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FALLOUT CONTAMINATION OF FOOD AND WATER

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Protection of the civilian population in wartime from external exposure to gamma radiation has received much more attention than protection against contamination in food and water. External exposure is far more dangerous not only in early effects -- lethality and acute radiation sickness -- but probably in the longer-term effects -- reduction of life expectancy, increased malignancies, and genetic consequences.

During a nuclear war, early deaths due to the ingestion of contaminated food and water are highly improbable. The effects to be expected if fallout radionuclides gain entry to the body, are of the type that would be seen years afterward. Most of the external gamma radiation exposure would occur in a short period -- during hours to days after the attack, while the internal exposures could occur over a prolonged period -- in the case of strontium-90, years to perhaps a few decades. Radioiodine is the exception. Because of the short half-life of the important iodine isotopes (about 8 days for I^{131}), the radioiodine exposure would occur in the first days to weeks. Results of the exposure, however, might not be seen for years.

It is essential that protection against the external gamma radiation be prepared preattack. A policy depending on improvization in the post-attack period may be very dangerous. There probably would be insufficient time. On the contrary, if indeed the internal emitter problem should turn out to be very serious, there would be time available to take protective action. Obviously, the more we know about ways of reducing this hazard, and the better our plans are for coping with it, the better off we would be if we should have to use them.

It is the objective of this paper to discuss problems of fallout contamination in food and water as we view them today in the civil defense context. After outlining certain pertinent background experience that has led to our current understanding of the biological and physiological effects of the more dangerous radionuclides, I will mention our experience in the development of explicit standards and measurement techniques and equipment, and why we now consider such an approach to be unworkable and unnecessary. Then I will touch on the Office of Civil Defense research program, emphasizing our procedures for predicting the contamination levels likely to be associated with various types of nuclear wars, including quantitative estimates of maximum internal doses associated with certain hypothetical wars. Finally, I will mention the countermeasures that seem to merit consideration.

Probably the first human death from acute radiation poisoning was reported at a Berlin Medical Society Meeting in 1912.[1] A woman who had been treated for arthritis over a period of 16 days with injections of thorium-X, a short-lived isotope of radium, died within a month. The attending pathologist clearly recognized the cause of death. He reported, ". . . one cannot doubt for a minute that we have here a case of death caused by mesothorium." But the danger signals went largely unheeded.

The story of the painters of luminous watch dials has become a classic in the annals of industrial hygiene.[1,2,3] Girls, employed as dial painters during the period 1914 to 1925, achieved a fine point on paint-laden brushes by shaping them with their lips. Minute amounts of radioactive material thus were ingested. In 1922, -23, -24, nine of these girls died with severe and unexplained anemia, and destructive lesions of jawbone and mouth. Many others have died of radium poisoning over the years, although some are still alive.

Also during the early part of the century, there was a fad of administering radium by injection and by mouth for ailments ranging from bad colds and broken bones, to insanity and old age. One Chicago physician gave radium to more than a thousand patients -- probably several thousand -- his own children included. Ironically, these victims of radium poisoning tended to come from the higher-income class since the radium treatments were not inexpensive.

During this period, one group of mental patients received known amounts of radium chloride intravenously for therapeutic purposes. Follow-up studies of these patients, involving repeated and comprehensive observations, have yielded extensive data on the detection, distribution, retention, and injury sequelae of the medication.

Continuing studies of the radium poisoning cases are being carried on by Dr. Robley Evans and his co-workers at the Massachusetts Institute of Technology, Cambridge, Massachusetts; and at the AEC's Argonne National Laboratory in Chicago. Some additional, but more limited studies are being carried on elsewhere in the United States.

In 1941, standards for maximum permissible body burdens for radium for man were established by an Advisory Committee* to the U. S. National Bureau of Standards.[4] The maximum body burden was set at 0.1 microcurie -- the value that is still in use today and the value adopted by the International Commission on Radiological Protection.[5]

Additional information about the effects in man of internally-deposited radionuclides comes from experience with the fission-product radioiodine produced during nuclear weapons tests. The case of the Rongelap Atoll natives is well known. Accidentally they were exposed to the

* This Committee is now called the National Council on Radiation Protection and Measurements and frequently is referred to as NCRP.

fallout from a nuclear device detonated at the Pacific Proving Ground in the spring of 1954. Fallout began to arrive 4 to 6 hours after burst, and at about 50 hours after burst, the natives were evacuated. These people were not aware they were being exposed to fallout, and were not aware of its significance. They remained out of doors and took no special precautions. For example, they continued to drink water collected in open cisterns. Early estimates of the maximum external doses were about 175 roentgens and the maximum internal doses were estimated to be between 100 and 150 Rads to the thyroids.[6] Later recalculations of the thyroid doses in the smaller children due to radioiodine indicated they may have been in the range of 700 to 1400 Rads.[7]

During the past few years, abnormalities have been detected in thyroid glands of some of the people exposed. The following is quoted from a report of the medical survey conducted in March 1966 of the people of Rongelap and Utirik Atolls.

