575
	91	0.00109	0.000743	0.00816	0.00659	0.881	0.525	0.014	0.0113

a Dose conversion factors taken from Reference 38

b Time in days

c Dose to total bone; does not include contributions from La-140 (daughter of Ba-140)

Table 35

SOURCE WATER QUALITY AFTER MC ATTACK
IN SOLUBLE RADIONUCLIDE ATOMS PER LITER
AVAILABLE TO PERCENTAGE OF U.S. PREATTACK POPULATION[a]
(Percent of Population)

Radio-nuclide	Concentration Range (atoms/liter) 0	10^5-10^8	10^8-10^9	10^9-10^{10}	10^{10}-10^{11}	10^{11}-10^{12}	10^{12}-10^{13}
Ba-140	70.0	6.3	4.0	8.1	2.8	6.4	2.5
Cs-137	70.0	6.5	4.4	8.6	1.0	0.4	2.5
I-131	70.0	6.5	4.6	7.3	2.0	0.4	2.5
Ru-106	70.0	6.7	9.0	3.7	3.2	5.2	1.5
Sr-90	70.0	6.5	4.6	8.2	2.0	0.4	2.5
Sr-[illegible]	70.0	6.5	4.6	8.5	1.5	7.0	1.0

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a Assuming the same concentration distributions for the United States as for the 104 selected communities average radionuclide concentrations may be used for comparative purposes. Table 30 lists, for both attacks, the quality of water in atoms per liter available to various percentages of the population. Also, for reference, the maximum equivalent thyroid doses, in rems, for I-131 ingestion at 1 liter of water per day for each concentration level were included.

The [illegible]onuclide concentrations in the water, from which dosages to the adult human were derived, were for untreated water. The partial removal of these radionuclides or reduction of radionuclide concentrations may be obtained through water treatment.

Water treatment experiments involving various coagulation and filtration methods have produced reduction factors between 2 and 100 for the various radionuclides. The lower reduction factors reported generally were for radioiodine. On the other hand, reduction factors greater than 1,000 have been uniformly reported for water decontamination of many radionuclides, except I-131, by commonly-used ion exchange methods. Anionic resin ion exchangers are required to remove I-131 and other anionic nuclides from water. Although water from lakes, and especially from streams, usually is processed prior to distribution to the public, the process generally does not include ion exchange softening. Ion exchange softening in public systems is extremely rare. Softening units do exist in private residences in limited numbers throughout the country, mainly where the available water is considered objectionably hard by individual users.

The water contamination conditions after both attacks are summarized as follows:

1. A small percentage of the population would have water contaminated to relatively high levels.

2. The drinking of this water would not cause sickness or death; late somatic effects are unknown, and serious late somatic effects would be improbable.

3. After the HM attack, 80 percent of the population would have water that is at least 100 times cleaner than that discussed above.

4. The ingestion of these cleaner waters would produce only negligible dosages.

5. After the MC attack, these cleaner waters would be available to 90 percent of the population.

6. Various methods of water treatment, if instituted, would further reduce radionuclide concentrations in water.

Table 36

AVERAGE RADIONUCLIDE CONCENTRATION IN WATER AVAILABLE TO THE CUMULATIVE PERCENTAGE OF THE POPULATION

Average Radionuclide Concentrations (atoms/liter)	Maximum Thyroid Dose[a] (rems)	Percent of Population	
		HM Attack	MC Attack
$< 10^7$	0	50	70
10^8	0.153	51.4	76.5
10^9	1.53	53.2	81.8
10^{10}	15.3	60.9	89.2
10^{11}	153	80.2	91.6
10^{12}	1,530	94.7	97.9
10^{13}	15,300[b]	100	100

a For adult humans, 91 day ingestion period for ingestion starting at 1 day after attack; for infants, the dose would be ten times these values

b The highest thyroid dose calculated was 9,550 rems for the HM attack and 5,350 rems for the MC attack

Exter   Contamination of (Crop) Plants

Foliar contamination of food crops (growing at the time of the attack) by local fallout was calculated for both attacks under existing shelter and good shelter conditions for the farmer. The results of the computed national summaries are presented in Tables 37 and 38. A cumulative plot of crop production as a function of increasing level of contamination was used to obtain a maximum contamination-level value (atoms/gm) that 50 percent of the total (harvested) crop would not exceed. A similar maximum concentration-level value was obtained for 90 percent of the crop.

Good shelters would limit the early-time radiation dose to farmers, thus allowing them to harvest crops without receiving an exposure dose in excess of 200 roentgens ERD(max). Therefore, the contamination levels of the harvested foods are somewhat higher for the good shelter case because more of the crops are harvested at the higher fallout levels. These more highly contaminated crops, if unneeded, could be left unharvested to reduce the exposure dose to farmers; crops would not be left unharvested because of their contamination level. In other words, the food requirements for the survivors and the shelter available to the farmer must be considered in setting the planned exposure-dose criteria to farmers for harvesting as well as for planting the next crop. The allocation of up to 200 roentgens ERD(max) in all limiting cases assumes that the food crops would be urgently needed. The proposed U.S. Department of Agriculture program to quarantine land on the basis of Sr-90 contamination fails to recognize the general basic assessment principles for considering all factors that are critically related to national survival after a nuclear attack.

The leafy vegetables showed the highest levels of contamination; the grains and root crops gave the lowest concentrations. The significance of the foliar contamination of food crops is discussed later in this section, where the consumption of the food in a normal diet is considered and the absorbed dose for several body organs of humans is estimated.

The data summaries of Tables 37 and 38 indicate that the fraction of the crop acres that could be harvested after all of the assumed attacks is generally in excess of 50 percent. The exceptions are cabbage, sorghum, dry bean, tomato, snap bean, carrot, and lettuce; most of these crops, with the smallest fraction harvested, are fresh vegetables.

The initial crop contamination levels are generally higher for the good shelter case; for the HM attack, the median (50 percent) crop concentrations for the good shelter recovery base are as much as 45 times those for the existing shelter recovery base (see potato). The exception to this trend is cabbage. Similar comparisons between the two attacks for the median crop concentrations give ratios, for HM recoveries to HC recoveries, as high as 1,000 for the 10-PF shelter case and as high as 9,000 for the 1,000-PF shelter case (except cabbage, for which the ratios were higher). These ratios, for most crops, are much larger than the ratios in the total yields of the two attacks.

Table 37

RADIONUCLIDE CONTAMINATION OF FOOD: EXISTING SHELTER[a]

Crop	Normally Planted Acres (thousands)	HM Attack: Harvestable Acres (percent)	HM Attack: Maximum Concentration Level (atoms/gm)[b], 0.5 of Crop	HM Attack: Maximum Concentration Level (atoms/gm)[b], 0.9 of Crop	MC Attack: Harvestable Acres (percent)	MC Attack: Maximum Concentration Level (atoms/gm)[b], 0.5 of Crop	MC Attack: Maximum Concentration Level (atoms/gm)[b], 0.9 of Crop
Corn	79,605	53	1×10^8	2×10^9	80	2×10^7	5×10^8
Sweet corn	566	62	1×10^8	2×10^9	85	1×10^5	2×10^8
Sorghum	17,903	28	1×10^5	1×10^8	29	1×10^5	2×10^8
Wheat (Grain)	49,762	50	3×10^7	7×10^8	70	6×10^5	4×10^8
Oat	35,559	54	1×10^6	2×10^9	77	2×10^7	4×10^8
Barley	14,165	49	2×10^7	1×10^9	61	8×10^5	2×10^8
Dry beans	730	17	3×10^5	4×10^9	19	1×10^5	1×10^8
Soybean	22,064	32	1×10^6	2×10^9	46	5×10^7	6×10^8
Alfalfa	26,093	57			80		
Clover (Hay)	14,025	53	1×10^{10}	1×10^{12}	81	8×10^7	3×10^{10}
Oat (Hay)	3,477	54			67		
Potato	1,122	49	2×10^7	3×10^9	68	1×10^5	2×10^8

a Foliar contamination resulting from local fallout, harvestable crop contaminated . less than indicated levels

b Concentration of Sr-89, Sr-90, Ru-106, I-131, Cs-137, or Ba-140

Table 37 (concluded)

Crop	Normally Planted Acres (thousands)	CM Attack: Harvest-able Acres (percent)	CM Attack: Maximum Concentration Level (atoms/gm)[a] 0.5 of Crop	CM Attack: Maximum Concentration Level (atoms/gm)[a] 0.9 of Crop	MC Attack: Harvest-able Acres (percent)	MC Attack: Maximum Concentration Level (atoms/gm)[a] 0.5 of Crop	MC Attack: Maximum Concentration Level (atoms/gm)[a] 0.9 of Crop
Green pea	306	84	6×10^{7}	4×10^{8}	100	1×10^{5}	2×10^{8}
Sugar beet	391	61	3×10^{7}	2×10^{9}	80	1×10^{5}	2×10^{8}
Tomato	393	30	1×10^{8}	2×10^{9}	51	1×10^{5}	1×10^{8}
Snap bean	200	29	2×10^{7}	2×10^{8}	37	1×10^{5}	2×10^{7}
Cabbage	72	10	1×10^{10}	2×10^{11}	13	1×10^{5}	9×10^{7}
Dry onion	82	48	9×10^{6}	2×10^{9}	60	1×10^{5}	4×10^{6}
Carrot	61	25	1×10^{5}	3×10^{9}	25	1×10^{5}	4×10^{6}
Lettuce	177	18	1×10^{5}	3×10^{7}	19	1×10^{5}	3×10^{7}
Apple	19,853[b]	65	1×10^{8}	1×10^{9}	92	1×10^{5}	8×10^{7}
Peach	30,631[b]	58	1×10^{8}	2×10^{9}	82	1×10^{5}	2×10^{9}
Orange	23,762[b]	57	1×10^{5}	5×10^{10}	98	1×10^{5}	2×10^{7}

a Concentration of Sr-89, Sr-90, Ru-106, I-131, Cs-137, or Ba-140

b Thousands of trees

Table 38

RADIONUCLIDE CONTAMINATION OF FOOD: GOOD SHELTER[a]

Crop	Normally Planted Acres (thousands)	HM Attack: Harvestable Acres (percent)	HM Attack: Maximum Concentration Level (atoms/gm)[b] 0.5 of Crop	HM Attack: Maximum Concentration Level (atoms/gm)[b] 0.9 of Crop	MC Attack: Harvestable Acres (percent)	MC Attack: Maximum Concentration Level (atoms/gm)[b] 0.5 of Crop	MC Attack: Maximum Concentration Level (atoms/gm)[b] 0.9 of Crop
Corn	79,605	88	5×10^{8}	4×10^{10}	96	6×10^{7}	3×10^{10}
Sweet corn	566	86	2×10^{8}	4×10^{10}	88	1×10^{5}	2×10^{8}
Sorghum	17,903	39	2×10^{6}	2×10^{10}	43	1×10^{7}	3×10^{9}
Wheat (Grain)	49,764	80	1×10^{8}	3×10^{10}	92	2×10^{7}	2×10^{9}
Oat	26,559	91	5×10^{8}	4×10^{10}	94	6×10^{7}	2×10^{9}
Barley	14,165	83	5×10^{8}	1×10^{10}	93	1×10^{8}	4×10^{9}
Dry bean	733	19	1×10^{7}	5×10^{9}	21	1×10^{5}	3×10^{8}
Soybean	22,064	51	3×10^{9}	5×10^{9}	54	1×10^{8}	2×10^{9}
Alfalfa	26,093	97			99		
Clover (Hay)	14,026	94	1×10^{11}	1×10^{12}	96	2×10^{9}	7×10^{10}
Oat (Hay)	3,477	92			98		
Potato	1,122	66	9×10^{8}	5×10^{10}	73	1×10^{5}	5×10^{9}

a Foliar contamination resulting from local fallout: harvestable crop contaminated to less than indicated levels

b Concentration of Sr-89, Sr-90, Ru-106, I-131, Cs-137, or Ba-140

Table 38 (concluded)

Crop	Normally Planted Acres (thousands)	EM Attack: Harvestable Acres (percent)	EM Attack: Maximum Concentration Level (atoms/gm)[a]: 0.5 of Crop	EM Attack: Maximum Concentration Level (atoms/gm)[a]: 0.9 of Crop	MC Attack: Harvestable Acres (percent)	MC Attack: Maximum Concentration Level (atoms/gm)[a]: 0.5 of Crop	MC Attack: Maximum Concentration Level (atoms/gm)[a]: 0.9 of Crop
Green pea	306	99	1×10^{8}	2×10^{10}	100	1×10^{5}	1×10^{8}
Sugar beet	891	84	1×10^{8}	6×10^{9}	91	1×10^{5}	1×10^{9}
Tomato	393	41	4×10^{8}	5×10^{9}	52	1×10^{5}	1×10^{8}
Snap bean	300	34	5×10^{7}	1×10^{9}	37	1×10^{5}	4×10^{7}
Cabbage	72	13	3×10^{9}	3×10^{10}	13	1×10^{5}	6×10^{6}
Dry onion	52	57	9×10^{7}	3×10^{9}	63	1×10^{5}	1×10^{7}
Carrot	61	25	1×10^{5}	2×10^{9}	26	1×10^{5}	8×10^{6}
Lettuce	177	16	1×10^{5}	3×10^{9}	19	1×10^{5}	5×10^{7}
Apple	19,853[b]	67	1×10^{8}	5×10^{9}	95	1×10^{5}	3×10^{8}
Peach	30,631[b]	75	3×10^{9}	4×10^{10}	93	1×10^{7}	1×10^{10}
Orange	23,762[b]	53	2×10^{6}	3×10^{9}	98	1×10^{5}	4×10^{7}

a Concentration of Sr-89, Sr-90, Ru-106, I-131, Cs-137, or Ba-140

b Thousands of trees

Internal Contamination of (Crop) Plants

The internal contamination of plants was calculated for the first planting of all crops after the attack. Since the assumed attack date was June 1, many of the crops planted after June 1, where possible, were susceptible to internal contamination by both local and worldwide fallout up to the time of planting and to foliar contamination by worldwide fallout during the month of harvest.

