CONTAMINATION OF FOOD PROBLEM AFTER NUCLEAR WAR

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Aina J. Shapley

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Note.

The vast majority of papers referred to have been copied.

A lot of subjects have not been discussed, e.g. units, different instruments, properties of radiation, and dose calculations. They are described in health physics text books. You have An introduction to radiation protection by Alan Martin and Samuel A. Harbison and Radiation Protection by Jacob Shapiro.

OVERVIEW

The most thorough and the most authoritative book on The effects of nuclear weapons is a book by that title compiled and edited by S. Glasstone and P. J. Dolan, 3rd ed., U. S. Department of Defense and U.S. Department of Energy, 1977. This book is referred to in almost all the articles and books dealing with a nuclear war. It is the source book on the description of the different atomic bombs, their uses and the consequent explosive blast, direct nuclear radiation, direct thermal radiation, EMP, and fallout.

The most thorough study of the probable consequences of nuclear weapons on the United States, as well as on the Soviet Union, was done by the Office of Technology Assessment (OTA), The effects of nuclear war, 1979, (for complete ref see p. 8). They considered five major cases ranging from 1 atomic weapon to an all out mixed military and population attack of 6500 MT (half of it air bursts and the other half surface bursts).

We are interested in the latent health effects. I have copied 7 of the most interesting pages and given them page numbers in the upper right hand corner. The risk factors for the latent health effects, as well as the sources and the compromises they made to arrive at them are given on p. 2. The risk factors they used for latent cancer deaths from internal organ exposures are given on p. 3.

Before we go any further, we have to examine some of the categories they use for the way they present their data. Local fallout is what is deposited within 24 hours after the burst. The fraction of nuclear debris in the local fallout varies from 0.8 from surface bursts to 0 from air-bursts. Worldwide fallout can be of two kinds, tropospheric and stratospheric. Tropospheric fallout is short (weeks). Stratospheric fallout is in years, e.g. removal half-time for Cs-137 is 5 years. Stratospheric fallout can be from 0 to .99 of the fallout, depending on the altitude and

Absolute risk is defined as the product of assumed relative risks times the total population at risk. Relative risk is defined as the ratio of the risk in those exposed to the risk to those not exposed. The difference between the two risk models leading to major differences in the projected number of cancer deaths lies in the calculated excess of cancers arising from the 0 - 9 years age group at the time of irradiation. Because data on relative risks are sparse and inconclusive, and more data exist supporting the absolute model, the absolute model was used to calculate the latent health effects. Also, because the effectiveness of low exposure rates and/or low radiation exposure doses for producing late health effects remains unresolved, projected cancer deaths were calculated with dose effectiveness factors (DEF) of 1.0 and 0.2 for low exposure rates and doses.* Also, because there is insufficient data to warrant limiting the risk plateau period to 30 years, a 40 year risk period was used.[9] Estimates of radiation genetic risks are also uncertain. Reference 8 estimates that the doubling dose for genetic risks to be between 20 and 200 rems although the possibility of it being lower than 20 rems or higher than 200 rems is not dismissed. Since a doubling dose of 100 rems was suggested by Reference 6 and it is within the estimated range of Reference 8, it was used to project the genetic risks. It follows that if the doubling dose is 20 rems then the projected number of genetic disorders (spontaneous abortions and "other genetic effects") should be multiplied by 5, and if the doubling dose is 200 rems then the projected number of genetic disorders should be halved. The resulting projected latent health effects from radiation exposures using a DEF=1 for cancer deaths are as follows:

Effects	Number per 10^6 person rems
Cancer deaths*	194.3
Thyroid cancers	134.1
Thyroid nodules	197.4
Spontaneous abortions	42
Other genetic effects	132.4

*Multiply by 0.2 for DEF = 0.2.

*A DEF=0.2 implies that the radiation received is only one-fifth as effective per unit of dose for producing latent effects when compared to a high dose received over a short period of time.

The projected latent cancer deaths from internal organ exposures are as follows:

Organ	Cancer deaths per 10^6 organ rems
Marrow	45.4
Lung	35.5
Digestive	27.1
Bone	11
Others	75.3

Also, for thyroid exposures from ingested I-131, the effectiveness of the exposure is estimated to be one-tenth that of an external (gamma) exposure.[6)]

size of the weapon.

For the worst scenario (6500 MT) they predict 100 million early fatalities (could be as high as 160 million). On p. 5 they give a comparison of latent health effects from external and internal exposures from local fallout. By far the most of the effects are from external exposure rather than from internal exposure. For cancer deaths only 7% are from internal exposure and for thyroid cancers it is less than 1%.

On p. 6 they give worldwide fallout health effects for the U.S. The most interesting thing about this is that they see carbon-14 as the biggest problem in this category. Next table is total latent health effects and the numbers do look high. The thing to keep in mind is that these figures are for the subsequent 40 years. 6.6 million cancer deaths in 40 years is about 40% of the current U.S. annual rate. It is interesting to note that there are almost as many latent health effects outside of the U.S. (e.g. 4,545,000 cancer deaths). These would be distributed all over the world. If there was a similar attack on the Soviet Union, there would be 167,000 cancer deaths plus all the other latent health effects in the U.S.

Pages 7 and 8 give the summary of their conclusions.

Page 9 gives their references.