"Among the Rongelap people, in whom nodules of the thyroid gland had first been detected three years ago, a further increase in cases with nodules was noted. There has been a total of 16 cases in the 69 people now living (of the original 82 people exposed), 15 in the more-heavily-exposed group, and 1 in the less-exposed group. Thirteen of 19 children in the more-heavily-exposed group, all of whom had been "exposed at less than 10 years of age, had nodules (68%). In addition, there were two boys with hypothyroidism in that group who had previously shown considerable growth retardation. These boys have improved on thyroid hormone therapy instituted six months ago. Six Rongelap people with nodules have been operated upon, 5 children in whom the nodules proved to be benign and one woman who had cancer of the thyroid. The latter case is now doing well.

"Of interest was the absence of thyroid abnormalities in the 60 Utirik children examined who were in the same age range of the high-incidence group of Rongelap-exposed children, but who had received considerably less exposure.

"Five of the Rongelap thyroid cases will be brought to the Medical Research Center at Brookhaven National Laboratory in May 1966, for further evaluation and possible surgery."[8]

There seems little question that the radioiodine entered the bodies of the Rongelap natives as a result of their drinking water from open cisterns.

Another possible source of information on effects of radioiodine in man is experience within the continental United States resulting from fallout from atmospheric weapons tests in Nevada during the period 1951 to 1962.

Although most of the local fallout was confined to the tests site, occasionally some extended into inhabited areas. The estimates are that the total doses to people within these areas were low. Dr. Gordon Dunning of the U.S. Atomic Energy Commission has estimated that the highest external exposure for any one person was 13.5 roentgens and to any community was 6 roentgens.[9] Most of the doses were far lower than these values. Some fallout radionuclides, however, were deposited on pasture land, and they could have been ingested as a result of drinking fresh milk from the grazing cattle. Children were at greatest risk because of the smaller size of their thyroids, and because children usually drank more milk than adults. During the Fall of 1965, physicians examined some 2,000 of the Utah children from areas where the fallout occurred and, as a control, some 1400 children from Arizona where there was little or no fallout. Preliminary findings indicated thyroid abnormalities, as evidenced by the presence of nodules, in appreciably more of the Utah children than in those of Arizona.[10,11]

In March of this year, a further report on the results of the Utah and Arizona study was released by the U.S. Public Health Service. This report stated that no malignant growths of the thyroid gland were found in any of the children. The study revealed, however, a number of cases of thyroiditis, an inflammation of the thyroid that may produce nodules in the gland. The report stated that the significance of the thyroiditis was not clearly understood, but it noted that during recent years a general increase in thyroiditis has been observed in several widely-scattered areas in the United States and elsewhere. A conclusion of the report was that, as of that date, March 1966, no relationship had been established between the thyroiditis and exposure to radiation.[12,13]

The next phase of this study is now underway -- May 1966. Thyroid specialists are again examining those children originally thought to have thyroid abnormalities. I would assume the results will be available in the near future.

There seems to be firm evidence that weapon-produced radioiodine can produce physiological effects. In the case of the Rongelap incident, the thyroid damage was produced by the fallout from a single nuclear explosion. In Nevada, if indeed the thyroid abnormalities are found to be attributable to radioiodine (and as I just mentioned, no such causal link has been established), the fallout from a number of test detonations may have contributed, and if the radioiodine should be implicated, there seems little question that its route of entry was through fresh milk. Drinking water supplies predominantly are from wells.

During the Atomic Energy Project of World War II, large research programs in radiobiology were undertaken; and through the use of animal experiments, a great deal of knowledge has been generated on various internally-deposited radionuclides. But the basic source of information on the bone seekers (and this includes strontium-90) stems from the early radium experience.

The animal experiments have shown that certain of the bone-seeking nuclides produce greater damage to the bone than radium for the same dosage.[5] This can be attributed to several factors, including greater sensitivity for portions of the bone where the nuclide is deposited, and greater importance of damaged tissue. These factors are taken into account in establishing maximum permissible values.

Determinations of maximum permissible values for body burdens of the various radionuclides are based on two somewhat differing criteria. One criterion, as I have just discussed, is for the bone-seekers; the second, for the other radionuclides, is based on limiting the weekly dose to the organ where the nuclide concentrates to a value commensurate with the limitation for whole-body external exposure. Calculations have been made for the gamut of nuclear-weapon-produced radionuclides and the results may be found in the NRRP report "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water," U.S. Department of Commerce, National Bureau of Standards Handbook 53, March 20, 1953. This report was superseded by the NCRP Handbook No. 69 published in June 1959 and entitled "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure." These calculations also are reflected in the "Report of ICRP Committee on Permissible Dose of Internal Radiation (1959)" published in the 1960 issue of Health Physics.