The worldwide fallout component for the contamination included that from the postulated attack on the United States and an assumed counterattack on a typical enemy. The nature of the counterattack, which was programmed according to the worldwide fallout model described in the second section of this report, is given in Table 39. In the counterattack, a 50 percent fission yield was assumed for all weapons.

The crop contamination data for the first crop grown after attack, based on the national summary of the planted (and harvested) acres, the fractional crop yields, and the maximum nuclide contamination levels at 50 and 90 percent of the harvested crop for the HM attack, are summarized in Tables 40 and 41 for existing and good shelter cases, respectively. The data summaries were computed in the same way as those for the foliar contamination. The fraction of the acres planted refers to the first crop of each kind to be planted after attack, based on the exposure dose criteria and shelter living routines given in the second section of this report. The crop planting and harvest recovery for the existing shelter case do not include the assumption that other people from lower contaminated areas would come in and use the land. Such an assumption, however, is implied for the good shelter case where evacuation and area reentry were involved. With the good shelter, essentially all of the crops could be planted on schedule after the HM attack, however, with existing shelter (as defined), the fraction of accessible land drops as low as 50 percent for some crops. Improved estimates of the first and other postattack crop contamination levels and production availabilities would require a more detailed account of the fate of the manpower by local area.

The lower limits of the crop contamination for consideration may be made with reference to current contamination levels of Sr-90 in food from worldwide fallout; the latter generally are in the range of 10^6 to 10^7 atoms/gm of foodstuff.[92] Since the current levels would be additive to those from any attack, new contributions of Sr-90 giving less than 10^6 atoms/gm of foodstuff are not considered for Sr-90 and all other radionuclides.

The root uptake process causes large changes in the relative abundance of the different fission-product nuclides in the various food crops. Thus, while the calculated concentration of Sr-89 and Sr-90 is higher in many of the crops from the first planting after attack than it is for the crop standing at the time of attack, the concentration of other elements is much lower. The higher concentrations of Sr-89 for the first postattack crop, relative to the foliar contamination of the

Table 39

COUNTERATTACK:
WEAPON YIELD, ALTITUDE, AND WEAPON NUMBER DISTRIBUTION

Burst Latitude (°N)	1 MT		5 MT		20 MT	
	Surface	Air	Surface	Air	Surface	Air
35-40	-	7	1	-	6	-
40-45	-	26	9	1	58	2
45-50	2	41	17	2	80	3
50-55	4	59	26	3	130	8
55-60	9	50	35	4	130	1
60-65	-	13	3	-	17	-
65-70	-	8	1	-	18	-
70-75	-	-	-	-	2	-
Total	15	204	92	10	441	14

Total weapons: 776

Total yield: 9,829 MT

Fission yield at 0.5 fission/total = 4,914 MT

Time of counterattack = time of attack on United States

Fission yields of selected nuclides, atoms/fission, used in all worldwide fallout computations:

Sr-89	0.0281
Sr-90	0.0309
Zr-95	0.0552
Ru-106	0.0452
I-131	0.0310
Cs-137	0.0600
Ba-140	0.0551
Ce-144	0.0436

Table 40

MAXIMUM NUCLIDE CONTAMINATION LEVELS OF CROPS GROWN AFTER THE HM ATTACK: EXISTING SHELTER

Crop	Normally Planted Acres (thousands)	Acres Planted (percent)	Maximum Nuclide Concentration Level (atoms gm): Sr-89, 0.5 of Crop	Sr-89, 0.9 of Crop	Sr-90, 0.5 of Crop	Sr-90, 0.9 of Crop	Zr-95, 0.5 of Crop	Zr-95, 0.9 of Crop	Ru-106, 0.5 of Crop	Ru-106, 0.9 of Crop	Cs-137, 0.5 of Crop	Cs-137, 0.9 of Crop	Ce-144, 0.5 of Crop	Ce-144, 0.9 of Crop
Corn	79,605	52	1.8×10^{8}	1.2×10^{9}	2.7×10^{8}	1.5×10^{9}	2.2×10^{6}	6.5×10^{6}	3.0×10^{6}	1.1×10^{7}	3.2×10^{7}	7.5×10^{7}	2.0×10^{6}	6.0×10^{6}
Sweet corn	566	70	1.1×10^{8}	7.0×10^{8}	1.6×10^{8}	8.5×10^{8}	1.2×10^{6}	6.8×10^{6}	3.4×10^{6}	1.4×10^{7}	1.5×10^{7}	6.1×10^{7}	$< 10^{6}$	6.0×10^{6}
Sorghum	17,903	53	3.3×10^{8}	2.8×10^{9}	3.6×10^{8}	3.2×10^{9}	2.4×10^{7}	2.1×10^{8}	1.4×10^{8}	6.9×10^{8}	2.4×10^{8}	2.0×10^{9}	2.4×10^{7}	2.1×10^{8}
Wheat	49,762	51	3.7×10^{7}	5.7×10^{8}	5.8×10^{7}	6.5×10^{8}	$< 10^{6}$	4.0×10^{7}	10^{6}	3.9×10^{7}	4.3×10^{6}	3.9×10^{9}	$< 10^{6}$	1.0×10^{7}
Oat	26,559	57	3.5×10^{8}	1.0×10^{9}	4.3×10^{8}	1.4×10^{9}	4.0×10^{7}	1.3×10^{8}	2.5×10^{8}	7.5×10^{8}	4.0×10^{8}	1.3×10^{9}	4.0×10^{7}	1.3×10^{8}
Barley	14,165	50	1.1×10^{8}	6.5×10^{8}	1.6×10^{8}	7.0×10^{8}	1.4×10^{7}	6.8×10^{7}	2.6×10^{7}	8.6×10^{7}	1.5×10^{8}	6.8×10^{8}	1.4×10^{7}	6.8×10^{7}
Dry bean	733	73	7.0×10^{8}	6.0×10^{9}	9.0×10^{8}	6.2×10^{9}	$< 10^{6}$	2.2×10^{6}	4.4×10^{6}	4.5×10^{7}	3.0×10^{7}	3.5×10^{8}	$< 10^{6}$	2.5×10^{6}
Soybean	22,064	43	9.5×10^{8}	5.5×10^{9}	1.4×10^{9}	7.0×10^{9}	$< 10^{6}$	6.6×10^{7}	1.5×10^{7}	7.0×10^{7}	9.7×10^{7}	5.0×10^{8}	$< 10^{6}$	2.3×10^{7}
Alfalfa	26,093	57	1.8×10^{9}	4.5×10^{10}	2.5×10^{9}	6.0×10^{10}	$< 10^{6}$	4.9×10^{8}	5.4×10^{7}	7.6×10^{8}	3.7×10^{7}	2.5×10^{9}	$< 10^{6}$	4.7×10^{7}
Clover & timothy	14,026	55	1.8×10^{9}	1.6×10^{10}	2.9×10^{9}	3.6×10^{10}	$< 10^{6}$	6.0×10^{6}	7.8×10^{7}	3.5×10^{9}	1.5×10^{8}	5.0×10^{9}	$< 10^{6}$	4.9×10^{6}
Potato	1,122	57	4.2×10^{7}	4.0×10^{8}	5.4×10^{7}	4.5×10^{8}	2.0×10^{6}	7.0×10^{6}	2.2×10^{6}	1.1×10^{7}	3.4×10^{8}	3.3×10^{9}	1.8×10^{6}	6.7×10^{6}
Green pea	306	81	7.0×10^{7}	6.0×10^{8}	1.2×10^{8}	6.8×10^{8}	9.5×10^{6}	4.0×10^{7}	2.7×10^{7}	6.0×10^{7}	1.5×10^{7}	5.4×10^{7}	4.0×10^{6}	1.6×10^{7}
Sugar beet	891	61	3.0×10^{8}	3.3×10^{9}	4.1×10^{8}	4.4×10^{9}	2.2×10^{6}	7.3×10^{6}	2.7×10^{6}	7.9×10^{6}	3.0×10^{8}	8.0×10^{8}	2.2×10^{6}	7.3×10^{6}
Tomato	393	65	1.7×10^{9}	7.5×10^{9}	1.8×10^{9}	1.2×10^{10}	1.7×10^{9}	6.8×10^{9}	1.7×10^{9}	6.8×10^{9}	1.4×10^{10}	7.0×10^{10}	1.7×10^{9}	6.8×10^{9}
Snap bean	200	77	6.7×10^{8}	6.0×10^{9}	8.2×10^{8}	6.5×10^{9}	1.7×10^{7}	6.4×10^{7}	3.4×10^{7}	9.0×10^{7}	2.0×10^{8}	2.5×10^{9}	9.0×10^{6}	1.8×10^{7}
Cabbage	72	79	2.1×10^{9}	2.5×10^{10}	2.6×10^{9}	1.8×10^{10}	1.4×10^{9}	4.3×10^{9}	1.4×10^{9}	4.3×10^{9}	9.0×10^{9}	5.4×10^{10}	1.1×10^{9}	1.3×10^{9}
Dry onion	82	82	2.8×10^{7}	1.6×10^{9}	3.3×10^{7}	1.6×10^{9}	1.9×10^{6}	6.0×10^{6}	2.7×10^{6}	1.3×10^{7}	2.5×10^{9}	6.5×10^{9}	1.9×10^{6}	6.0×10^{6}
Carrot	61	85	4.9×10^{6}	1.8×10^{9}	2.2×10^{7}	2.6×10^{9}	6.8×10^{6}	1.4×10^{9}	2.1×10^{6}	1.4×10^{9}	2.1×10^{9}	7.0×10^{9}	$< 10^{6}$	1.1×10^{9}
Lettuce	177	70	2.5×10^{9}	[illegible]	3.0×10^{9}	1.4×10^{10}	1.9×10^{9}	7.0×10^{9}	1.9×10^{9}	7.0×10^{9}	1.6×10^{10}	7.0×10^{10}	1.9×10^{9}	[illegible]
Apple	198,853[a]	66	9.0×10^{7}	6.0×10^{8}	1.0×10^{8}	8.5×10^{8}	1.4×10^{6}	7.5×10^{6}	3.5×10^{6}	1.5×10^{7}	2.6×10^{7}	7.5×10^{7}	$< 10^{6}$	1.5×10^{6}
Peach	30,631[a]	61	9.0×10^{7}	7.0×10^{8}	1.5×10^{8}	1.0×10^{9}	$< 10^{6}$	5.0×10^{6}	1.7×10^{6}	6.0×10^{7}	1.3×10^{7}	5.0×10^{8}	$< 10^{6}$	5.0×10^{6}
Orange	23,762[a]	72	2.7×10^{8}	9.0×10^{8}	3.3×10^{8}	2.0×10^{9}	7.0×10^{7}	4.0×10^{8}	2.0×10^{8}	6.0×10^{8}	2.2×10^{9}	5.5×10^{9}	2.6×10^{7}	7.5×10^{7}

a [illegible]