LOCAL FALLOUT HEALTH EFFECTS 5

	PFs=5	PFs=10	PFs=40	Mixed PFs
External Exposure				
ADDITIONAL SHELTER FATALITIES	21,712,000	9,441,000	327,200	---
CANCER DEATHS (DEF=1)	2,390,000	2,099,000	1,005,000	1,720,000
CANCER DEATHS (DEF=0.2)	2,359,000	2,082,000	993,800	1,700,000
THYROID CANCERS	1,650,000	1,449,000	693,500	1,190,000
THYROID NODULES	2,429,000	2,132,000	1,021,000	1,750,000
SPONTANEOUS ABORTIONS	516,700	453,700	217,200	372,000
OTHER GENETIC EFFECTS	1,629,000	1,430,000	684,700	1,170,000
Internal Exposure				
CANCER DEATHS (DEF=1)	47,200	80,200	127,800	132,000
CANCER DEATHS (DEF=0.2)	9,400	16,000	25,600	26,400
THYROID CANCERS	2,600	4,400	7,000	7,200
THYROID NODULES	3,800	6,500	10,300	10,600
SPONTANEOUS ABORTIONS	3,100	5,300	8,400	8,700
OTHER GENETIC EFFECTS	9,800	16,600	26,400	27,300

WORLDWIDE FALLOUT HEALTH EFFECTS

	TROPOS	STRATOS	C-14	TOTAL
CANCER DEATHS (DEF=1)	360,100	1,543,000	2,886,000	4,789,000
CANCER DEATHS (DEF=0.2)	72,000	308,600	577,200	957,800
THYROID CANCERS	606,800	1,206,000	1,570,000	3,383,000
THYROID NODULES	893,200	1,776,000	2,311,000	4,980,000
SPONTANEOUS ABORTIONS	49,700	188,200	736,500	974,400
OTHER GENETIC EFFECTS	156,700	590.800	2,324,000	3,072,000

TOTAL LATENT HEALTH EFFECTS

	PFs=5	PFs=10	PFs=40	Mixed PFs
ADDITIONAL SHELTER FATALITIES	21,712,000	9,441,000	327,200	----
CANCER DEATHS (DEF=1)	7,226,000	6,968,000	5,922,000	6,640,000
CANCER DEATHS (DEF=0.2)	3,326,000	3,056,000	1,977,000	2,680,000
THYROID CANCERS	5,036,000	4,836,000	4,084,000	4,580,000
THYROID NODULES	7,413,000	7,119,000	6,011,000	6,730,000
SPONTANEOUS ABORTIONS	1,494,000	1,433,000	1,200,000	1,360,000
OTHER GENETIC EFFECTS	4,711,000	4,515,000	3,783,000	4,270,000

TOTAL LATENT HEALTH EFFECTS OUTSIDE OF THE U.S.

	DEF=1	DEF=0.2
CANCER DEATHS	4,545,000	909,000
THYROID CANCERS	3,254,000	
THYROID NODULES	4,549,000	
SPONTANEOUS ABORTIONS	926,000	
OTHER GENETIC EFFECTS	2,919,000	

CONCLUSIONS

The long-term major adverse health effects resulting from hypothesized nuclear scenarios covering a nuclear employment range from a single weapon to a massive attack utilizing thousands of nuclear weapons were calculated. The general findings were as follows:

1. Several million latent cancer deaths could result from a massive nuclear attack directed at urban-industrial, military, and counterforce targets.* However, without improved civil defense capabilities, the number of projected latent cancer deaths is small when compared with the total number of early fatalities. Similar magnitudes of thyroid cancers, thyroid nodules, and genetic anomalies are also projected.

2. For limited attacks where the target points are in relatively low population density areas, the resulting number of latent cancer deaths could be large when compared with the total number of early fatalities.

3. For nuclear employments that are dominated by airbursts, the projected number of long-term adverse health effects that would occur in the attacked country is only a small percentage of the projected worldwide total.

4. For airbursts, the resulting number of long-term adverse health effects are larger for low yield weapons (40 KT) than for high yield weapons (1 MT) when compared on a per unit fission yield basis. The reason is that the nuclear debris of low yield airbursts is confined within the troposphere, whereas most of the nuclear debris from high yield airbursts enters the stratosphere.

5. Increasing the local fallout decontamination effectiveness to residual levels below 0.1 will not materially decrease the total number of long-term latent health effects because the local fallout post-shelter population dose constitutes only a small

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*5 million worldwide cancer deaths over a period of 40 years represent an increase of about 2 to 3 percent of the current cancer death rate. - They must be using Northern Hemisphere or something. For U.S. this would be closer to 30%

fraction of the total population dose when the fallout levels are reduced by a factor of 0.1 by decontamination.

6. The use of low yield weapons in the surface burst mode rather than high yield weapons as air bursts would increase the long-term latent adverse health effects in the country attacked and decrease the number of the effects in the rest of the world.

7. For massive nuclear attacks (Scenario 5a and 5b), although the number of early fatalities are sensitive to the shelter protection provided the population, the projected total number of latent health effects are relatively insensitive to the shelter protection provided.

Office of Technology Assessment, The Effects of Nuclear War, Gale Research Company, Book Tower, Detroit, Michigan 48226, 1984. (This is an extended version of 1979 publication by U.S. Govt. Printing Office.)

Abbreviation used: OTA, The effects of Nuclear War.

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1. The Effects of Nuclear Weapons, Compiled and edited by S. Glasstone and P. J. Dolan, Third Edition, U.S. Department of Defense and U.S. Department of Energy, 1977.

2. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, General Assembly, Official Records: Seventeenth Session, Supplement No. 16 (A/5216), United Nations, New York, 1962.

3. H. Lee, P. W. Wong, and S. L. Brown, SEER II: A New Damage Assessment Fallout Model, DNA3008F, SRI International, Menlo Park, California, May 1972.

4. (Classified Report)

5. G. R. Crocker and T. Turner, Calculated Activities, Exposure Rates, and Gamma Spectra for Unfractionated Fission Products, USNRDL-TR-1009, U.S. Naval Radiological Defense Laboratory, San Francisco, California, 28 December 1965.

6. N. C. Rasmussen et al., Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, Appendix VI, Calculation of Reactor Accident Consequences, WASH-1400, Nuclear Regulatory Commission, October 1975.