How can such guidelines be applied for the case of a war emergency? Dr. Edwin G. Williams, member of the U.S. National Council on Radiation Protection (NCRP), the original Director of the Division of Radiological Health of the U.S. Public Health Service, and an early advisor to Civil Defense, had an expressive way of pointing out that radiation and biology are precisely the same in peacetime as in wartime. His statement to this effect was somewhat as follows: "Gamma photons and beta particles don't know or care whether a war is on or not, and the cross section of a gene or chromosome is independent of the state of National emergency."

But there are two important differences between peacetime industrial standards as defined by the NCRP and those that might have to be used in a war-time emergency. The peacetime standards apply to continuous exposure -- perhaps as long as one's normal working span -- whereas the wartime exposure situation most probably would be much shorter. And, secondly, in peacetime one must apply factors of safety which might not be achieved in a war situation. Living in wartime is more dangerous and attempting to apply peacetime safety factors might divert attention and effort from more serious survival or recovery problems.

The first official Civil Defense guidance on levels of radioactivity in food and water to be permitted under emergency conditions in war-time was developed in 1950 by Dr. William F. Bale of the University of Rochester while on temporary assignment to the Division of Biology and Medicine of the U.S. Atomic Energy Commission. I should like to quote from Dr. Bale's report.[14]

> "It is probably not generally realized that water, and also food, can be very appreciably radioactive as measured by many portable radiation monitoring instruments now available and still be perfectly acceptable for human use under emergency conditions. The danger at the present time is probably greater that the presence of small amounts of radioactivity will lead to unwarranted shutting off of a municipal water supply or to a proclamation forbidding its use for drinking purposes thus causing an acute exacerbation of emergency conditions that may exist, rather than that consumption of contaminated water will cause significant damage to a military organization or a civilian municipality."

At about the same time, Mr. Adrian Dahl of the University of Rochester, and later Dr. Edwin P. Laug of the U.S. Food and Drug Administration prepared comparison standards to be used with a conventional-type Geiger counter survey meter for evaluating the degree of contamination of a sample of food and water. In 1952, the FCDA published two bulletins; one provided guidance on the levels of contamination acceptable under emergency conditions[15] (based on Dr. Bale's work); and the other described methods for making measurements, and instructions for preparing the comparison standards based on Dahl's and Laug's work.[16] It should be noted, at this time (1952), it was expected that in an atomic war only limited areas would be seriously affected by fallout, and in those areas, the levels would be fairly low. Relatively, weapon yields were much less -- kiloton _vs_ megaton -- and it was thought that the likely detonation condition would be an airburst so as to maximize blast effects. Therefore, a relatively conservative approach could be used. The calculations were based on the assumption that the total fallout activity was strontium-89 and -90; that daily water consumption was 2.2 liters; that the strontium in fallout was 100% soluble; that 40% of the content in water is absorbed in the stomach and GI tract; and finally, that the total dose to any macroscopic region of the bone must be limited to 50 Reps.[14]*

The results of these calculations are shown below.

ACCEPTABLE BETA-GAMMA ACTIVITY

Estimated Consumption Period	$\mu c/cc$	dps/cc
10 days	9×10^{-2}	3×10^{3}
30 days	3×10^{-2}	1×10^{3}

The level 9×10^{-2} microcuries per cubic centimeter of food or water was the limit to be allowed for an assumed consumption period (10 days).

* An obsolete unit of dose, now replaced by rads.

The level was 1/3 this amount if the consumption period was assumed to last for 30 days.

This guidance was accepted as doctrine by U.S. Civil Defense organizations over the next several years. The count-rate produced by a few cc's of sample containing 9×10^{-2} microcuries per cc is easily measured by an ordinary Geiger counter instrument. The Geiger tube probe with the beta shield open was placed over a compound in the lid of a standard 4-ounce ointment tin containing an amount of U-238 or radium that empirically had been adjusted to give the count rate desired. The unknown water or food sample was placed in the bottom section of the tin, and a comparison of the two readings indicated whether the radioactivity of the sample was above or below the acceptable level. These comparison standards were purchased by OCD and distributed so as to be available for emergency use.

Today both the standards and the measurement techniques are no longer used by U.S. Civil Defense for the following reasons. First, the fallout is now known to be a principal hazard of a nuclear war. Studies of hypothetical nuclear attacks show that fallout could seriously affect very large areas of the country. Thus, adherence to the conservatism reflected in the earlier calculations could unnecessarily deny the use of badly-needed food and water. Second, because of high backgrounds expected from gamma radiation sources outside a protected location, and from the almost inevitable beta contamination even within a shielded area, the measurement equipment probably would not operate because the background levels would drive it off scale.