Table 41

MAXIMUM NUCLIDE CONTAMINATION LEVELS OF CROPS GROWN AFTER THE HM ATTACK: GOOD SHELTER

Crop	Normally Planted Acres (thousands)	Acres Planted (percent)	Sr-89 0.5 of Crop	Sr-89 0.9 of Crop	Sr-90 0.5 of Crop	Sr-90 0.9 of Crop	Zr-95 0.5 of Crop	Zr-95 0.9 of Crop	Ru-106 0.5 of Crop	Ru-106 0.9 of Crop	Cs-137 0.5 of Crop	Cs-137 0.9 of Crop	Ce-144 0.5 of Crop	Ce-144 0.9 of Crop
			Maximum Nuclide Concentration Level (atoms/gm)											
Corn	79,605	100	5.8×10^{8}	6.5×10^{9}	8.0×10^{8}	1.0×10^{10}	3.1×10^{6}	6.8×10^{6}	1.3×10^{7}	1.0×10^{8}	1.6×10^{8}	5.8×10^{8}	2.2×10^{6}	5.2×10^{6}
Sweet corn	566	100	2.2×10^{8}	2.9×10^{9}	3.0×10^{8}	1.7×10^{9}	2.9×10^{6}	5.6×10^{6}	7.0×10^{6}	4.5×10^{7}	2.0×10^{8}	5.9×10^{8}	2.4×10^{6}	5.0×10^{6}
Sorghum	1,7903	85	1.0×10^{9}	2.6×10^{10}	1.5×10^{9}	7.9×10^{10}	3.8×10^{7}	1.5×10^{8}	1.8×10^{8}	2.1×10^{9}	1.3×10^{9}	6.8×10^{9}	3.5×10^{7}	9.0×10^{7}
Wheat	49,762	92	4.1×10^{8}	4.3×10^{9}	6.2×10^{8}	7.1×10^{5}	$<10^{6}$	4.5×10^{7}	3.0×10^{7}	1.8×10^{8}	1.4×10^{8}	3.0×10^{9}	$<10^{6}$	2.4×10^{7}
Oat	26,559	100	8.6×10^{8}	4.0×10^{9}	1.1×10^{9}	6.2x10[illegible]	6.6×10^{7}	1.4×10^{8}	1.9×10^{8}	4.5×10^{8}	1.1×10^{9}	6.1×10^{9}	5.9×10^{7}	1.4×10^{8}
Barley	14,165	100	4.0×10^{8}	5.5×10^{9}	6.2×10^{8}	7.0×10^{9}	1.3×10^{7}	4.1×10^{7}	6.9×10^{7}	2.0×10^{8}	9.5×10^{8}	3.0×10^{9}	8.2×10^{6}	2.1×10^{6}
Dry bean	733	100	1.5×10^{9}	1.3×10^{10}	2.0×10^{9}	2.5×10^{10}	$<10^{6}$	4.9×10^{6}	1.1×10^{7}	1.1×10^{8}	1.7×10^{8}	2.7×10^{9}	$<10^{6}$	4.9×10^{6}
Soybean	22,064	84	2.6×10^{9}	2.7×10^{10}	4.2×10^{9}	4.7×10^{10}	$<10^{6}$	2.0×10^{7}	3.3×10^{7}	1.9×10^{8}	3.1×10^{8}	2.7×10^{9}	$<10^{6}$	1.5×10^{7}
Alfalfa	26,093	95	8.4×10^{9}	9.0×10^{10}	1.2×10^{10}	2.0×10^{11}	$<10^{6}$	1.4×10^{8}	2.5×10^{8}	3.4×10^{9}	1.7×10^{8}	2.2×10^{9}	$<10^{6}$	4.5×10^{7}
Clover & timothy	14,026	96	1.0×10^{10}	8.2×10^{10}	1.5×10^{10}	2.0×10^{11}	$<10^{6}$	5.0×10^{9}	3.5×10^{8}	4.5×10^{9}	6.4×10^{8}	9.2×10^{9}	$<10^{6}$	3.2x10[illegible]
Potato	1,122	98	2.3×10^{8}	4.3×10^{9}	3.3×10^{8}	2.5×10^{9}	2.2×10^{6}	5.8×10^{6}	9.8×10^{6}	1.6×10^{8}	4.3×10^{8}	1.9×10^{9}	2.1×10^{6}	5.8×10^{6}
Green pea	306	100	1.1×10^{8}	1.1×10^{9}	1.6×10^{8}	1.5×10^{9}	8.5×10^{6}	1.8×10^{7}	2.1×10^{7}	9.4×10^{7}	1.1×10^{8}	5.2×10^{8}	3.9×10^{6}	1.3×10^{7}
Sugar beet	891	100	1.5×10^{9}	4.5×10^{10}	2.1×10^{9}	6.0×10^{10}	1.1×10^{6}	2.0×10^{6}	4.8×10^{6}	1.5×10^{8}	1.9×10^{8}	5.9×10^{8}	1.0×10^{6}	1.7×10^{6}
Tomato	393	100	1.7×10^{9}	2.4×10^{10}	3.6×10^{9}	5.5×10^{10}	1.6×10^{9}	5.6×10^{9}	1.6×10^{9}	5.6×10^{9}	1.3×10^{10}	4.2×10^{10}	1.6×10^{9}	5.6×10^{9}
Snap bean	200	99	1.2×10^{9}	1.2×10^{10}	1.5×10^{9}	2.8×10^{10}	1.1×10^{7}	5.0×10^{7}	3.7×10^{7}	1.5×10^{8}	3.0×10^{8}	2.0×10^{9}	7.5×10^{6}	4.3×10^{7}
Cabbage	72	97	3.2×10^{9}	4.6×10^{10}	4.0×10^{9}	6.1×10^{10}	2.1×10^{9}	5.2×10^{9}	2.1×10^{9}	5.2×10^{9}	6.4×10^{9}	8.5×10^{10}	2.1×10^{9}	5.2×10^{9}
Dry onion	82	100	3.0×10^{8}	1.8×10^{10}	4.0×10^{8}	3.0×10^{10}	3.4×10^{6}	1.2×10^{7}	8.0×10^{6}	1.3×10^{8}	1.1×10^{9}	5.0x1	2.6×10^{6}	9.0×10^{6}
Carrot	61	100	8.0×10^{6}	4.0×10^{9}	1.8×10^{7}	4.0×10^{9}	1.5×10^{6}	2.6×10^{6}	2.1×10^{6}	1.4×10^{7}	2.4×10^{9}	7.4×10^{9}	2.6×10^{6}	7.1×10^{6}
Lettuce	177	100	2.2×10^{9}	3.8×10^{10}	7.8×10^{9}	5.8×10^{10}	1.8×10^{9}	6.0×10^{9}	1.9×10^{9}	6.8x10[illegible]	1.5×10^{10}	6.0×10^{10}	1.8×10^{9}	6.0x10[illegible]
Apple	198,853[a]	100	2.0×10^{8}	2.6×10^{9}	2.6×10^{8}	6.8×10^{9}	6.0×10^{6}	[illegible]8x10^6	7.7×10^{6}	7.0×10^{7}	5.0×10^{7}	4.5×10^{8}	$<10^{6}$	1.5×10^{6}
Peach	30,631[a]	94	2.0×10^{8}	4.8×10^{9}	2.8×10^{8}	7.0×10^{9}	$<10^{6}$	1.7×10^{6}	5.8×10^{6}	1.1×10^{7}	2.5×10^{7}	6.8×10^{8}	$<10^{6}$	1.7×10^{6}
Orange	23,762[a]	100	4.6×10^{8}	3.0×10^{9}	7.0×10^{8}	5.9×10^{9}	1.4x10[illegible]	2.6×10^{8}	1.1×10^{8}	2.6×10^{8}	1.7×10^{9}	7.0x10[illegible]	3.6×10^{7}	6.2x10[illegible]

a. Thousands of trees

standing crop, occur especially in sorghum, dry bean, lettuce, and orange. Because of both the fractionation among the radionuclides in the first crops grown after attack and the relative decay rates over time, no direct comparison can be made, with respect to the relative severity of contamination levels between the crops standing at the time of attack and the first crop planted after attack, simply on the basis of the relative concentration of the nuclides in the two crops.

Internal Contamination of Animals and Fowl

The estimates of the internal contamination of animal-derived foods (meat, milk, and eggs) for human consumption require prior specification of animal diets. The assumed diets for dairy cattle, beef cattle, sheep, swine, and poultry are given in Table 42 for ingestions starting at 1, 14, 183, 365, and 548 days after attack. The first three times are associated with the ingestion of foods with foliar contamination from crops growing at the time of attack and of water contamination from local fallout. The last two times are associated with consumption of foods from the first crop planted after attack that are contaminated through root uptake (including contribution from both local and worldwide fallout contamination of agricultural land) and through foliar contamination from worldwide fallout that is deposited during the month of harvest.

The computed zero-time concentrations for meat, milk, and eggs, from animals and chickens that consume foods with nuclide concentrations not exceeding those for 50 and 90 percent of the available food, are given in Table 43. The concentrations were computed using the food consumption rates given in Table 42, the 50 and 90 percent levels of contamination for the various animal foods, and the C^o_{if} values given in Table 43. The U^o_i values were calculated by summing the products of the consumption rates and nuclide concentrations for the various foods in the assumed diets.

The nuclide concentrations in milk from cows grazed in contaminated pastures were calculated separately from curves relating D_{ik} to U^o_i versus time for several ages at attack and the pasture contamination levels as summarized in Table 44. The pasture concentrations are based on the initial foliar contamination for a given milk production rate for the number of cows that survive after the attacks. In all known cases, the limitation on milk production was due to the loss of the dairy herd rather than to the exposure dose limitations for the dairymen; however, no exposure routine different from other farm operations was developed for dairymen. In future evaluations such as this, special routines should be developed to reflect more accurately the range of animal husbandry practices that could be followed under various attack situations.

Table 42

ANIMAL DIET VERSUS TIME OF INGESTION
(Intake in Grams per Day, Dry Weight Basis)

	t_o				
	1 day	14 days	183 days	365 days	548 days
Dairy Cattle					
Pasturage	7,000	7,000	7,000	7,000	7,000
Hay	-[a]	-	1,000	1,000	1,000
Grain	-	-	1,000	1,000	1,000
Water	-	-	-	-	-
Beef Cattle					
Pasturage	800	800	800	800	800
Corn	-	-	800	800	800
Clover (Hay)	-	-	6,400	6,400	6,400
Water	25,000	25,000	25,000	-	-
Sheep					
Corn	-	-	200	200	200
Oat	-	-	200	200	200
Sorghum	-	-	200	200	200
Pasturage	200	200	200	200	200
Clover (Hay)	-	-	1,200	1,200	1,200
Water	4,000	4,000	4,000	-	-
Swine					
Corn	-	-	1,600	1,600	1,600
Sorghum	-	-	1,600	1,600	1,600
Soybean meal	-	-	-	400	400
Alfalfa meal (Hay)	-	-	-	400	400
Water	-	-	-	-	-
Poultry					
Corn	-	-	36.8	36.8	36.8
Wheat (Grain)	-	-	36.8	36.8	36.8
Soybean oil	-	-	-	9.2	9.2
Alfalfa meal (Hay)	-	-	-	9.2	9.2
Water	-	-	-	-	-

a Dash indicates that uncontaminated (stored) food or clean well water was available

Table 43

ESTIMATES OF RADIONUCLIDE CONCENTRATIONS, C^{o}_{if}, IN MEAT, MILK, AND EGGS RESULTING FROM CONSUMPTION OF DIETS WHOSE CONCENTRATIONS ARE NOT EXCEEDED BY 50 AND 90 PERCENT OF THE AVAILABLE ANIMAL FOODS AFTER THE HM ATTACK: EXISTING SHELTER

(Values of C^{o}_{if} Are in Atoms per Gram)