7. H. Lee, W. L. Owen, and C. F. Miller, General Analysis of Radiological Recovery Capabilities, SRI International, Menlo Park, California, June 1968.

8. The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, Advisory Committee on the Biological Effects of Ionizing Radiations, National Academy of Sciences, Washington, D.C., November 1972.

9. R. A. Armistead et al., Analysis of Public Consequences from Postulated Severe Accident Sequences in Underground Nuclear Power Plants, Advanced Research and Applications Corporation, Sunnyvale, California, December 1977.

THE MOST IMPORTANT FISSION PRODUCTS IN FOOD

There are a number of good books on the subject. The most valuable probably is Radioactivity and Human Diet, ed. R. Scott Russell, Pergamon Press, 1966. Others: Radionuclides in Foods, National Academy of Sciences, 1973. Radioactive Fallout, Soils, Plants, Foods, Man, ed. Eric B. Fowler, 1965.

Iodine, strontium, and cesium are the most important radionuclides that enter the food chain and are absorbed by man from the intestinal tract. Barium-140, ruthenium-103, iron-55 can also be absorbed to a small extent. Tritium and carbon-14 are also very important but they are so mobile in the environment, no one can do anything about them. There are many other radionuclides that are important in the first few months after a nuclear explosion if one eats food directly contaminated by the fallout. Although the latter radionuclides are not absorbed by the body, they can do great damage to the intestinal tract while they are passing through the body.

Iodine. There are some 11 isotopes of iodine that are produced in fission. All except I-129 which as a half-life of 1.6×10^7 years have shorter half lives than I-131.

Isotope	Half-life	Activity relative to I-131 24 hrs after thermal fission of U-235
I-131	8.05 days	1
I-132	2.3 hrs	3
I-133	20.8 hrs	9
I-135	6.7 hrs	5

Although I-132, I-133, and I-135 are more abundant initially, they result in lower doses thant I-131 because of their shorter half-lives. I-132 persists in appreciable amounts longer than its half-life would indicate, because it is produced mainly from tellurium-132 which has a half-life of 78 hours. The doses from and I-132 and I-133 can exceed I-131 near the explosion site for the first week. (R. J. Garner and R. Scott Russell, "Isotopes of iodine", in Radio-

activity and Human Diet, 1966.)

Iodine is readily absorbed through any moist skin or mucosal surface, and essentially all that is ingested is absorbed. The amount of radioiodine taken up by the thyroid is closely dependent on the dietary level of stable iodine, About 20% of the intake ends up in the thyroid. Most of the iodine in man is excreted via the urine, and its biological half-life is 2-4 months. The effective half-life is a little less than its physical half-life, 7.6 days. Iodine is actively concentrated in the thyroid, that means that the concentration in the thyroid is much higher than in plasma.

Since thyroid is relatively small, 20 g, it doesn't take much to damage the gland. The first type of damage is nodules, then cancers and if the dose has been extremely high, destruction of the tissue itself. The result of the last case is hypothyroidism. Radiation induced cancers are almost invariably less malignant than the usual type that aren't induced by radiation. It is, therefore, believed that radiation increases the number of cancers but does not increase mortality as a whole. (Diane G. Crocker, "Nuclear reactor accidents - the use of KI as a blocking agent against radioiodine uptake in the thyroid," Health Physics, 46:1265-1279, 1984.)

There is a lot of literature on I-131 as well as on potassium iodide (KI) as a means of preventing the uptake of radioiodine by the thyroid. The reason is that potentially there could be high releases of I-131 from nuclear power plant accidents. Windscale accident in England resulted in the withholding of milk from the market for a while. Initial exposure in such cases is from inhalation, but the subsequent dose from eating contaminated food is 400-700 times higher. The main source of I-131 in human diet is milk, partly because milk is consumed relatively fresh.

Both KI and potassium iodate (KIO_3) can be used to saturate the iodine uptake system of the thyroid. The advantage of KIO_3 is that it has a much longer shelf life,

up to 10 years, versus about 2 years for KI. Inside the body IO_3^- gets quickly converted to I^- and acts the same way as if originally it had been KI. About 130 mg of KI completely blocks radioiodine uptake for about 24 hours, 65 mg of KI is probably sufficient for children. It is most effective if given shortly before to 1-2 hours after exposure. The effectivenes of KI decreases rapidly with time after exposure, limited benefit is possible up to 12 hours after a single exposure. KI can be bought at drugstores without prescription in the U.S.

Unfortunately, there are side effects to taking large quantities of KI. It is only when the exposure level is 10 rem that the risk from radiation damage exceeds the risk from KI. In geriatric or coronary patients the hazard from KI might be greater than the radiation hazard under any circumstances. Asthmatics, chronic heart or renal failure patients, patients with hypocomplementemic vasculitis and autoimmune related diseases have reacted very severely to KI treatments. The fetus and the newborn are also susceptible to harmful effects. Unfortunately, this group is also more susceptible to the adverse effects of radioiodine. (Diane G. Crocker, ibid.)

The half-life of I-131 is too short for absorption from the soil or from the plant base to be major routes of entry into the food chain. The interval between grain harvesting and consumption is long enough that one doesn't have to worry about iodine. When iodine is deposited on leaves of plants, most of it is not absorbed. A lot of it can be washed of by rain or removed by mechanical processes. All of the above explains why a cow eating grass directly is the main entry route of iodine into the food chain. Levels of contamination in milk have frequently decreased more rapidly than the physical half-life of I-131. This is due to "field-loss" factor. In one case, the activity decreased by a factor of 2 in 2 weeks compared to the loss due to physical decay.