Without definitive emergency standards, and without food- and water-monitoring equipment, what is to be done?

We believe that the internal-emitter hazard is so small compared to the external gamma radiation hazard that essentially it can be ignored, at least during the shelter stay-period. Later, as health standards return to more-nearly-normal peacetime criteria, evaluations of food and water based on radiochemical analyses will be necessary so that the specific nuclides can be identified, and precautions or countermeasures can be taken accordingly.

There are two common-sense procedures that should be followed in any fallout area: first, primarily because of the radioiodine problem, water from open reservoirs should be avoided if other sources are available; and second, during the first few weeks following the attack, children (especially babies), also because of the radioiodine hazard, should not be given milk from cattle that have grazed on contaminated pasture. However, in any situation where the requirement for food or water became stark, always it would be better to use any available source of supply than to deny it.

Let me discuss further the basis for de-emphasizing the importance of the internal emitter hazard.

There is no direct experience to call upon. The two nuclear bombs used during World War II in Japan were detonated at altitudes intended to maximize blast effects. The weapons were air bursts and no early fallout was produced. Since no other nuclear weapons have been detonated over a city, the basis for predicting the type of fallout that would be created by ground-bursting a weapon on a target city must be drawn from the tests in Nevada and the Pacific, and from theoretical and laboratory studies. Through such studies, a great deal is now known about fallout's physical, chemical and radiological properties.

Mathematical models have been developed that simulate the fallout creation and distribution processes. Inputs include weapons design data, meteorological information, and detonation conditions. Outputs include not only external gamma dose rates as a function of time and location in the fallout pattern, but also the density of individual radionuclides per unit area and their solubility. By the use of electronic computers, such models are being used to analyze hypothetical nuclear wars, providing specific estimates of radionuclide concentrations and their biological availability for any assumed war situation and applicable to any place in the country. Such models take into account both locally-deposited fallout and that due to world-wide contributions. Results of a two-sided nuclear exchange can be considered by adding the contribution that weapons detonated on enemy soil would make to the world-wide fallout.

Additional mathematical models, also computerized, consider the various paths by which radionuclides could enter the body ultimately to become deposited in the critical organs; or example: the amount of Sr^{90} in the bone, and the amount of I^{131} in the thyroid. Such models may start with any war situation one wants to hypothesize and wind up with the body burden of any isotope of interest for people of different ages in the different parts of the country. Through these studies, the expected benefit of various types of countermeasures can be evaluated, as can comparisons between the probable seriousness of external and internal exposure doses.

The models used in civil defense studies of food and water contamination and for many other consequences of nuclear attack were developed by Dr. Carl F. Miller, now of Stanford Research Institute, formerly of the Naval Radiological Defense Laboratory and the Office of Civil Defense. The basic descriptive material of Dr. Miller's work may be found in a 2-volume report entitled "Fallout and Radiological Countermeasures."[17]

Additional reports in this general subject area by Dr. Miller's group include: "Vulnerability of Municipal Water Facilities to Radioactive Contamination from Nuclear Attacks," "Biological Availability and Uptake of Fission Products in Fallout," "Plant Uptake of Radioelements from Soil," and "Fallout Models and Radiological Countermeasure Evaluations."