[illegible]	[illegible]	[illegible]	Maximum Concentration Level 0.5 of Diet, t_o (b): [illegible]	11	183	365	548	Maximum Concentration Level 0.9 of Diet, t_o (b): 1	11	183	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]3x10^{8}	[illegible]x10^{8}	1.4x10^{9}	2.[illegible]x10^{8}	2.6x10^{8}	[illegible]x10^{9}	[illegible]x10^{9}	[illegible]x10^{10}	6x10$^{[illegible]}$	6x10$^{[illegible]}$
[illegible]	[illegible]	[illegible]	[illegible]	1.3x10^{8}	1.4x10^{9}	3.8x10^{8}	3.8x10^{8}	[illegible]x10^{9}	[illegible]	[illegible]	[illegible]2x10^{9}	2x10^{9}
	[illegible]	[illegible]	[illegible]x10^{9}	1.6x10^{9}	1.8x10^{10}	-	-	2.[illegible]x10^{10}	2.[illegible]x10^{10}	1.9x10$^{1[illegible]}$		
	[illegible]	[illegible]	[illegible]	6.4x10^{9}	7x10^{10}	[illegible]x10^{8}	3x10^{8}	[illegible]8x10^{10}	[illegible]8x10^{10}	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0	0	[illegible]x10^{6}	[illegible]	[illegible]	0	0	[illegible]4x10^{8}	[illegible]x10^{9}	[illegible]
[illegible]	[illegible]	[illegible]	0	0	[illegible]x10^{6}	1.[illegible]x10^{8}	1.1x10^{8}	0	0	[illegible]4x10^{8}	[illegible]	[illegible]
	[illegible]	[illegible]	0	0	1.8x10^{7}			0	0	[illegible]		
	[illegible]	[illegible]	0	0	8x10^{8}	2.6x10^{9}	2.6x10^{9}	[illegible]	0	1.[illegible]x10^{10}	[illegible]	[illegible]
	[illegible]	[illegible]	1.3x10^{8}	1.3x10^{8}	1.4x10^{9}	2.2x10^{8}	2.[illegible]x10^{8}	1.9x10^{9}	1.9x10^{9}	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.3x10^{8}	1.3x10^{8}	1.4x10^{9}	[illegible]x10^{8}	[illegible]x10^{8}	1.9x10^{9}	1.9x10^{9}	1.1x10^{10}	8x10$^{[illegible]}$	8x10$^{[illegible]}$
	[illegible]	[illegible]	6.4x10^{8}	6.4x10^{8}	[illegible]6x10^{9}			9.6x10^{9}	9.6x10$^{[illegible]}$	[illegible]x10^{10}		
	[illegible]	[illegible]	1.3x10^{10}	1.3x10^{10}	1.1x10^{11}	2.2x10^{9}	2.[illegible]x10^{9}	1.9x10$^{1[illegible]}$	1.9x10^{11}	[illegible]	[illegible]x10^{10}	[illegible]x10$^{1[illegible]}$
[illegible]	[illegible]	[illegible]	0	0	2.9x10$^{[illegible]}$	2.[illegible]x10^{6}	[illegible]	0	[illegible]	6.[illegible]x10$^{[illegible]}$	[illegible]	
[illegible]	[illegible]	[illegible]	0	0	2.9x10$^{[illegible]}$	[illegible]x10^{6}	1.[illegible]x10^{6}	0	0	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	0	0	1.9x10$^{[illegible]}$	3.[illegible]x10^{6}	[illegible]x10^{6}	0	0	[illegible]x10^{8}	[illegible]	[illegible]
	I-131	[illegible]	0	0	1.8x10$^{[illegible]}$			0	0	[illegible]		
	[illegible]	[illegible]	0	0	3.4x10^{6}	1.8x10^{6}	1.8x10^{6}	0	0	[illegible]		
[illegible]	[illegible]-89	[illegible]	0	0	2.9x10$^{[illegible]}$	2.[illegible]x10^{6}	2.[illegible]x10^{6}	0	0	[illegible]		
	[illegible]-90	[illegible]	0	0	2.9x10$^{[illegible]}$	[illegible]x10^{6}	[illegible]x10^{6}	0	0	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	0	0	2.9x10$^{[illegible]}$	[illegible]2x10^{6}	[illegible]x10^{6}	0	0	[illegible]6x10^{8}	[illegible]x10^{8}	[illegible]x10^{8}
	I-131	[illegible]	0	0	9.6x10$^{[illegible]}$	-	-	0	0	2.2x10	-	-
	Cs-137	[illegible]	0	0	1.4x10^{6}	7.8x10$^{[illegible]}$	7.8x10$^{[illegible]}$	0	0	[illegible]3x10	6x10$^{[illegible]}$	6x10$^{[illegible]}$
Milk	[illegible]-89	1.[illegible]x10^{-6}	9x10$^{[illegible]}$	7.9x10$^{[illegible]}$	9.[illegible]x10$^{[illegible]}$	[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]x10^{8}	[illegible]x10^{8}
	[illegible]-90	1.[illegible]x10^{-6}	[illegible]9x10$^{[illegible]}$	7.9x10$^{[illegible]}$	9.3x10$^{[illegible]}$	2.[illegible]x10$^{[illegible]}$	2.[illegible]	[illegible]x10$^{[illegible]}$	1.[illegible]x10^{9}	[illegible]	[illegible]x10^{8}	[illegible]x10^{8}
	I-131	1x10$^{[illegible]}$	6x10^{8}	[illegible]6x10^{8}	6.6x10^{8}	-		[illegible]x10^{9}	[illegible]x10^{9}	8.[illegible]x10$^{[illegible]}$		
	Cs-137	1x10^{-2}	2.2x10^{9}	2.2x10^{9}	[illegible]6x10^{9}	4.1x10^{7}	4.1x10^{7}	3.1x10^{10}	4.1x10^{10}	3.[illegible]x10^{10}	[illegible]2x10$^{[illegible]}$	[illegible]2x10$^{[illegible]}$
	Ba-140	1x10^{-7}	[illegible]6x10^{6}	[illegible]6x10^{6}	6.6x10^{6}	-	-	[illegible]7x10^{7}	[illegible]7x10^{7}	8.[illegible]x10^{7}		

[illegible] C^{o}_{if} [illegible] in days·gm

(b) t_o is the time after attack at which ingestion of the contaminated diet begins

Table 44

PERCENTAGE OF SURVIVING MILK PRODUCTION FROM PASTURE CONTAMINATED TO LESS THAN THE INDICATED LEVELS[a]

Initial Pasture Contamination (atoms/gm)	Nuclide					
	Sr-89	Sr-90	Ru-106	I-131	Cs-137	Ba-140
HM Attack						
5×10^{8}	29.8	27.5	32.4	27.6	27.4	27.2
1×10^{9}	33.4	31.5	36.4	31.7	31.0	30.9
5×10^{9}	45.1	41.1	50.0	41.7	40.5	40.5
1×10^{10}	52.1	48.0	58.7	48.5	47.3	47.4
5×10^{10}	75.0	70.1	84.6	70.9	67.6	68.4
1×10^{11}	87.8	82.7	94.7	83.2	80.2	80.0
5×10^{11}	98.8	98.3	99.1	98.3	97.1	98.1
1×10^{12}	99.2	99.0	99.8	99.0	98.9	99.0
5×10^{12}	100.0	100.0	100.0	100.0	100.0	100.0
MC Attack						
5×10^{8}	62.4	59.5	64.8	59.6	59.9	59.1
1×10^{9}	66.6	64.2	68.6	64.5	64.1	63.6
5×10^{9}	77.5	75.6	82.1	76.1	75.0	75.0
1×10^{10}	83.5	80.7	87.6	81.2	79.3	79.8
5×10^{10}	95.2	93.6	97.6	93.7	92.5	93.1
1×10^{11}	98.1	97.0	99.3	97.3	96.3	96.5
5×10^{11}	99.7	99.6	99.8	99.7	99.6	99.6
1×10^{12}	99.9	99.8	99.9	99.8	99.7	99.7
5×10^{12}	100.0	99.9	100.0	99.9	99.9	99.9
1×10^{13}	100.0	100.0	100.0	100.0	100.0	100.0

a Based on the number of dairy cows that survive; data apply only to pasture contamination by local fallout

Crop damage and loss due to external gamma radiation from fallout is presented in Tables 45 and 46 for the HM and MC attacks, respectively. The influences of existing shelter (PF = 10) and good shelter (PF = 1,000) for the farmer have been calculated for each case.

In these tables, acres assessed are the total acres normally devoted annually to the specific crop. In most cases, this total is equal to the total U.S. acreage for the crop, but in some cases, of which cabbage is the worst, acre-counting criteria in the original data compilation led to a total assessment of only 65 percent of the actual crop. The planted column is the percentage (of the acres assessed) in the ground at the time of the attack.

Acres designated as destroyed are those for which the crop was killed by the external gamma radiation from fallout. Crops killed are counted as unusable, although this may not always be true. Harvestable acres include those acres that were planted, not destroyed, and that may be harvested at the scheduled normal time without exceeding an exposure dose of 200 roentgen ERD(max). Plantable next-crop acres are those acres not excluded because of radiation levels and worker doses (in the case of trees, the percentage of the assessed number surviving). It was assumed that 1 week each was required for planting and harvesting. The degree of shelter protection available, which in this study was taken as PF = 10 or 1,000, affects the remaining dose allowable for these activities; hence, the better the PF, the larger the number of harvestable acres.

From Table 45, it can be seen that the crop on approximately 20 percent of the acreage is killed outright, with the potato crop suffering the greatest loss (27 percent). With existing shelter, about 50 percent of all crops are harvestable, increasing to the 70 to 90 percent level with good shelter. The harvested crops are contaminated so that final usability depends on the availability of food in general and, for stocks in excess of needs, on the human internal dose levels acceptable from each food source.

As for the next crop, it is notable that with existing shelter only about 50 percent of the acreage is plantable, whereas with good shelter this value increases dramatically to virtually 100 percent.

For the HM attack and existing shelter, it appears reasonable to conclude that, with only about 50 percent of the crops recoverable, consideration regarding its harvest relative to the need of the crop might be made in terms of both the consumption of fuels (not considered here) and lowered (or more restrictive) dose criteria. The latter would imply a lower degree of urgency in recovering the crop. Likewise, the desirability of planting the next season's grain crop would probably be governed largely by similar considerations. This problem, however, is closely related to other postattack problems that are sensitive to the time scale of repairing the whole economy and building up capital goods. It may

Table 45

NATIONAL SUMMARY OF CROP DAMAGE FROM LOCAL FALLOUT: HM ATTACK

Crop	Acres Assessed (thousands)	Percent of Acres Assessed: Planted[a]	Destroyed	Harvestable: Existing Shelter	Harvestable: Good Shelter	Plantable Next Crop: Existing Shelter	Plantable Next Crop: Good Shelter
Corn	79,605	100	12	53	88	53	100
Sorghum	17,903	47	8.6	28	39	53	85
Wheat	49,762	100	20	50	80	51	92
Oat	26.559	95	3.5	54	91	57	100
Barley	14.165	98	14	49	83	50	100
Bean, dry field	733	21	2.1	17	19	73	100
Soy bean	22.064	57	6.1	32	51	43	84
Alfalfa	26,093	100	0.6	57	97	57	95
Clover and timothy	14,026	96	1.9	53	94	55	96
Oat (Hay)	3,477	100	7.1	54	92	54	98
Potato	1,122	92	27	49	66	57	98
Green pea	306	100	0.8	84	99	84	100
Sugar beet	891	100	17	61	84	61	100
Tomato	392	55	14	30	41	65	100
Sweet corn	566	89	2.6	62	86	79	100
Snap bean	200	37	1.6	29	34	77	99
Cabbage	72	13	0	10	13	79	97
Onion	82	65	8.1	48	57	82	100
Carrot	61	26	0.8	25	25	85	100
Lettuce	177	21	1.4	18	18	70	100
Apple	19,853[b]	100	11	65	87	68	100
Peach	30.631[b]	100	20	58	75	64	94
Orange	23.762[b]	100	15	57	83	72	100

a At the time of attack (June 1)

b Thousands of trees

Table 45

NATIONAL SUMMARY OF CROP DAMAGE FROM LOCAL FALLOUT: MC ATTACK

Crop	Acres Assessed (thousands)	Percent of Acres Assessed		Harvestable		Plantable Next Crop	
		Planted[a]	Destroyed	Existing Shelter	Good Shelter	Existing Shelter	Good Shelter
Corn	79,605	100	4.0	80	96	81	100
Sorghum	17,903	47	4.6	29	43	69	96
Wheat	49.762	100	8.2	70	92	70	100
Oat	26,559	95	1.0	77	94	80	100
Barley	14,165	98	5.1	61	93	63	100
Bean, dry field	733	21	0	19	21	98	100
Soybean	22,064	57	3.5	46	54	78	92
Alfalfa	26,093	100	0.1	80	99	80	100
Clover and timothy	14,026	96	0.2	81	96	84	100
Oat (Hay)	3.477	100	1.1	67	98	67	100
Potato	1,122	92	19	68	73	75	100
Green pea	306	100	0	100	100	100	100
Sugar beet	891	100	3.6	80	91	80	100
Tomato	393	55	0.3	51	52	95	100
Sweet corn	566	89	0.14	85	88	97	1
Snap bean	200	37	0	37	37	98	99
Cabbage	72	13	0	13	13	98	100
Onion	82	65	1.9	60	63	95	100
Carrot	61	26	0	25	26	99	100
Lettuce	177	21	0	19	19	99	100
Apple	19,853[b]	100	2.8	92	95	97	100
Peach	30,631[b]	100	1.3	82	93	99	100
Orange	23,762[b]	100	0	98	98	100	100

a At the time of attack (June 1)

b Thousands of trees

always be the best policy to keep the food stocks as high as possible so that the surviving work force could be maintained for longer times in spite of other recovery failures; the extra food could serve as an additional factor of safety to the overall recovery process.