Fraction of ingested I-131 taken up by the thyroid can vary quite a bit but it is approximately 20% in cow as well as man. I-131 starts appearing in milk in 30 minutes and reaches maximum within 12 hours after a single exposure. The kind of conditions that would be true after a nuclear war, it would be 2-4 days after the start of fallout that it would reach the maximum concentration in milk. Both the cow's udder and the human breast concentrate iodine into milk in relation to the blood iodine level.

I-131 can also be incorporated into egg yolks in chickens on free range. After Windscale accident the activity of I-131 per egg averaged approximately 1/20 of that per litre of milk. (R. J. Garner and R. Scott Russell, ibid.)

If iodine were deposited in winter, the iodine hazard would be greatly reduced. The highest levels of contamination occur when the cows are grazing or are fed recently cut herbage. Contamination decreases markedly when stored food is substituted. From this it can be seen that the greatest danger would be right at the haying season. Previous year's stocks would have been exhausted and the next year's stocks wouldn't be in the barn yet.

Summary of the proposed protective measures:

1. Removal of lactating cows from pasturage-feeding system and substitution of stored feed rations. I-131 is reduced to insignificant levels in 3-4 days. The reverse is true if cows are placed on contaminated pasture. If cows were in and kept in when the fallout started, no problem would arise.
2. Withholding contaminated product to allow radioactive decay.
3. Supplying milk to areas of high contamination from areas where contamination is low.
4. Diverting contaminated milk into manufactured products and substituting processed milk, e.g., powdered or canned milk.
5. Storage of frozen fresh milk.

6. Storage of fresh concentrated milk.
7. Storage of frozen concentrated milk.
8. Physical removal of iodine-131 from milk with ion-exchange resin.

(Frank A. Todd, "Protecting foods and water against radioactive contamination," pp. 235-256, Protection of the Public in the Event of Radiation Accidents, World Health Organization, 1965.

All of the above, except #1, are completely dependent on the availability of electricity and transportation. Number one is partly dependent on transportation. If there was no electricity, the cows would not be milked. We don't have the personnel who know how to milk cows. So you could learn it in a day, but there is no way you could develop the strength in a short time to milk more than one cow. I called up the local dairy farmer to ask what they would do if there was no electricity. They have 40 cows and they would not be milked unless they obtained a generator. They have had to do that once in the past. Their milk goes down to Guelph, that is more than 100 km away. There are 2 small cheese plants that are a little closer, but she couldn't think of any milk processing plant that would be closer.

Strontium. There are two types of strontium (Sr). Sr-89 is important the first month and Sr-90 is important for a long time. Both emit only B rays.

$$\text{Strontium-90} \xrightarrow[28\ \text{years}]{B} \text{Yttrium-90} \xrightarrow[64\ \text{hours}]{B} \text{Zirconium-90 (Stable)}$$

$$\text{Strontium-89} \xrightarrow[50.5\ \text{days}]{B} \text{Yttrium-89 (Stable)}$$

Strontium is metabolized the same way as calcium (Ca). Strontium absorption, however, is discriminated against by body, compared to calcium absorption. Ratio of Sr/Ca in blood is 1/3 to 1/4 of what it is in diet . Mother's milk has half the Sr concentration in blood and the fetus

also has only half the concentration. The effective half-life in body is 50 days for Sr-89 and 17.5 years for Sr-90. (Cs also has a long half-life but its effective half-life in body is less than 100 days.) Its long effective-half life is what makes Sr-90 such a dangerous radionuclide.

Ratio of Sr to Ca in new bone is in equilibrium with body fluids. In other words, the amount of strontium that gets deposited in bone is dependent on the ratio of Sr/Ca in blood. Therefore, radiostrontium concentration is a lot of times expressed in terms of Ca concentration. The common units are pc of Sr/g of Ca or for milk pc Sr/l.

The main source of strontium in a western diet is dairy products. But that doesn't give the whole picture. As explained above, strontium absorption depends on the level of calcium and dairy products are also the major source of calcium in western diets. It might look like elimination of dairy products would improve the situation but the reverse would be true. More vegetables would be consumed and there the ratio of Sr/Ca is much higher. Third world countries got twice the amount of strontium in their diets compared to that of the western countries. The following table of contribution of various foods to Sr-90 in population of N.Y. City illustrates the differences in calcium levels and their subsequent effect.

Food	pc/yr	% total intake	
		Ca	Sr-90
Dairy products	2080	58	38
Vegetables	1212	9	22
Fruits, fresh and canned	1192	3	22
Cereals and bakery products	588	20	11
Meat, poultry, eggs	178	8	3
Fish	5	2	-
Water	200	-	4

Radionuclides in Foods, p. 34, National Academy of Sciences, 1973.

In vegetables the strontium content can be reduced 19-55% by common home preparation. In canned fruit the reduction can even be higher compared to fresh fruit. The following are given as methods for reducing strontium intake. 1. Protection of packaged and stored foods.
2. Removal of surface contamination by washing and scrubbing of fruits and vegetables.
3. Removal of surface contamination by peeling.
4. Removal of internal contamination of food through processing.
5. Reduction of strontium-90 secretion into milk by supplementing rations of dairy cows with calcium.
6. Removal of radioactivity by use of such processes as ion-exchange, electrodialysis, or calcium phosphate treatment. Frank A. Todd, ibid. One important method Todd doesn't mention is milling of wheat. Whole wheat has twice the Sr/Ca than white flour.

There is a good discussion of remedial measures by C. L. Comar and J. C. Thompson, Jr. with emphasis on "certain aspects of feasible large-scale measures" in Survival of Food Crops and Livestock in the Event of Nuclear War, 1970, "Status of remedial measures against environmental radiocontamination".