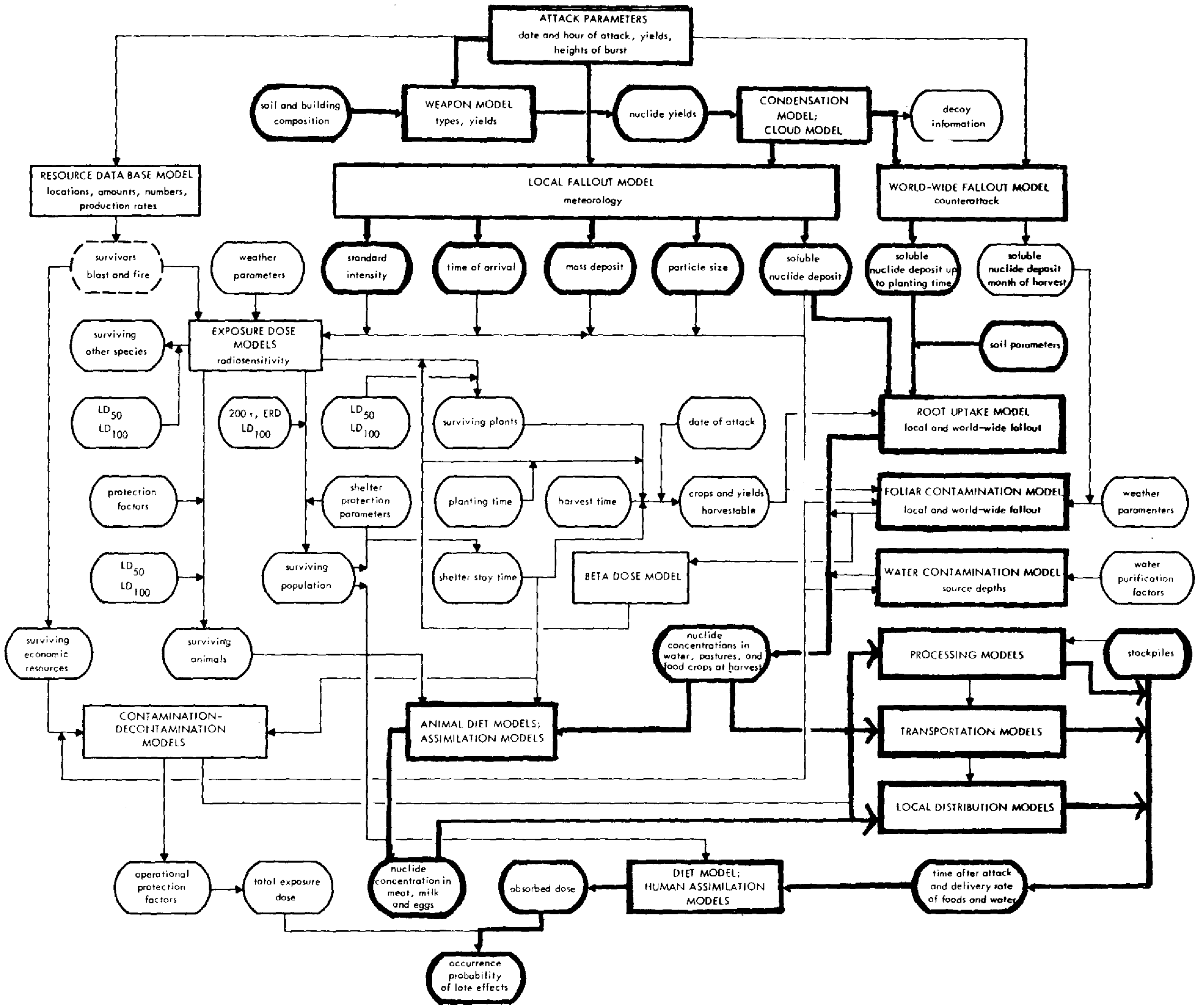
I will not attempt to describe the intricacies of Dr. Miller's models here, but the schematic outline (on the next page) indicates how comprehensive they are and illustrates (within the heavy black lines) the sub-models that would be involved in estimating food and water contamination levels.[18]

Starting with ATTACK PARAMETERS which include date and hour of attack, yields and heights of burst, through a WEAPON MODEL, and taking into account "soil and building composition," the "nuclide yields" are calculated. These are then fed into the CONDENSATION MODEL and CLOUD MODEL where the flow splits into two components; on the right, those nuclides which go into the WORLD-WIDE FALLOUT MODEL, and down the center, those nuclides going into the LOCAL FALLOUT MODEL.

The LOCAL FALLOUT MODEL produces output data on "standard intensity," "time of arrival," "mass deposit," "particle size," and

Figure 2

SCHEMATIC OUTLINE OF MODEL SYSTEMS FOR ESTIMATING RADIOLOGICAL EFFECTS



"soluble nuclide deposit." On the right, the WORLD-WIDE FALLOUT MODEL, taking into account both offensive strikes and counterattacks, produces data on "soluble nuclide deposit up to planting time." This data and information on "soil parameters" feeds into the ROOT UPTAKE MODEL, as does the data on "soluble nuclide deposit" from the LOCAL FALLOUT MODEL.

Similar considerations and appropriate mixing of outputs from the local- and world-wide fallout models apply to the FOLIAR CONTAMINATION MODEL and the WATER CONTAMINATION MODEL. Account is taken of those plants which would be killed by external gamma radiation exposure. Eventually data are produced on "nuclide concentrations in water, pastures, and food crops at harvest." The outputs split into two parts: the first goes through the ANIMAL DIET MODEL and ASSIMILATION MODEL, eventuating in "nuclide concentration in meat, milk, and eggs," the other path takes into account the PROCESSING MODELS, TRANSPORTATION MODELS, and LOCAL DISTRIBUTION MODELS and, after considering availability of stockpiled supplies, the output is fed through the DIET MODEL and HUMAN ASSIMILATION MODEL, arriving at "absorbed dose" data which then may be translated into the "occurrence probabilities of late effects."

I have not discussed a number of other considerations shown in the schematic, and also I should point out that, although an attempt is made to take all relevant factors into account in these computations, the basic knowledge relating to some of them is quite meager. A number of components of our research program are aimed at improvements.