For the HM attack and good shelters for all the farmers, most of the crops standing during the attack are harvestable; hence, if external gamma dose to workers is the only limiting factor, the next crop is almost 100 percent plantable.

For the MC attack, all damage is considerably lower. The worst direct kills are on wheat at 8 percent and sugar beets at 9 percent. Existing shelter results in the same acres harvestable as good shelter did with the HM attack--namely, 70 to 90 percent. With good shelter, this acreage increases to virtually 100 percent of the planted acreage. Plantability of the next crop is about 80 percent with existing shelter; hence, it is also virtually 100 percent with good shelter. It would, therefore, appear that the MC attack would cause no significant damage to agriculture even under existing shelter conditions. Some general direct comparisons between the two attacks and the two assumed shelter conditions are given, by crop, in Tables 47 and 48 for crop recovery and capability for planting the first postattack crop.

It was beyond the scope of the current computational program to apply many of the above tests in any manner except on a go - no go basis; that is, no variations were possible on planting or harvesting dates or on the possible usability of destroyed crops. Additional factors of potential importance not included were reduction of yields due to radiation damage and effects of the interruption of care normally required, such as spraying, irrigation, and cultivation. Also, as previously mentioned, the effects of beta radiation were not considered.

The effects of the two assumed attacks on the coniferous and deciduous forest lands are shown in Figures 6 and 7. These maps show that although some areas almost as large as the state of Tennessee may be severely damaged to a degree that rapid natural recovery would not be expected, less than 10 percent of the total U.S. forest area is affected. That is, for the assumed attacks, almost 90 percent of the forest would be expected to have recovered to preattack condition within 2 years, and most of this forest land would not be visibly affected.

However, as with agricultural crops, which can survive higher accumulated doses than can humans, the resumption of normal human-forest relationships over extensive areas will be governed by the tolerance of people to existing dose rates.

The results of the computations of the farm animals and poultry that survive the two assumed attacks are summarized in Table 49 by state, civil defense region, and nation. The tabulations show that from 45 to 83 percent of the nation's livestock would survive the two postulated nuclear attacks. For the HM attack, the state totals ranged from no survivals in Delaware to 100 percent survival in Oregon.

Table 47

PERCENT INCREASE IN CROP HARVESTABILITY FOR HM OR MC ATTACKS WHEN SHELTERS WITH A PF OF 10 OR 1,000 ARE AVAILABLE

Crop	Increase for PF Differences (1,000:10)		Increase for Attack Differences (MC:HM)	
	HM	MC	PF 10	PF 1,000
Corn	66	20	51	9
Sorghum	39	48	4	10
Wheat	60	31	40	15
Oat	68	22	43	3
Barley	69	52	24	12
Bean, dry field	12	10	12	10
Soybean	59	17	44	6
Alfalfa	70	24	40	2
Clover and timothy	77	18	53	2
Oat (Hay)	70	46	24	6
Potato	35	7	39	11
Green pea	18	0	19	1
Sugar beet	38	14	31	8
Tomato	37	2	70	27
Sweet corn	39	4	37	2
Snap bean	17	0	28	9
Cabbage	30	0	30	0
Onion	19	5	25	10
Carrot	0	4	0	4
Lettuce	0	0	6	6
Apple	34	3	42	9
Peach	29	13	41	24
Orange	46	0	72	18

Table 48

PERCENT INCREASE IN NEXT CROP PLANTABILITY FOR HM OR MC ATTACKS WHEN SHELTERS WITH A PF OF 10 OR 1,000 ARE AVAILABLE

Crop	Increase for PF 1,000		Increase for Light MC Attack	
	HM	MC	PF=10	PF 1,000
Corn	87	23	53	1
Sorghum	57	39	30	16
Wheat	94	43	37	1
Oat	75	25	40	0
Barley	98	59	26	1
Bean, dry field	37	2	34	0
Soybean	81	18	66	8
Alfalfa	74	25	40	1
Clover and timothy	78	19	53	2
Oat (Hay)	83	49	24	1
Potato	75	33	32	0
Green pea	19	0	19	0
Sugar beet	64	25	31	0
Tomato	52	5	44	0
Sweet corn	41	3	39	1
Snap bean	26	1	27	2
Cabbage	23	2	24	3
Onion	22	5	16	0
Carrot	16	1	15	0
Lettuce	43	1	41	0
Apple	47	6	38	0
Peach	56	14	38	0
Orange	72	0	72	0