The plant root makes little distinction between Ca and Sr if they are in the same chemical form. Soluble Ca in the soil acts as a diluent for the Sr - the amount of calcium in soil is important. Generally good agricultural soils result in lower Sr content in food. Strontium deposited on the plants may be trapped and absorbed through those parts of the plant which are above the ground. The amount that is so trapped depends on the form of the plants, it is usually considerable in grasses. Again, a cow comes along and picks it all up, the absorbed and the unabsorbed Sr. Luckily, there is discrimination against strontium relative to calcium by a factor of about 10 which occurs in the transfer of the two elements from the diet of cattle to milk.

Cesium. Cesium (Cs)-137 is the third most dangerous radionuclide that enters very quickly the human food chain after a nuclear fallout. It is an alkali metal like potassium (K) and its behaviour in nature as well as the human body is similar to that of potassium. The relationship between the two, although, is not as close as between Sr and Ca. The decay scheme of Cs-137 is shown below.

$$\text{Cs-137} \xrightarrow[\beta]{30\ \text{yrs.}} \text{Barium-137} \xrightarrow[\gamma]{2.57\ \text{min.}} \underset{\text{(Stable)}}{\text{Barium-137}}$$

Cesium is around in the environment for a long time, its half-life is 30 years. Quite commonly Cs is referred to as a γ source. Thechnically this is not correct. Cs decays by a β emission to Ba-137 which has a half-life of only 2.57 min. when it decays by a γ emission to a stable form of Ba. Its "daughter", however, has such a short half-life that Cs is ordinarily identified by γ spectometry of the γ emission of its daughter. Cs is more common in fallout than Sr by 1.3 to 1.7.

Cesium is freely absorbed from the human intestinal tract and appears to have an average stay of 4 months. Compared to other radionuclides, it is distributed fairly uniformly over the body. The human body content of Cs-137 is closely related to the level of it in the diet. It is absorbed preferentially to potassium. The ratio of Cs-137/gK is 3 times higher in body than in food. In animal studies one has to take 9 times the normal level of K to cut Cs-137 level by half. L. Fredriksson, R. J. Garner and R. Scott Russell , "Caesium-137", in Radioactivity and Human Diet, 1966.

Sources of Cs in human food:

Cows milk 30% or 25-40%
Grain products 25% or 17-30%
Meat 20% or 12-26%
Fruit 10% or 15%
Vegetables 10% or 15%
Fish important where it forms a large part of diet.

The two sets of figures just given are from two different sources. They indicate that cesium is distributed relatively evenly among the different food groups.

Because cesium has volatile precursors, a lot of it ends up in stratosphere. Very roughly its mean time in stratosphere is 2 years. As it falls down, it is deposited on any growing vegetation. Most of the Cs that enters the food chain is absorbed by the plants directly and not from soil after it has been washed down. The heaviest fallout occurs in spring because most of the mixing between stratosphere and troposhere occurs during late winter. Areas with higher rainfall can reeeive twice as much fallout.

Cesium is readily absorbed by clay particles in soil. It is held tightly enough that only a few per cent of Cs-137 in soil is taken up through the roots of plants. Sandy soils and especially soils with a high content of organic matter bind Cs less effectively. Plants grown on these soils have higher Cs-137 content. Most of the Cs contained in the edible parts of vegetables is due to deposition of particulate material on leaves.

Under certain conditions, Cs can undergo considerable concentration in terrestrial and aquatic food chains. Freshwater fish have been shown to contain it in concentrations several thousand times higher than the concentration in their surroundings. Fish feed on lower aquatic organisms which have already concentrated it above the levels present in water. Shellfish do the same thing. Cesium is effectively trapped and retained by the lichen and moss of the tundra, which are major sources of food for caribou and reindeer. Caribou flesh contained up to 100 times the quantities found in meat in mid latitudes.

Once fallout has stopped Cs becomes trapped in the top 2 cm of soil. External radiation from it would continue for many years. Its greatest danger is considered to be genetically.

Carbon-14. Most of the carbon(C)-14 is released into the stratosphere, from where it equilibrated with the troposphere with a half-time of about 2 years. Tissue C-14 comes into equilibrium with C-14 in the atmosphere with a delay time of about 1.4 years. The retention half-time of dietary carbon in mammals is estimated to be about 40 days. Like tritium, carbon 14 is highly mobile in the environment and no one can do anything about it.

Tritium. Tritium is radioactive hydrogen. Less than 1% of tritium becomes part of the water molecule but it is in this form that it passes through the eco-systems. It behaves identically to ordinary water. It is highly mobile in the environment and very quickly equilibriates in the different systems.

Iron-55. Two pathways are known for the concentration of iron (Fe)-55. Lichen-caribou pathway is important for Eskimos and Lapps. The second source is marine fish. The marine food chain concentrates Fe-55 even more than than the first pathway. The reason for this is the low concentration of stable iron in sea water.

Half-life of Fe-55 in lichens is 1.4 years.

Erythrocyte is considered to be the critical organ.

Ruthenium-106. Ruthenium is known to have accumulated in at leat one known food chain. A seaweed in Irish sea that is used by some people in making bread. Critical organ for this case is the lower large intestine. Some people got as much as half the yearly dose limit of rems/yr for lower intestine during the Windscale accident.

METHODS OF MEASUREMENT

There is a lot of literature on the measurement of Sr-89 and -90, I-131 and cs-137 in the environment and in food. Scientists have been doing it all over the world as the result of the atomic bomb tests in the fifties and the first part of the sixties. The most comphrehensive references are: Esther Ferri, Paul J. Magno and Lloyd R. Setter, Radionuclide analysis of large numbers of food and water samples, U.S. Dept. Health, Education, and Welfare, 1965. National Center for Radiological Health, Radioassay Procedures for Environmental Samples, U.S. Dept. of Health, Education, and Welfare, 1967. Manual of Standard Procedures, NYO-4700, Health and Safety Laboratory, U.S. Atomic Energy Commission, New York Operations Office. The above do give details for the procedures but are designed for quantities much smaller than what one would be measuring after a nuclear war. They require highly skilled personnel and very sophisticated equipment.