Also, it is important to note that the CONDENSATION MODEL and the CLOUD MODELs account for fractionation. The most hazardous radionuclides if ingested (strontium and cesium) are among the more volatile of the fission products and, therefore, are among the last to condense. Thus, they become associated mostly with the smaller fallout particles and consequently are enhanced in world-wide and depleted in local fallout. The result is a reduction in the maximum concentrations of these nuclides compared to the values calculated if fractionation is ignored.

Let me give you two illustrations of the application of these models. One by Mr. Hong Lee of Stanford Research Institute was a study of the vulnerability of municipal water facilities to radioactive contamination from nuclear attack;[19] and the other by Isotopes, Inc., a private research organization located in Westwood, New Jersey, was a study of the contamination of human food following nuclear attack.[20] Both studies were conducted under contract to the Office of Civil Defense.

The analysis by Mr. Lee dealt with the effects of drinking filtered but otherwise unprocessed surface-source waters that were contaminated by fallout deposited directly into the surface sources. Two hypothetical attacks were studied: first, a heavy, mixed attack against city and counterforce targets with a total yield of 12,000 MT; and second, a city-avoidance, medium counterforce attack with a total yield of 7,000 MT. In both attacks the weapons were assumed to be surface burst, and the yields were assumed to be 50% from fission and 50% from fusion. Because only the soluble radionuclide concentrations were of interest, computer print-outs listed the maximum soluble concentrations of Sr^{89} and Sr^{90}, Ru^{106}, I^{131}, Ce^{137}, and Ba^{140}. As a measure of the radiological situation, the computer print-out also listed the external gamma radiation dose rates. It was assumed that everyone drank 1 liter of water per day. The absorbed doses for various organs derived from ingestion of the most contaminated water (this happened to be St. Louis, Missouri, which was assumed to be a target city) were calculated. It was estimated that no serious biological effect in adult humans would be expected from the consumption of the most contaminated water (even without the benefit of decontamination by normal water-treatment methods). The probable exception of this conclusion for the entire population, is for the thyroid doses to young children, where continued consumption of the more highly contaminated waters would result in (at least) partial destruction of children's thyroids.

In this worst-case city, St. Louis, the computed physical destruction from blast and fire causes was extremely severe. Also the H + 1 dose rate from fallout from close-in weapons and weapons detonated up-wind to the west was computed to be about 17,000 R/hr. It is apparent that in targeted cities such as St. Louis, the major problem confronting survivors would be to continue to avoid large dosages of external radiation and to secure subsistence levels of water, food, and shelter. Through such comparisons in each critical community, it became evident that the problem of water contamination was secondary to other postattack exigencies.

Specifically, this study indicated:

1. A large proportion of the postattack population will have ground source water available, and these waters, if protected from source to distribution, will be free of radioactivity.

2. Communities which must rely upon surface sources that are in the fallout region will have contaminated water available for consumption.

3. The biological effects arising from drinking surface waters contaminated by fallout deposited directly into the surface source generally would be insignificant compared with other hazards.

4. The contamination of surface waters by run-off from contaminated land areas probably would not exceed the initial contamination from direct deposit of fallout in exposed water sources.

5. Water-softening and water-purification plants would provide sufficient decontamination of the water to reduce significantly the absorbed doses to body organs.

6. In the postattack environment, water-source contamination would not be as critical a problem as the distribution of water for the survivors in damaged cities.

The other study that I want to mention relates to the contamination of human food following nuclear attack. It is the one that was performed for OCD by Isotopes, Inc.

The following diagram (next page) illustrates the approach. Radioactivity produced in the attack is separated into three categories -- that injected into the stratosphere, that into the high troposphere, and that into the local atmosphere. Estimates of the amount and nature of local fallout were based on Dr. Miller's models. Fallout of stratospheric debris was obtained from studies performed for the Defense Atomic Support Agency under Project Stardust. Consideration then was given, using the local fallout data, to the determination of contamination of crops that would be standing at the time of attack. Future crop