Figure 6

FOREST SURVIVAL FROM THE HM ATTACK

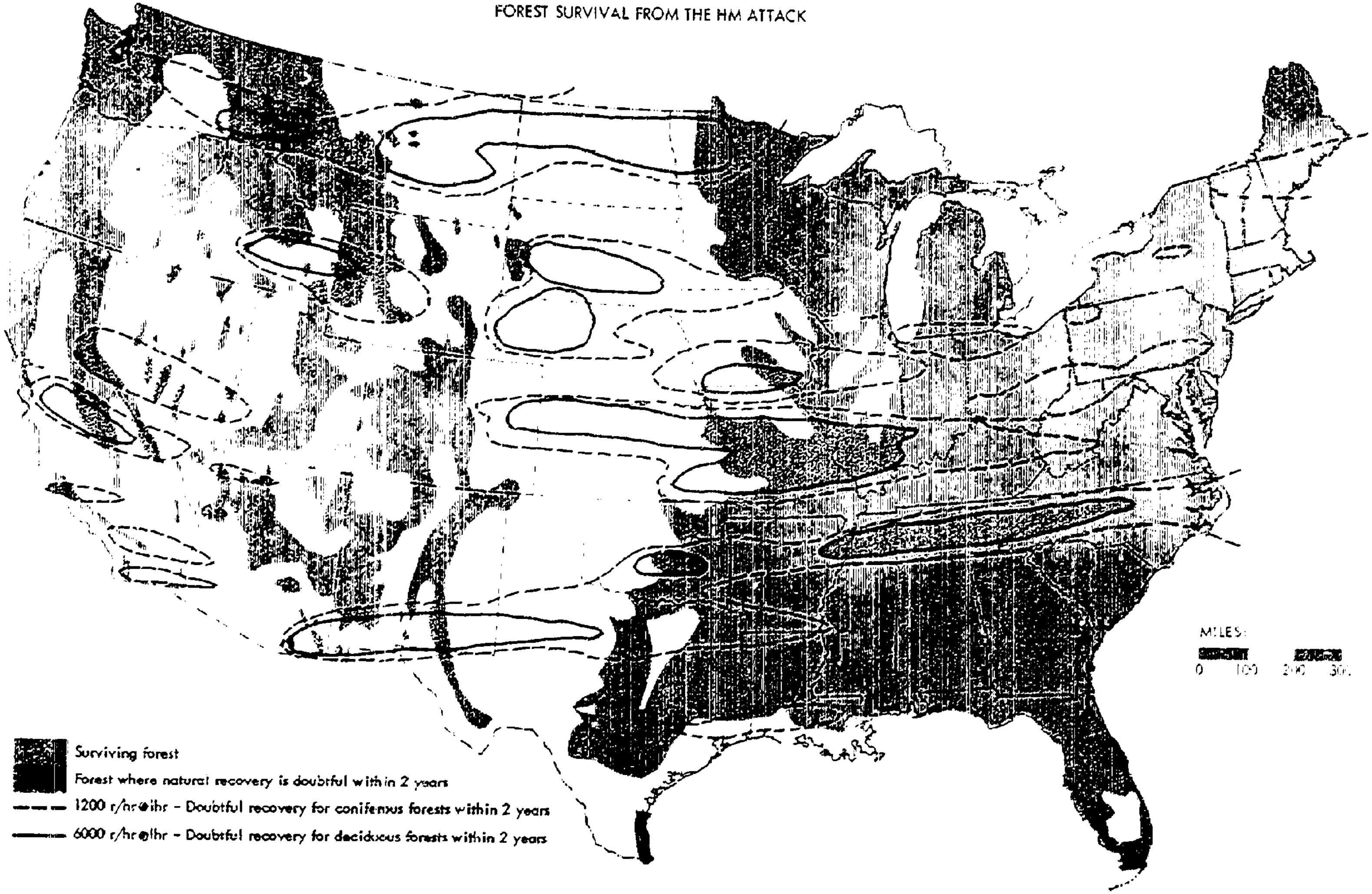

Figure 7
FORESI SURVIVAL FROM THE MC ATTACK

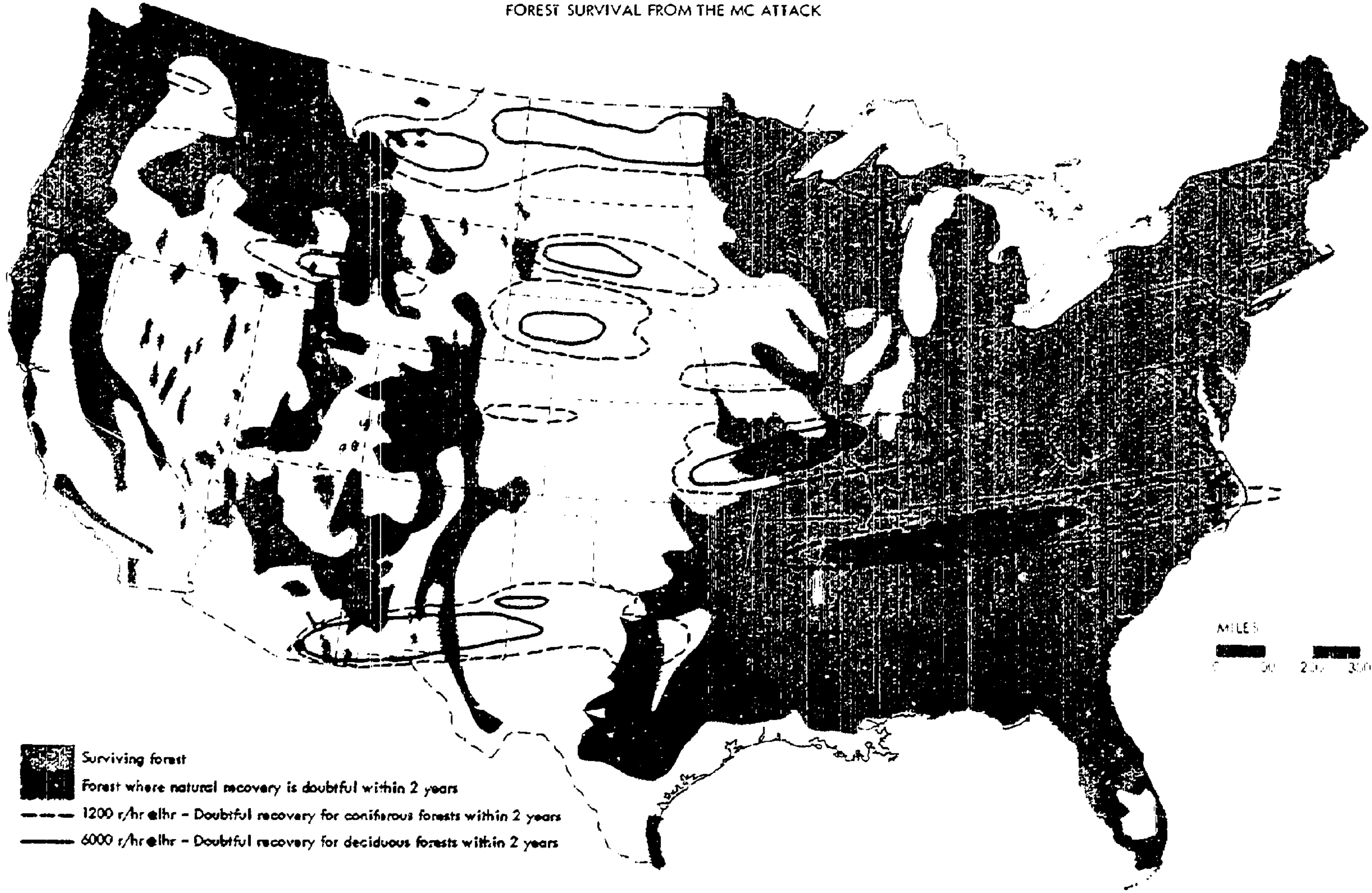

Table 49

FARM ANIMALS AND POULTRY SURVIVING NUCLEAR ATTACK

Area Summarized	Bulls, Steers, and Calves: Preattack Total (thousands)	% Surviving HM	% Surviving MC	Milk Cows: Preattack Total (thousands)	% Surviving HM	% Surviving MC	Swine: Preattack Total (thousands)	% Surviving HM	% Surviving MC	Sheep: Preattack Total (thousands)	% Surviving HM	% Surviving MC	Chickens: Preattack Total (millions)	% Surviving HM	% Surviving MC
Conn.	8	56	100	83	[illegible]	100	21	11	100	7	[illegible]	100	[illegible]	[illegible]	[illegible]
Maine	17	17	62	89	48	58	25	18	72	11	51	61	1.18	34	[illegible]
Mass.	7	73	99	89	71	99	108	19	99	11	65	97	3.30	81	[illegible]
N.H.	6	19	93	18	41	86	11	55	97	8	18	97	[illegible]	[illegible]	[illegible]
N.J.	11	31	100	120	28	100	179	15	100	15	41	100	[illegible]	8	100
N.Y.	106	49	100	1,173	50	100	166	54	100	189	42	100	9.68	[illegible]	100
R.I.	1	28	100	11	36	100	9	71	100	2	16	100	[illegible]	[illegible]	100
Vt.	13	36	52	248	34	44	14	34	52	12	16	67	0.82	18	67
Region I	169	47	92	1,865	47	90	336	39	98	285	39	93	30.11	49	[illegible]
Del.	6	0	100	24	0	100	38	0	100	1	0	100	0.73	0	100
Ky.	428	35	70	466	50	73	1,652	19	82	516	11	[illegible]	5.17	55	[illegible]
Md.	82	36	100	198	24	100	217	46	100	38	12	100	2.09	[illegible]	[illegible]
Ohio	607	33	92	641	40	89	3,060	36	89	1,234	40	86	13.32	30	[illegible]
Pa.	336	12	100	827	16	100	622	11	100	260	26	100	15.41	36	100
Va.	276	80	100	308	84	100	785	80	100	314	71	100	[illegible]	90	100
W. Va.	103	41	100	121	33	100	118	33	100	290	10	100	[illegible]	57	[illegible]
Region II	1,838	37	90	2,585	37	92	6,521	13	90	2,715	37	83	44.16	[illegible]	[illegible]
Ala.	301	94	100	208	92	100	1,222	92	100	36	89	100	7.68	96	100
Fla.	313	86	100	180	91	100	423	88	100	7	57	100	[illegible]	93	100
Ga.	293	86	99	195	88	99	1,833	78	98	28	90	97	11.90	91	[illegible]
Miss.	321	83	100	333	89	100	811	83	100	73	59	100	7.72	95	100
N.C.	151	19	40	243	11	32	1,660	34	54	53	8	26	12.16	24	[illegible]
S.C.	93	82	99	100	85	99	573	73	99	11	86	98	1.51	89	[illegible]
Tenn.	319	20	28	456	14	21	1,610	18	28	261	10	19	6.84	21	29
Region III	1,791	59	82	1,715	58	69	8,232	60	76	169	30	47	55.75	70	82
Ill.	1,562	35	85	542	42	76	8,285	29	79	813	26	81	13.31	32	64
Ind.	587	39	76	411	32	76	5,357	46	82	557	16	83	13.81	13	[illegible]
Mich.	355	35	100	612	42	100	968	22	100	459	11	100	8.37	19	100
Minn.	898	55	74	1,216	75	84	4,706	61	81	1,107	13	55	22.19	75	[illegible]
Wisc.	350	86	100	2,095	80	100	2,461	87	100	279	84	100	10.55	86	100
Region IV	3,752	15	84	4,876	66	91	21,777	46	83	3,215	39	77	68.30	59	[illegible]
Ark.	216	49	74	204	60	76	499	53	76	17	73	85	5.69	57	91
La.	230	65	93	205	75	94	353	73	94	95	64	92	3.62	75	92
N. Mex.	244	71	77	39	76	39	62	64	73	992	62	85	0.82	62	[illegible]
Okla.	846	63	73	238	63	72	524	54	66	276	70	76	1.19	62	71
Texas	1,987	70	73	507	60	62	1,160	69	71	6,064	95	95	15.87	71	77
Region V	3,523	67	74	1,193	61	72	2,598	63	74	7,174	89	93	30.19	67	80
Colo.	669	87	97	118	92	98	243	84	97	2,055	96	99	1.81	88	98
Iowa	2,770	19	80	834	51	83	11,789	16	82	1,792	36	69	2.67	56	89
Kans.	1,638	21	[illegible]	[illegible]	12	[illegible]	[illegible]	10	30	775	35	59	7.71	17	65
Mo.	1,054	14	40	613	23	52	1,777	10	40	825	7	13	10.17	19	[illegible]
Nebr.	1,776	38	46	319	41	50	3,245	42	48	756	37	12	10.19	47	70
N. Dak.	446	48	52	264	51	52	508	67	69	509	17	15	[illegible]	61	[illegible]
S. Dak.	937	24	29	243	36	39	2,042	17	20	1,935	13	11	[illegible]	26	48
Wyo.	331	76	90	29	62	86	45	65	91	2,373	74	93	0.37	76	89
Region VI	9,621	40	61	2,733	39	62	26,990	36	64	11,420	55	69	69.10	44	71
Ariz.	140	31	85	13	14	91	29	12	84	173	51	84	[illegible]	94	[illegible]
Calif.	1,156	54	81	751	66	87	379	68	89	2,094	78	95	11.02	64	[illegible]
Nev.	129	59	82	11	22	39	10	15	[illegible]	312	47	75	[illegible]	41	[illegible]
Utah	171	89	100	88	93	100	71	85	100	1,290	88	100	1.65	98	100
Region VII	1,896	52	85	899	66	88	192	68	89	1,169	76	94	[illegible]	[illegible]	87
Idaho	110	11	72	194	51	72	174	12	68	1,242	78	62	1.37	[illegible]	[illegible]
Mont.	604	14	57	73	52	68	186	17	62	1,706	18	62	[illegible]	19	64
Ore.	340	100	100	152	100	100	198	100	100	887	100	100	2.86	100	100
Wash.	315	62	89	218	79	89	159	48	76	313	55	86	5.00	79	88
Region VIII	1,669	59	75	637	72	84	717	61	77	4,148	54	72	[illegible]	79	[illegible]
U.S.	24,259		73	16,503	54	82	67,863	45	75	33,795	64	80	[illegible]	58	[illegible]

Surviving livestock will require care and feeding, even during the first 7 days after the nuclear attack, when the dose that determines their eventual survival or death is being accumulated. Since the $LD_{50}/30$ for animals is of the same order of magnitude as that for humans, who must care for them, all livestock that will eventually survive, as well as some that may die in 30 days, could be taken care of if the farmer has adequate shelter for himself. This assumes that the exposure dose to the human is maintained within required ERD levels (discussed elsewhere) by his remaining in shelter, with limited daily work periods (2 hours twice a day) in radiation fields to perform the necessary chores.

The lethal dose to pasture land (7,500 roentgens) is so much larger than the lethal dose to animals (~ 600 roentgens) that surviving animals would be able to graze in the normal preattack manner.

A summary of the estimated available postattack agricultural crop, animal, and poultry production per capita for the HM and MC attacks, for existing and good shelters, is given in Table 50. The per capita production was computed from the ratio of the agricultural products available after attack (including the harvest of the crops planted at the time of attack) to the survivors, divided by the ratio of the current agricultural products available to the population. The existing shelter for both the farmer and the urban population has been defined previously. The term "good shelter" is defined as 100 psi blast shelters for urban areas and fallout shelters with PF values of 1,000 for the farmers.

The values of the per capita production potential in excess of 100 percent, for the existing shelter cases, are indications of the general difference in the relative survival rates of the farmers to those of the urban population for the assumed attacks. The relative survival rate for the farmer over the urban population is actually greater than any of the indicated ratios, because the crop availability was associated with a 200 roentgen ERD exposure. The lowest values of the per capita production potential are for the exposed animals; for these, the potential is reduced to about 50 percent for the good shelter condition for the HM attack.

Absorbed Dose in Humans

In order to be able to use the equations and procedures presented in the second section of this report, it is necessary to specify the human daily intake rate, U_i^o, for each nuclide, i, that is under consideration. For this, it is, in turn, necessary to know the composition of the human diet in terms of the daily intake rate, V_f, of each food, f, and also the concentrations, C_{if}, of each of the nuclides for which absorbed dose estimates were available in each of these foods. Then the following equation can be used:

Table 50

POSTATTACK PRODUCTION POTENTIAL PER CAPITA
(Values in Percent of Normal)

Crop	HM Attack Existing Shelter	HM Attack Good Shelter	MC Attack Existing Shelter	MC Attack Good Shelter
Corn	92	92	92	97
Sorghum	140	95	93	100
Wheat	88	84	80	92
Oat	102	99	92	99
Barley	88	88	72	95
Bean, dry field	112	102	112	101
Soybean	130	98	101	97
Alfalfa	99	101	94	100
Hay	98	100	93	100
Potato	99	76	86	82
Green pea	146	104	114	101
Sugar beet	106	87	90	92
Tomato	131	85	109	98
Sweet corn	127	102	108	100
Snap bean	159	101	114	101
Cabbage	164	104	114	101
Onion	144	97	108	98
Carrot	171	104	105	101
Lettuce	171	102	114	101
Apple	117	93	106	97
Peach	112	84	111	99
Orange	126	88	114	101
Bull, steer, and calf	85	51	83	74
Milk cow	94	56	93	83
Swine	78	47	85	76
Sheep	106	66	91	81
Chicken	101	60	94	84

$$U_i^o = \sum_f V_f C_{if} \qquad (65)$$

The composition of the adult human diet used in the dose calculations is shown in Table 51. This diet has been obtained from the data in the second section of this report, which lists the normal diet for 1955. The original data are modified to include the fact that much of the diet during the first few weeks or even months after attack would be obtained from preexisting uncontaminated food sources and hence would not contribute to the sum of Equation 65. Except for minor details and substitutions, the diet of Table 51 is not very different from the U.S. Department of Agriculture emergency diet.[83]

In the present calculations, with the attack in June, only the local fallout foliar contamination was used for the food ingested within the first 9 months of the time of attack. All ingestion times of over 1 year after attack, on the other hand, were treated by using a combination of uptake routes: (1) by food crops whose edible aboveground parts are contaminated through root uptake of nuclides from both local and worldwide fallout during the month of harvest; (2) by food crops whose edible parts are contaminated through root uptake of nuclides from both local and worldwide fallout deposited up to planting time; and (3) by animal-derived foods from animal ingestions from the first two sources. The crop sources for the longer ingestion times are those from the first crop planted after attack. This treatment parallels that for the internal contamination of the animal-derived foods discussed above.

To illustrate the magnitude of the absorbed doses to humans from consumption of the contaminated food sources, the C_{if} values for Equation 65 were selected from the national summaries of the contamination of all food crops (and water) using the previously discussed concentrations that do not exceed 50 and 90 percent of the available crop food of each kind. While this procedure in no way connects the food source with a given surviving consumer in a given locality, it assumes some distribution of the foods so that, over the whole population, a large fraction could receive the absorbed doses represented by the computed median dose and that probably less than 10 percent of the population would receive the absorbed dose represented by the computed 90 percentile dose.