E. R. Mercer ("Analytical Methods" in Radioactivity in Human Diet, ed. R. Scott Russell, 1966.) has a short but clear revue of the above methods. He says that in emergencies, when much higher levels of contamination than normal will be acceptable, much simpler analytical methods are adequate. Unfortunately he doesn't describe them. This happens quite a few times, they aren't desribed because they are obvious to people who work with radioactivity but not so obvious for a person who doesn't have any experience using different radiation detection instruments or measuring mixtures of different radionuclides. He does make a few relevant comments in passing. If Cs-137 exceeds 300 pc/l in milk, it can be measured directly in a sodium iodide (NaI) crystal scintillation counter. Gamma spectrometric measurement of I-131 can also be done directly on whole milk if the level is high enough. Cesium and iodine can also interfere with each other.

Strontium assays are very complicated, numerous radiochemical separations have to be done. Usually Sr-90 is

calculated from the amount of its daughter yttrium-90 (Sr-90 decays to Y-90) and Sr-89 is determined by the difference.

Daniel A. Gollnick does give a simple method for analyzing milk (Experimental radiological health physics, 1978). Since the ratio of Cs-137 to each of the Sr isotopes is a fixed constant at the time when fission takes place, the strontium concentrations can be calculated from the cesium concentration.

$$\frac{\text{Cs-137}}{\text{Sr-90}} = 5 \qquad \frac{\text{Cs-137}}{\text{Sr-89}} = 0.03$$

First of all, these formulas are for milk, in the fallout Cs-137 to Sr-90 ratio is about 1.6. Second, Sr-89 has a relatively short half-life compared to Cs-137, so the ratio changes with time, it has to be doubled every 51 days after the fissions have occurred. Cs-137 and Sr-90 have similar enough half-lives that the change with time can be ignored.

The milk is passed through an anion exchange resin. I-131, being the only anion in the group of 4 we are interested in, is retained on the resin and everything else passes through. Resin is transferred to a bottle that is counted in a solid scintillation counter. The result is calculated from a known I-131 sample that has been treated the same way. The strontium isotopes are pure beta emitters, therefore, the effluent can be poured into a beaker that fits into a NaI counter and counted for gamma emissions from cesium. The result is compared to a known amount of Cs-137 under the same conditions. The cesium value is used in the formulas given above to calculate the amounts of the two different strontiums.

Gollnick also gives a very useful table of what would be the dose committment from milk, given a level of activity in milk when it is at the highest (2-4 days after the event). See next page. There must be, however, some mistake in rads for Sr-89. If it is 3 rads in the first year, there is no way with its short half-life it can give 2 more rads

in subsequent years.

Radionuclide	RADS	Max. conc. in milk uc/l
Sr-89	3 in 1st yr, 5 total	1.1
Sr-90	3 in 1st yr, 5 total	0.05
I-131	10	0.07
Cs-137	3 in 1st yr, 5 total	0.72

The above is the sort of approach, that I think would be taken, if there were a nuclear holocaust. There are different models for predicting dose committment from the level of fallout. R. Scott Russel, B. O. Bartlett, and R. S. Bruce, "The significanceof long-lived nuclides after a nuclear war," in Survival of Food Crops and Livestock in the Event of Nuclear War, 1970. A. Aarkrog, "Prediction models for Strontium-90 and Caesium-137 Levels in the Human Food Chain", Health Physics, 20:297-311, 1971. W. F. Lengeman has many papers on prediction models. The measurement would be done from an airplane or for more detail from a car. A. C. Chamberlain, R. J. Garner and D. Williams, "Environmental monitoring after accidental deposition of radioactivity," React. Sci. Technology, 14:155-167, 1961.

There are some references that sound good but are not easily available. Guidance on Offsite Emergency Radiation Measurement Systems, Phase 2: The Milk Pathway, B. J. Salmonson, L. G. Hoffman, R. J. Honkus, and J. H. Keller, Westinghouse Idaho Nuclear Company, Inc., WINCO-1009, April 1984. Also by the same people, company and title but a different subtitile: Phase 3: Water and Non-Dairy Food Pathway, WINCO-1012, October 1984. I wanted to send for these two papers but I couldn't find Westinghouse Idaho Nuclear Co. listed in any of the industrial indexes. The closest I could get is that Westinghouse does have a subsidiary called Bettis Atomic Power Lab, Idaho Falls, Idaho (1-208-526-0111). It could be the same company.

Daniel A. Gollnick also has a book out Basic Radiation

Protection Technology, Pacific Radiation Press, 1983.
It isn't available in Toronto. It might have the type of information we are interested in because it has been referred to in places where the concern has been nuclear war.

LACK OF STANDARDS AND MPD

Currently there aren't any guide lines for intake of radioactive material under the conditions of a nuclear war. The main reason for this is that radioactivity in food is not regarded as a priority in an event of a nuclear war.

"Eating food produced in the years after a large attack would cause an increase in the cancer rate... this increase would be a small fraction of the number of additional cancer deaths that would result from external radiation." Cresson H. Kearney, Nuclear War Survival Skills, p. 65, 1980.

Most vegetables would be fit to eat once they had been thoroughly washed. When it is safe to work outside, can plant new crops - they will be safe to eat. Ivan Tyrell, The survival Option, A guide to living through nuclear war, 1982.

"Standing crops in the early stages of growth are damaged by radiation but otherwise are safe to eat if washed clean of dust." p. 105. "Lack of food and water will cause starvation and death of many millions, especially the young and old." p. 115. Diane Diacon, Residential Housing and Nuclear Attack, 1984. The latter two books are English and I don't know anything about the credentials of their authors. The quotes that follow are by R. Scott Russell, unquestionably one of the world authorities on strontium and cesium in fallout and their biological pathways.