COMPUTATION OF THE RADIATION DOSE TO MAN FROM THE INGESTION OF CONTAMINATED FOOD

PROJECT DIAGRAM

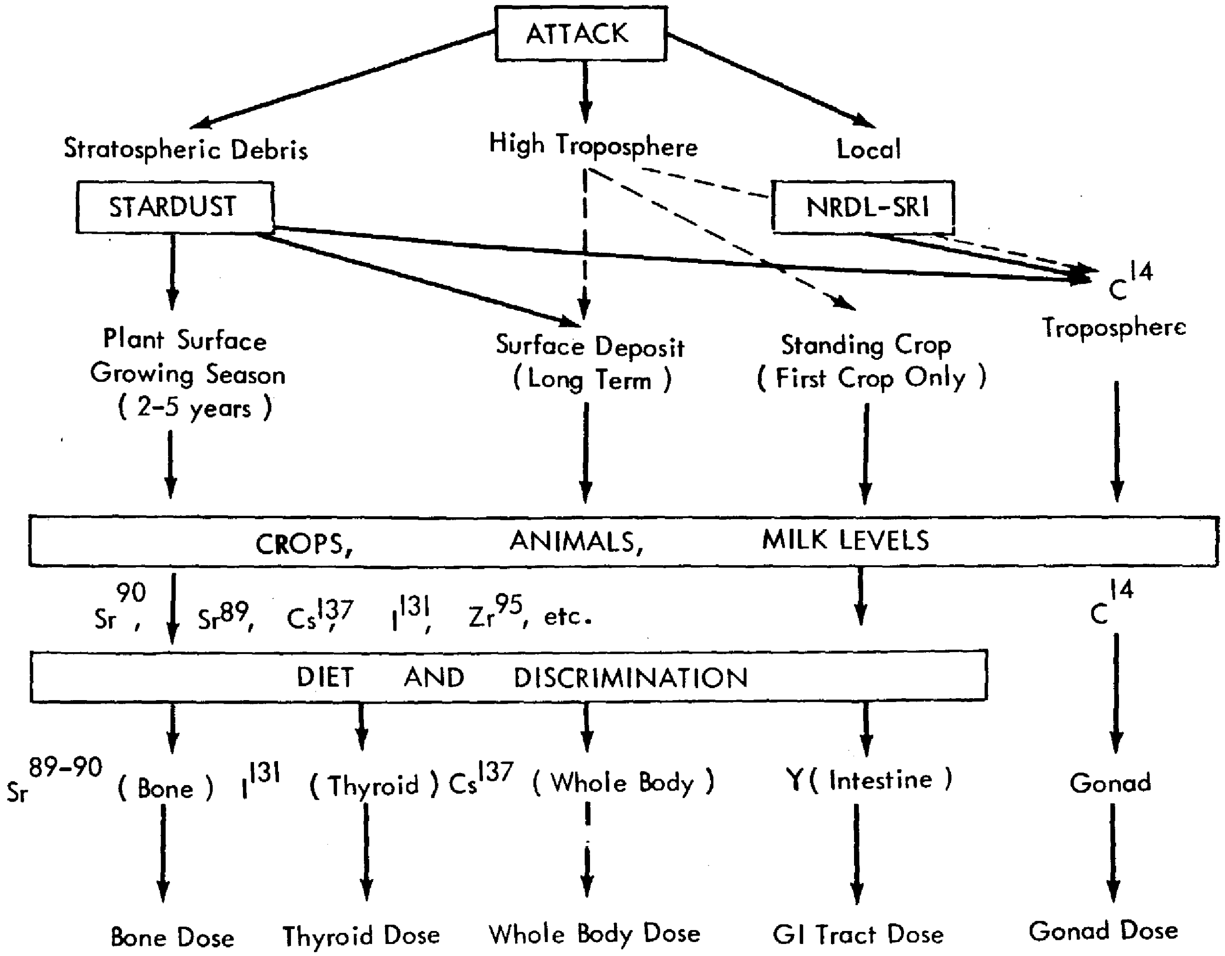
I. Attack Model
- Quantity
- Composition
- Geographical Distribution

II. Contamination of Environment
- Deposition of Fallout
- Ground Air Concentration C^{14}

III. Contamination of Foodstuffs
- Foliar Absorption
- Root Absorption
- Grazing

IV. Ingestion
- Diet Concentration
- Biological Half-Life
- Critical Organ Concentration

V. Radiation Dose



contamination was estimated by consideration both of cumulative deposition on the soil and subsequent deposition in rain of the stratospheric component.

The deposition of radioactivity on crops and on the surface of the earth was related to concentration in human food. The study was limited to consideration of hazards associated with strontium-89 and -90, and the principal food types in the Western diet. Concentrations of radioactivity in these food types were assessed and the resulting radiation doses to people of all ages calculated monthly for 16 months, and yearly for 99 years. The attack assumed for this study was extremely heavy and all weapons were assumed to be surface bursts. The attack was assumed to have occurred in mid spring.

The maximum concentration of strontium accumulated in the bone of individuals who were fetuses and newborn babies at the time of attack. Because of the small amount of uncontaminated bone, and the rapid accretion of new bone by fetuses and children, these individuals accumulated the highest concentrations and, thus, would logically receive the highest doses. Since adults assimilate strontium only by the exchange of existing bone, they are relatively insensitive to high concentrations of strontium-90 in their diet. Teenagers, because of rapid accretion of new bone between the ages of 10 to 18 years, exhibit a secondary maximum accumulation of strontium-90. This maximum dose rate in the teenagers was received by individuals who were 10 years old at the time of attack.

Again, let me emphasize that in the SRI water study and the Isotopes food study, no countermeasures or preacutions were assumed to have been taken.

Now, what seem to be the requirements for countermeasures and what would be the difficulties in instituting them?