After the intake rates U_i^o, had been calculated for each of the nuclides in each of the postulated situations, the absorbed dose model was utilized in the form shown in the second section of this report. For foods whose initial origin was pasturage (i.e., beef, mutton, and milk) a modified model (see Reference 38) was used in the local fallout situations in order to avoid overestimates of dose. For all other foods, however, the unmodified absorbed dose model is sufficient, because loss of contamination is taken into account in the factors shown in Table 28. The body organs chosen as being critical are the total body, the lower large intestine, the bone, and the thyroid. In each case, only those of the six nuclides

Table 51

HUMAN DIET VERSUS TIME OF INGESTION
(Grams per Day)

	t_o				
	1 day	14 days	183 days	365 days	548 days
Milk products	-[a]	633	633	633	633
Meat, poultry, and fish					
Beef	-	-[a]	81	81	81
Pork	-	-	74	74	74
Mutton	-	-	6	6	6
Poultry	-	-	46	46	46
Egg	-	-	55	55	55
Flour and cereals (wheat)	-	-	-[a]	222	222
Vegetables					
Tomato	-	-	43(2)[b]	43(2)[b]	43(2)[b]
Sweet corn	-	-	42(10)	42(10)	42(10)
Bean	-	-	34(27)	34(27)	34(27)
Lettuce	-	-	23(0.9)	23(0.9)	23(0.9)
Cabbage	-	-	19(1.2)	19(1.2)	19(1.2)
Pea	-	-	15(3.4)	15(3.4)	15(3.4)
Onion	-	-	15(1.7)	15(1.7)	15(1.7)
Carrot	-	-	13(1.3)	13(1.3)	13(1.3)
Oils					
Soybean	-	-	-	52	52
Others	-	-	-	8	8
Sugar					
Sugarbeet	-	-	-	81	81
Fruits					
Orange	-	-	64(8)	64(8)	64(8)
Apple	-	-	29(4)	29(4)	29(4)
Peach	-	-	14(1)	14(1)	14(1)
Potato	-	-	117(27)	117(27)	117(27)
Water	1,000	1,000	1,000	1,000	1,000

a Dash indicates uncontaminated food sources
b Values in parentheses indicate dry weight

that were expected to give large contributions to the adsorbed dose to the organ were included in the computation. After the dose contributed by each nuclide was computed, the total absorbed dose was estimated by summing the individual nuclide contributions. The major factors considered in the calculation included: (1) the time at which ingestion of a contaminated food begins; (2) the period of ingestion of that food, and (3) the percentile contamination-level of the diet (i.e., the nuclide concentration of the food items in the diet, including water).

To facilitate the absorbed dose calculations, a table of absorbed dose multipliers, D_{1k}/U_1^y, in rems per atoms ingested per day, was prepared for each radionuclide and body organ of interest and for each selected ingestion starting time and ingestion period. The computed values of the multipliers for the several nuclides are given in Table 52. The absorbed dose calculations for the selected organs and radionuclides are summarized in Table 53 for existing shelter and in Table 54 for good shelter, both for the HM attack.

At both the 50 and 90 percentile contamination levels of the food items in the diet, the calculated absorbed doses for the good shelter case are from 2 to 10 times larger than those for the existing shelter, reflecting the relative capability to harvest and plant crops in areas of heavy fallout. The absorbed doses for the ingestions starting at 1 day are only from water sources; those starting at 14 days are from both water and milk consumption. The largest doses from these sources are from I-131 for the thyroid gland. The calculated absorbed doses in all organs from the crops planted after the attack are less than those received from consumption of the standing crops directly contaminated during the attack.

The calculated doses for the lower large intestine are probably underestimates of the dose for that organ, especially for the 14 and 183 ingestion starting times, because the contributions of many insoluble-type radionuclides are not included. Likely food sources for the contribution of these elements would be green vegetables, such as lettuce.

As previously mentioned, no detailed procedures were available for estimating a reasonable mixture of contaminated foods for any group of people at any given time after attack. Therefore estimates of the absorbed dose for a continuous long-term pattern of food ingestion were not attempted in this study; suitable methods for estimating the time-delays for processing and distribution of the various food items in the postattack period could not be developed within the time period of the study.

The relationships among the total absorbed dose, the time over which it is received, and the biological effect produced (especially if the external dose is also considered) are not well understood. However, it is safe to say that the computed doses for the median contamination levels of food for both shelter cases and the HM attack would produce no noticeable biological effects on adult humans. Also, it is unlikely

Table 52

ABSORBED DOSES PER UNIT INGESTION RATE FOR ADULT HUMANS
(D_{ik}/U_i^o in 10^{-14} Rem per Atom per Day)

$t-t_o$ \ t_o[a]	1	14	183	365	548	1	14	183
	Sr-89 Total Body					Sr-89 Total Body Modified		
29	15.4	13.0	1.43	0.134	0.012	9.65	4.20	8.2×10^{-5}
90	91.8	77.5	8.40	0.798	0.075	33.0	14.4	2.8×10^{-4}
	Sr-89 Bone					Sr-89 Bone Modified		
29	237.0	200.2	22.0	2.06	0.194	147.0	64.0	1.25×10^{-3}
90	1,400.0	1,182.4	129.7	12.2	1.14	504.0	219.5	4.3×10^{-3}
	Sr-89 Lower Large Intestine					Sr-89 Lower Large Intestine Modified		
29	463.0	391.0	42.9	4.03	0.378	236.0	102.7	2.0×10^{-3}
90	1,040.0	378.4	96.8	9.04	0.850	281.0	122.4	2.4×10^{-3}
	Sr-90 Total Body					Ru-106 Total Body		
29	0.201	0.201	0.199	0.196	0.194	0.350	0.341	0.248
90	2.00	2.00	1.98	1.95	1.93	1.37	1.34	0.970
	Sr-90 Bone					Ru-106 Bone		
29	3.90	3.90	3.86	3.80	3.76	2.16	2.11	1.53
90	31.3	31.3	31.0	30.5	30.2	10.1	9.85	7.15

a $t-t_o$ = period of ingestion, in days; t_o = time of start of ingestion, in days after detonation

Table 52 (continued)

$t-t_o$ \ t_o [a]	Sr-90 Lower Large Intestine					Ru-106 Lower Large Intestine		
	1	14	183	365	548	1	14	183
29	6.12	6.12	6.06	5.97	5.90	261.0	254.6	184.7
90	19.0	19.0	18.8	18.5	18.3	784.0	764.9	554.8
	I-131 Total Body					I-131 Total Body Modified		
29	71.8	23.4	-	-	-	48.8	8.20	-
90	98.8	32.2	-	-	-	59.0	9.90	-
	I-131 Bone					I-131 Bone Modified		
29	85.2	27.8	-	-	-	57.2	0.64	-
90	105.0	34.3	-	-	-	62.8	10.57	-
	I-131 Thyroid					I-131 Thyroid Modified		
29	111,500.0	36,390.0	-	-	-	75,500.0	12,700.0	-
90	153,000.0	49,935.0	-	-	-	91,100.0	15,330.0	-
	Cs-137 Total Body					Ba-140 Total Body		
29	0.290	0.290	0.287	0.284	0.281	3.40	1.60	-
90	2.34	2.34	2.32	2.29	2.27	6.46	3.04	-
	Cs-137 Bone					Ba-140 Bone		
29	0.288	0.288	0.285	0.282	0.280	89.3	41.9	-
90	2.51	2.51	2.48	2.46	2.44	170.0	79.8	-

[a] $t-t_o$ = period of ingestion, in days; t_o = time of start of ingestion, in days after detonation

Table 52 (concluded)

$t-t_o$ \ t_o[a]	Cs-137 Lower Large Intestine					Ba-140 Lower Large Intestine		
	1	14	183	365	548	1	14	183
29	0.0208	0.0208	0.0206	0.0204	0.0202	854.0	400.9	-
90	0.0648	0.0648	0.0642	0.0635	0.0629	1,085.0	509.4	-

a $t-t_o$ = period of ingestion, in days; t_o = time of start of ingestion, in days after detonation

Table 53

ABSORBED DOSE[a] TO ADULT HUMANS
FROM FOOD CONTAMINATED BY THE HM ATTACK: EXISTING SHELTER

$t-t_0$ (days)	t_0 (days) 1	14	183	365	548
		At maximum concentration levels for 0.5 of available foods			
		Lower Large Intestine			
29	-	0.068	0.052	0.029	0.021
90	-	0.089	0.15	0.084	0.061
		Total Body			
29	-	0.035	0.023	0.001	0.001
90	-	0.076	0.20	0.013	0.012
		Bone			
29	-	0.074	0.034	0.010	0.007
90	-	0.20	0.28	0.076	0.062
		Thyroid			
29	-	44	-	-	-
90	-	54	-	-	-
		At maximum concentration level for 0.9 of available foods			
		Lower Large Intestine			
29	6.3	5.2	3.2	0.25	0.17
90	11.7	9.9	9.3	0.70	0.50
		Total Body			
29	0.37	0.64	0.29	0.024	0.020
90	0.81	1.5	2.3	0.19	0.18
		Bone			
29	1.7	2.1	0.70	0.12	0.089
90	6.9	8.1	5.1	0.88	0.72
		Thyroid			
29	450	770	-	-	-
90	610	950	-	-	-

a In rem

Table 54

ABSORBED DOSE[a] TO ADULT HUMANS
FROM FOOD CONTAMINATED BY THE HM ATTACK: GOOD SHELTER

$t-t_o$ (days)	t_o (days) 1	14	183	365	548
	At maximum concentration levels for 0.5 of available foods				
	Lower Large Intestine				
29	-	0.68	0.22	0.078	0.057
90	-	0.89	0.66	0.22	0.17
	Total Body				
29	-	0.35	0.22	0.007	0.006
90	-	0.76	1.8	0.055	0.042
	Bone				
29	-	0.74	0.29	0.039	0.031
90	-	2.0	2.5	0.30	0.25
	Thyroid				
29	-	440	-	-	-
90	-	540	-	-	-
	At maximum concentration level for 0.9 of available foods				
	Lower Large Intestine				
29	6.3	13.7	10	0.88	0.66
90	11.7	21.0	30	2.6	2.0
	Total Body				
29	0.37	5.1	2.7	0.069	0.061
90	0.81	11.0	22.0	0.57	0.52
	Bone				
29	1.7	11	4.2	0.50	0.41
90	6.9	33	34.0	3.9	3.3
	Thyroid				
29	450	6,400	-	-	-
90	610	7,700	-	-	-

a In rem

that any serious effects would result from the indicated doses at the 90 percent level. Although the calculations do not extend for long-period ingestions, the 90-day period is sufficiently long for achieving the infinity dose from I-131 to the thyroid (mainly from consumption of water and milk). On the other hand, the calculations cover too short a time period to assess longer-term effects from continued ingestion of Sr-90 and Cs-137.

The absorbed doses from I-131 to thyroids of young children at the 90 percent level for the existing shelter case, assuming about half the average ingestion rate of adults, would be from 3,000 to 5,000 rems for ingestions starting between 1 and 14 days after attack. For the good shelter case, the higher thyroid dose would be about 40,000 rems; this dose would be expected to be sufficient to result in serious early effects in the glands of infants. While the exact circumstances under which the doses for the 90 percentile contamination level could occur are not developed in the current model, the indicated doses must still be considered as possible, with a low occurrence frequency. At least for growing children, it would appear that some minor late effects from the absorbed dose in the thyroid, and possibly in the bone, would be evidenced at the 90 percent contamination level.

During this study, the described radiobiological model was developed and utilized for making the above summarized estimates for the first time. Both the development and the utilization of the model during the study provided useful guides in focusing attention on specific aspects of biological processes and on the many interrelations that require attention in order for a quantity such as the absorbed dose to a single human thyroid after a nuclear war to be estimated. Some of the major factors that could not be evaluated with present methods include: (1) the time or times at which ingestion of contaminated foods could start for a given group of people as a function of the postattack environment or location of the group and as a function of the damage (and recovery) of the processing industries and transportation systems; (2) the range of time periods over which the contaminated foods would be ingested; and (3) the range of nuclide concentrations in the various food items that could be consumed by any local group of people.

SUMMARY OF BIOLOGICAL AND ECOLOGICAL EFFECTS

General

The analysis and evaluation of the effects of nuclear war on biological species and on their ecological systems depend on the availability and organization of a great variety of data, background information, and related concepts. These range from input information on weapon explosion phenomena and the initial interaction of these phenomena with biological species, to information about the community behavior, the reproductive habits and cycles, and the recovery mechanisms of ecosystems.

Fallout Deposition Models

No fallout model exists that will reliably predict all radiological hazards at a given geographical location, not to mention the combined exposure doses from beta and gamma radiation on plants, animals, insects, and humans. For example, of the several fallout models considered, the total area within the 100 r/hr at 1 hr contour varies by as much as a factor of 4. The simple fallout pattern scaling system developed by Miller[2] was used in this study because it was derived directly from selective analyses of evaluated weapons test data and because the output information from the model is applicable to evaluations of both the external gamma hazard and the internal hazard from radionuclide ingestion.

Some of the major unresolved problems include (1) definition of the fallout formation process (including fractionation and solubility), (2) radiological and physical properties of fallout from detonations on likely target environments, (3) meteorological prediction techniques, (4) foliar and plant-part contamination variables, (5) effect of local environments on deposition patterns and radiation fields, (6) beta radiation levels in selected contamination environments, and (7) influence of weather and environment on radiation fields, contamination of objects, and nuclide transfer processes.