"In short, the total deaths caused by long-lived nuclides seem broadly comparable to the annual traffic death rate." (Incidentally, the figures for lung cancer from smoking are higher than traffic fatalities.) "Thus, by the standards the community now accepts, remedial action against the risks from long-lived nuclides would not seem justified; The number of casualties would be so small relative to the total loss and the difficulty of avoiding them would be so great that remedial action could not

reasonably be contemplated." "...efforts to mitigate doses from radiation should be devoted solely to the early period when short-lived nuclides predominate." R. Scott Russell, B. Bartlett, and R. S. Bruce, "The significance of long-lived nuclides after a nuclear war," in Survival of Food Crops and Livestock in the Event of Nuclear War, 1970.

The maximum permissible doses (MPD) used now are based on the philosophy that any radiation is bad and the less the better. Dose limiting recommendations by the National Council on Radiation Protection (NCRP) are given in Table 6.1. The levels are very low, for general population, 0.17 rem/year. This is less than the natural background radiation in some places.

There certainly is awareness that maximum permissible doses are not what would be in effect after a nuclear holocaust. J. C. Thompson, Jr., R. A. Wentworth, and C. L. Comar ("Control of fallout contamination in the post-attack diet," in Survival of Food... see above) expressed the need for guidelines that respond to tolerance or survival levels of radioactivity rather than the minimum-exposure concept that is in effect now. They would like to have a "system of radiation-exposure priorities" that would become operational after a nuclear attack. They are aware of the irony that the larger the attack, the lower the priority of fallout considerations in food. "It would be poor operational procedure to initiate efforts to reduce dietary contamination from 10 R to 1 R when general external radiation levels were 100 R and a state of pestilence threatened."

The problem of lack of radiation protection standards designed for nuclear war conditions has been discussed by Lauriston S. Taylor in "Standards for radiation exposure management in accident or nuclear attack," a talk he has given at some recent symposium. (I don't have a complete reference, the paper was sent to me.) The same as J. C. Thompson et al, he recognizes that there can really be no fixed standards that can be applied to basically uncontrollable

Table 6.1. Dose-limiting recommendations of NCRP (1971).

Occupational exposure limits	
Whole body, gonads, lens of eye, red bone marrow	5 rem in any one year
Skin	15 rem in any one year
Hands	75 rem in any one year (25/qtr)
Forearms	30 rem in any one year (10/qtr)
Other organs, tissues and organ systems	15 rem in any one year (5/qtr)
Fertile women (with respect to fetus)	0.5 rem in gestation period
Dose limits for the public, or occasionally exposed individuals	
Individual or occasional	0.5 rem in any one year
Students	0.1 rem in any one year
Population dose limits	
Genetic	0.17 rem av. per year
Somatic	0.17 rem av. per year
Emergency dose limits—lifesaving	
Individual (older than 45 yr if possible)	100 rem
Hands and forearms	200 rem, additional (300 rem total)
Emergency dose limits—less urgent	
Individual	25 rem
Hands and forearms	100 rem, total
Family of radioactive patients	
Individual (under 45 yr)	0.5 rem in any one year
Individual (over 45 yr)	5 rem in any one year

Source: NCRP, 1971, Table 6.

radiation situations. The best that we have are what is called "penalty tables". The following is based on brief, whole body gamma-ray doses:

Dose	Need Medical Care	Able to Work	Die
15-50 R	no	yes	0
50-200 R	no	yes	<5%
200-400 R	yes	no	<50%
450-600 R	yes	no	>50%
600- R	yes	no	100%

The above is the kind of data that is available but that is not what the situation would be after a nuclear war. There would be a long period of high radiation level followed by even longer period of moderate radiation levels. The following table is a little more useful:

Category	Need Medical Care	Accumulated Exposure in: 1 week	1 month	4 months
A	None	150 R	200 R	300 R
B	Some (5% die)	250 R	350 R	500 R
C	Most (50% die)	450 R	600 R	--

Lauriston S. Taylor, ibid.

There is very little information on chronic exposures that scientists could use to develop emergency standards. Needless to say, there is even less information on continuous internal intake of low or large amonts of radioactivity (the only exception is the radium dial painters). Japan did not have any early fallout in 1945. From the Japanese data and past medical uses of radioactivity it is known how many people would get leukemia and other cancers if a certain number of people would be exposed to a certain level of radiation. From this is derived a linear dose-effect relationship without a threshold. Both NCRP and ICRP (International Commission for Radiological Protection) work on assumption that there is no threshold dose of ionizing radiation below which there is no damage. The dose

effects are assumed to be additive. Taylor does not think it would be true for long range, low or moderate level chronic exposures. Too many theoretically dead persons are still walking around, as he puts it. There are many people who have been working for years within the maximum permissible dose limits for radiation workers. None of them have had any effects of practical importance. He feels the limits could be 10 times or more higher before there would be any detectable consequences. Taylor blames the lack of war time radiation guidelines on the media and the public. He feels that the news media have so over-exploited radiation matters that the public is truly frightened of any radiation exposure. "This makes the presentation and public acceptance of any kind of emergency planning extremely difficult." (There is an analogous phenomenon going on right now. 130 people have died so far from AIDS in Canada. At the same time 4000/yr. die in car accidents, plus many more permanently crippled. Half of the latter are caused by alcohol. Yet the public accepts one but is panic stricken of the other.)