For two of the radionuclides -- iodine and strontium -- it would appear prudent to have standby countermeasures for implementation when and if needed. Of the two, the iodine countermeasure problem seems far easier to solve since it would exist, at most, for a few weeks postattack, and iodine appears to be an important hazard only as a contaminant in water or milk. Its short half-life precludes its becoming incorporated in most other kinds of foods. Although iodine, with the other fallout radionuclides, could be deposited on plant surfaces, it easily could be cleaned off. Inhalation of iodine is not considered to be very important. Although some sublimation would occur, test experiences have indicated that the resulting concentrations of iodine vapor would not be dangerous. The iodine hazard would be limited essentially to the very young; thus a desirable policy would include selective rationing in order to provide the least-contaminated food to the young. If only a highly-contaminated supply were available, the uptake by the thyroid of I^{131} could be blocked through administration of stable iodine.

In a study sponsored by the U.S. Public Health Service,[21] sodium iodide was given in increasing doses to groups of children having normal thyroid function. The size of the sodium-iodide dose was varied in proportion to the skin area of the children. Maximum suppression of iodine-131 uptake was achieved with 1.5 to 2.0 milligrams of iodide per square meter of body surface per day. It quickly rebounded when the iodide was discontinued.

Based upon this experience, the research team calculated that the minimum dose of iodide required for almost complete suppression of the uptake of radioactive iodine by the normal human thyroid was 1.5 to 2.0 milligrams per day per square meter of body surface. For an adult, this dose of iodide would be 3 - 4 mg per day; and for children, about 1 mg per day.

At these iodide doses, suppression of uptake of radioiodine would begin almost immediately, and by 24 hours a 50% reduction would be expected. Subsequently, a gradual decrease in uptake to a minimum of about 5% would occur in 4 - 6 weeks. Toxic effects of iodide from daily doses of this order of magnitude given over relatively short periods of time would not be expected.

The strontium problem is more serious. Its duration would be far longer (the half-life of strontium is 28 years compared to a half-life of I^{131} of 8 days), and no relatively simple mechanism is known for blocking absorption of the strontium into the bone.

However, it seems strongly probable that if strontium-90 contamination were found to be highly dangerous in the postattack world, adequate countermeasures could be employed. Techniques exist now for decontaminating milk.[22,23] They are thoroughly effective and quite economical -- for about a cent a quart or less -- and these same techniques work with other liquid foods such as soups, purees, fruit juices, etc. Beer and wine, no doubt, could be included in this category. Other options exist. For example, contaminated grains could be fed to meat animals which serve very effectively as screening agents. There would, of course, be a net loss in the food value by the conversion of grain to meat. The maximum efficiency in terms of poundsof eatable meat per pound of grain is on the average about 15% for beef, about 30% for chickens, and for pork, it is somewhere in between.

In a postattack world, some strontium-bearing foods (grains especially) might have to be included in the human diet (at least, the strontium levels will be higher than they are now.).[24] Studies are underway in the U.S. Department of Agriculture and the U.S. Food and Drug

Administration to provide the rationale for allocating such foods. Since the physiological effects of high body burdens of strontium, like radium, are not expected until years after ingestion, older people obviously could tolerate the most contaminated of the supplies. Therefore, plans for allocation on the basis of age would seem to be desirable.

In a postattack world, the least contaminated food could become relatively expensive, a result to be expected if only the normal supply-and-demand factors were operative and no governmental control exercised. Thus, the more affluent of the survivors would be the least affected, and the poorer, the most affected. The situation easily could be exacerbated because of an exaggerated fear of contamination, the situation that probably exists among much of the population now. Thus, because the utilization of strontium-bearing food in a postattack world has not only physical and biological elements, but sociological, psychological, and economic implications as well, it needs careful study and planning now.

If, in a postattack situation, strontium-90 turned out to be a much greater hazard than the calculations indicate, and the countermeasures proved far less effective than expected, the consequences, although no doubt catastrophic in the eyes of those directly affected, would not be catastrophic in the sense of jeopardizing survival of the society.

Reproduction would not cease, the gene damage from the Sr^{90} would not be dangerous and the insult to the population would not continue indefinitely.

In summary, we believe:

1. The problem of contaminated food and water is far less important than the problem of external gamma radiation.

2. Hungry or thirsty people or animals should not be denied food or water because of possible fallout contamination.

3. If possible, during the first weeks postattack, water from open reservoirs and fresh milk from cattle grazing on contaminated pasture should be avoided, especially for use by small children.

4. It is not practicable to pre-set maximum permissible levels of gross fallout radioactivity as a basis for judging whether or not food or water should be used.

5. Further study, especially about the long-term strontium-90 problem, both requirements and methods for decontamination, is needed. Development of a rationale for allocating the foods containing varying levels of Sr^{90} contamination is essential.

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