One of the most important areas of future research for improving the fallout distribution models is continuation of studies that emphasize the specification of the particle source geometry during the period of fallout particle formation, as previously discussed. Continued research is needed on further development of predictive methods for weather data inputs to the models. Also, additional studies are needed on the appropriate operational use of early monitoring data by civil defense command and control centers and by damage assessment centers for evaluating the radiological hazard and for initiating transattack and postattack countermeasures. Because of the unreliability of prediction methods, it appears that these types of civil defense operations must be planned and scheduled on the basis of observed information.

Radiation Damage Criteria

The biological response, either to acute gamma radiation doses or to chronic doses (or both), is known for a few species, mainly the important higher vertebrate domestic animals. However, most of the information is for specific types of radiation source energies and exposure geometries that are not particularly representative of the conditions for exposures to radiation from fallout. The biological response of all species to the pattern of exposure in nuclear war radiation environments, such as a decaying source strength, intermittent exposures for different time periods, and the rate of exposure dose received, are not known, quantitatively; lack of information in this area is a major weakness in the current state-of-knowledge of biological effects from radiation exposure.

The mechanisms of biological recovery from radiation damage also are not known. But the principle of biological recovery from all types of injury is a firmly established concept for individual species as well as for ecosystems. The accepted description of the effects of acute gamma radiation doses on man have been deduced from scattered information, allowing for liberal use of technical judgment in lieu of factual information from carefully designed experimental investigations. Nevertheless, the recognition that a set of effects information must exist to establish damage criteria can be used to organize and categorize such information in terms of (1) the degree of injury from which recovery would be practically certain, (2) the degree of injury from which recovery would be practically impossible, and (3) the degree of injury from which recovery is uncertain, depending on small differences in the degree of injury, the state-of-health of the organism at the time, the amount of treatment available, and other factors.

For most species and ecosystems, because of many uncertainties in the application of the available data and incomplete coverage of the data, it is not yet possible to establish boundary conditions for injury categories. For the cases where the degree of injury can be categorized, damage assessment studies would require details about the third injury category given above. Information about the details of this injury category is least known for all species.

The use of damage criteria in civil defense system design can be shown to be associated with the definition of the first injury category (e.g., the degree of injury from which recovery would be practically certain). While this use is undoubtedly recognized and applied in the current civil defense programs, it is also apparent that the application more often has been in the form of misuse because the emphasis in the application has been on only one component of the system (i.e., shelter).

Some of the major unresolved problems include (1) radiobiological response of important species of the biota (at various stages in their respective reproductive cycle) to doses from exposure to gamma radiation from deposited fallout in terms of the energy spectrum, source geometry, and exposure chronology, (2) radiological response of selected species of animals, plants, and insects to beta radiation from fallout, and (3) injury recovery mechanisms and dependent variables.

Second-Order Effects

The second-order effects, such as the movement of soluble radionuclides within the biosphere, the response of species to a combination of nonlethal doses of radiation, or the erosion of land areas denuded by high radiation doses or fire, depend on many interrelated (and independent) variables and are poorly known. One main cause of existing controversies regarding the importance of the second-order biological effects stems from poor definition of the primary effects; another appears to arise from differences in interpretation of the efficiency of repair and recovery mechanisms of ecosystems.

Two major factors in the repair and recovery of biological communities appear to be important. The first is the time period over which the injury is sustained. The second is that the rate of the repair and recovery process, after injury, is usually slow, depending on the severity of the injury.

Plant species tend to dominate all important terrestrial ecosystems, and, since plants grow on nutrients in soils, the most serious type of injury to these ecosystems is one that leads to removal of the soil itself by erosion.

In the scale of injury that could result in a nuclear war, the cycling of radionuclides into the food chain of the higher animals appears to be a minor hazard. In the long term, it could be a general public health problem. Although the currently available plant and animal uptake data are incomplete and of rather poor quality, and occasionally are reported in nonuseful units of measure, the conclusion that the scale of injury from internal contamination would be low is generally supported by these data.

The second-order effects from a fractionation of the degree of injury within the species of an ecosystem have not yet been thoroughly treated: the insect problem, secondary fires, invasion by weeds, and similar problems are of this class of second-order effects. Much applicable data are known to exist. The compilation, organization, and analysis of these data are needed before second-order effects can be assessed.

At this time, all second-order effects from a nuclear attack appear to be unresolved. Some of the major ones are (1) damage leading to erosion and floods, (2) role of insects in ecosystem recovery processes, (3) ecological repair and recovery rates and dependent variables, (4) energy and matter flow in food chains, and (5) combined injury (long-term low-level) response of species.

Countermeasures

Man is a dominant factor in large segments of temporal ecosystems. While it is possible to enumerate the types of countermeasures and control that man could employ to aid in the recovery of the nation (including all types of contiguous ecosystems) after damage from a nuclear attack, it is not yet possible to establish the cost of preparations required to accomplish a desired level of recovery, the real need of the measures, or the capability of survivors to carry out any and all such conceived countermeasures. A better understanding of the nature and degree of the second-order effects is required before proposed countermeasures can be evaluated. At the present time, protective countermeasures against the immediate effects are more important.

Attack Analysis Findings

The following specific conclusions were reached with respect to the model computations carried out on the HM and MC attacks during the study:

1. The nationwide recovery of the production potential of agriculture would be readily achieved, in spite of the radiological effects of the attack, if the farmers have, and utilize, protective shelters with a shielding PF of at least 10. The computed per capita production potential of most crops for the crop in the ground at the time of attack was approximately unity for both the case of existing shelter (PF = 10) and the case of good shelter (PF = 1,000 for farmers and 100 psi blast shelters for urban population). However, for the good shelter case under the HM attack, the livestock availability is reduced to one-half of the preattack per capita level because of the larger survival rate of the human population in the cities. The effect of other factors, such as the availability of power and fuel, on the recovery of agriculture was not considered in this part of the study.

2. The consumption of foods and water contaminated by both local and worldwide fallout, without any special decontamination methods, would not produce absorbed doses to adult humans that would result in significant early or late biological effects. The same conclusion is applicable for infants that ingest foods contaminated to levels equivalent to those computed for the national median level. For foods contaminated to levels equivalent to those computed for the national 90 percentile level, some long-term effects to infants, from continuous ingestion, would be expected. The important sources of these effects are the assimilation of I-131 in the thyroid from early ingestion of water and milk and the concentration of Sr-89 and Sr-90 in the bone.

3. All crops contaminated to levels less than the 90 percentile level (national summary) of the harvestable crops would be edible, for both the existing shelter case and the good shelter case and for both attacks. The highest calculated absorbed dose to body organs from ingestion of contaminated food and water resulted from the deposition of small fallout particles on the aboveground plant parts and in exposed water sources. The absorbed doses from consumption of foods obtained from the first postattack crop (where the edible plant parts were contaminated through root uptake and foliar contamination from worldwide fallout) were less than those from consumption of the contamination on the crops in the ground at the time of attack.

4. No decontamination of agricultural land would be needed, and no quarantine of agricultural land because of contamination by Sr-90 and Cs-137 is required. Green leafy crops (and others) that are contaminated to levels in excess of the contamination level for 0.9 of the crop could be fed to animals.

5. About 10 percent of the forest land (coniferous and deciduous) area would receive sufficiently high radiation doses so that recovery to preattack conditions within about 2 years is questionable. In a smaller fraction of the forest land area, all vegetation would be killed. About the same fractional areas were involved in both assumed attacks.

6. In the HM attack, the crops in 11 percent of the planted crop land (all types) were destroyed (i.e., about 2 percent of the area of the country); in the MC attack, the crops in about 3 percent of the planted crop land (all types) were destroyed. These estimates are probably somewhat low because the computations were presumably based on the response of mature plants (data on the variation of the response with plant age being nonexistent) and because beta dose responses were not considered (no model and no response data being available). In addition, some of the available dose-response data are questionable. Therefore the estimated fractions of crops destroyed indicate only the likely magnitude of the damage. No radiological or ecological problems, except for delayed reentry because of dose limitations to the farmer, would be expected in the planting of the first crop after the attacks.

7. A large fraction of the population has well-water sources available to them; these sources are not expected to be contaminated during an attack. (However, the availability of the water would depend on the availability of power for pumping.) The consumption of contaminated water from exposed sources in the early postattack period, neglecting natural and normal water treatment decontamination processes, would not be expected to produce serious somatic effects at the 90 percentile (nationwide) water source contamination level.

Within the reliability of current information on the biological response of species to radiation exposures, the above results of the study lead to the conclusion that long-term biological and ecological effects would not be so severe as to inhibit or seriously delay the national recovery after a nuclear attack similar to one of those assumed in the study. Rather, the major problems of population and biological resource survival are concluded as being associated with the short-term biological effects that would result from the exposure of all biological species to gamma radiation from fallout. The alleviation of these effects thus centers on the availability of shelter for the protection of the population and a local capability for organized efforts to recover food and water and other survival resources that would be required to maintain the health of the survivors as a coherent work force in the early post-attack period. This is the time period after attack when the need for knowledgeable leadership would be critical and when errors in recuperative actions would be most likely to lead to secondary fatalities.

The effects of radiation from fallout in some areas of the country could result in fatal doses to all higher forms of life in exposed conditions. It is likely that a small fraction of the total land area of the country would be denuded of vegetation for a short period of time. However, the location and extent of these areas, with respect to other aspects of resource damage and economic recovery problems, are such that the ecological consequences of the biological damage in these areas could have little or no influence on national recovery. Essentially all of the economically important agricultural land is recoverable within the first year after attack, even for the case of existing shelters.

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INTRODUCTION TO LONG-TERM BIOLOGICAL EFFECTS OF NUCLEAR WAR

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

5 AUTHOR(S) (Last name, first name, initial)

MILLER, Carl F.
LA RIVIERE, Philip D.

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13 ABSTRACT

This report summarizes the state of knowledge and concepts about the reaction of biological systems to effects of nuclear weapons under nuclear war conditions, about the likely extent of damage to agricultural and wildlife ecosystems under nuclear war conditions, and about the factors involved in the long-term recovery potential of these systems after damage. In the study, an attempt was made to organize the available information for objective discussion of the subject, to outline the state of the art regarding capabilities to use the information (as well as its availability), and to make estimates of radiological effects using the available data and available (or new) computational methods.

For several assumed types of nuclear attack, the effects of the radiation from fallout in some areas of the country could result in fatal doses to all higher forms of life in exposed conditions. A few percent of the total land area of the country would likely be denuded of vegetation for a short period of time. However, the location and extent of these areas, with respect to other aspects of resource damage and economic recovery problems, are such that the ecological consequences of the biological damage in these areas could have little or no influence on national recovery. Essentially all of the economically important agricultural land is recoverable within the first year after attack for the case in which the existing shelter system is used.

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14 KEY WORDS		LINK A ROLE	WT	LINK B ROLE	WT	LINK C ROLE	WT
Fallout	Postattack recovery						
Radiobiological effects	Agriculture						
Nuclear war	Fallout models						
Radioecology	Radiation effects						
Radiological effects	Nuclear radiations						
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TITLE: Introduction to Long-Term Biological Effects of Nuclear War

By: Carl F. Miller and Philip D. LaRiviere

SUMMARY:

This report summarizes the state of knowledge and concepts about the reaction of biological systems to effects of nuclear weapons under nuclear war conditions, about the likely extent of damage to agricultural and wildlife ecosystems under nuclear war conditions, and about the factors involved in the long-term recovery potential of these systems after damage. In the study, an attempt was made to organize the available information for objective discussion of the subject, to outline the state of the art regarding capabilities to use the information (as well as its availability), and to make estimates of radiological effects using the available data and available (or new) computational methods.

Within the reliability of the current information on the biological response of biological species to radiation exposures, the results of the study lead to the conclusion that long-term biological and ecological effects would not be so severe as to inhibit or seriously delay the national recovery after a nuclear attack similar to one of those assumed in the study. Rather, the major problems of population and biological resource survival are concluded as being associated with the short-term biological effects that would result from the exposure of all biological species to gamma radiation from fallout. The alleviation of these effects thus centers on the availability of shelter for the protection of the population and a local capability for organized efforts to recover food and water and other such resources that would be required to maintain the health of the survivors as a coherent work force in the early postattack period. This is the time period after attack when the need for knowledgeable leadership would be critical and when errors in recuperative actions would be the most likely to lead to secondary fatalities.

For several assumed types of nuclear attack, the effects of the radiation from fallout in some areas of the country could result in fatal doses to all higher forms of life in exposed conditions. A few percent of the total land area of the country would likely be denuded of vegetation for a short period of time. However, the location and extent of these areas, with respect to other aspects of resource damage and economic recovery problems, are such that the ecological consequences of the biological damage in these areas could have little or no influence on national recovery. Essentially all of the economically important agricultural land is recoverable within the first year after attack for the case in which the existing shelter system is used.

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