Maximum permissible body burdens, plus all the other dose limits have been developed by the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection (NCRP). The body burden of a particular radioactive nuclide is the amount of the nuclide in uc which is present in an individuals body. The maximum permissible body burden is the body burden of a particular radioactive nuclide which results in a MPD (Maximum permissible doses that have been developed for external exposure) to the whole body or to one or more organs in the body. It is computed on the basis that it is the only one in the body. The maximum permissible body burden for a radionuclide of a bone seeking element (e.g. strontium, calcium, radium and plutonium) is the number of uc required to deliver to the bone a dose in rems equal to that provided by 0.1 uc of radium-226. Body burdens

for radionuclides other than bone seekers require the identification of "critical organ" (the organ which is the most sensitive or has the highest concentration). For a nuclide with the whole body as the "critical organ", the maximum permissible body burden for occupational exposure is the activity present continuously in the body which delivers a dose equivalent of 5 rem/year to the whole body. Nuclides which concentrate in abdominal organs are given limiting body burdens which provide 15 rem/year. (Kedar N. Prasad, CRC Handbook of Radiobiology, p. 241, 1984.)

Maximum permissible body burdens and maximum permissible concentrations of radionuclides in water for occupational exposures are given in ICRP publications (for references see Radiation Protection by Jacob Shapiro, 1981. The following values for the radionuclides that enter the food chain as a result of a nuclear fallout are from Radiological Health Handbook, U. S. Dept. Health, Education and Welfare, p. 207, 1970.

Radionuclide	Critical organ	Body burden uc	MPC water continuous intake uc/cc
Sr-89	Bone	4	10^{-4}
Sr-90	Bone	2	10^{-6}
Cs-137	Total body	30	2×10^{-4}
I-131	Thyroid	0.7	2×10^{-5}

Given equal concentrations, Sr-90 is 100 times more dangerous than Sr-89. The differences can even be higher, radium-226 is 10,000 times more dangerous than tritium.

ICRP Publ. 2 Report of Committee II Permissible Dose for Internal Radiation, Pergamon Press, p. 23-27, 1959 talks about permissible concentration of unidentified radionuclides, mixtures of known radionuclides and some of the problems one would run into if one tried to apply the occupational MPC for water to fallout in water and food.

Assuming Taylor was right that the external doses could be raised 10 times without much danger, the same thing would also apply here. Iodine and strontium -89 could still be increased by much more because of their short half-lives. The figures given were for continuous intake for 40 years. Although one can take in 100 times more Sr-89 than Sr-90, it initially occurs in 180 times the greater concentration than Sr-90. That is why initially it is the more important. Its half life is 51 days and after that Sr-90 becomes the most important contaminant. Unfortunately, strontium is the hardest to measure.

EMERGENCY SCHEMES

The only permissible emergency levels of radioactivity in food and water for civilisns were put out by the United States Agricultural Research Service in 1960, USDA Radiological Training Manual for Inservice Training. This procedure was still recommended by the U. S. Dept. of Health, Education and Welfare in 1965, Civil Defense information for food and drug officials. I haven't come across anything that would have replaced this procedure.

There is a food and water standard (CDV-787) that is placed in a standard tin. A Geiger-Mueller counter is placed on top of the tin and a reading is taken, should be in 10 to 15 mr/hr area. The tin is filled with food or water when an unknown is tested. Anything below the standard reading is fit for a 10 day consumption. Anything below 2/3 of the standard reading is fit for 30 day consumption period. The values that they represent are 9×10^{-2}uc/g and 3×10^{-2}uc/g for 10 and 30 day consumption periods respectively.

There is a more extensive emergency scheme by J. D. Teresi and C. L. Newcombe, "Calculations of maximum permissible concentrations of radioactive fallout in water and air based upon military exposure criteria," Health Physics 4:275-288, 1961. Although this is for water, I think it would also be applicable to directly contaminated food. Permissible levels for food and water are always the same in literature. It would not be applicable to food grown on contaminated soil. Their figures are based on the 14 major contributors in the fallout mixture. This is subdivided in 3 groups: major contributors for the first 7 days, major contributors for 8-104 days and major contributors for 105-365 days after the explosion.

On this basis they calculate the allowable ug/cm^3

to give 15 rem in 90 days, eaten in 7 different time spans, from 1 to 90 days and starting at 11 different times after time 0, from 3.5 hrs to 365 days. See their Table 6 on next page. They do the same thing for 150 rems in 30 days. See their Table 7. The tables can be used to get values for any other dose e.g., if you want 75 rem dose in 30 days, divide the value by half. They don't say what standard would be used to determine ug/cm^3 . I am concerned that the data on which they based their calculations would be outdated. They submitted their paper for puablication Nov 1959. The atomic weapons have changed since that time - the fission products would not be in the same proportions now. For example, cesium is not mentioned. There would also be a better idea of the biological effect of some of these radionuclides in 1985.

There are two other methods for emergency monitoring of drinking water. G.W.C. Tait and W. F. Merritt, "Emergency monitoring of drinking water", Health Physics 1:164-168, 1958. See their Table 5.

Dept. of National Health and Welfare (Ottawa), Control of radioactive fallout in water systems, 1965, have presented Teresi and Newcombe's 90 day scheme in form of a graph. Whatever the time after explosion, up to a year, one can read off the values for water contamination that would deliver 15 rems in 90 days. They also give a number of handy approximations to know. Curies of beta particle radioactivity = 2 x curies of gamma ray radioactivity for the first 3 months (p.7). One day following a nuclear detonation: curies of gamma radioactivity per sq. ft. = roentgens/hr divided by 100 (p.81).

Teresi and Newcombe, 1961

*Table 6. Maximum permissible concentration ($\mu c/cm^3$) in water and air of radioactive fallout for seven exposure times (n) at eleven different times after burst to deliver a dose to the critical organ of 15 rems in 90 days (t)**

n	Exposure	Time after fission										
		3.5 hr	12 hr	1 day	2 days	4 days	7 days	14 days	28 days	105 days	210 days	365 days
1	Ing.	2.5	0.81	0.48	0.29	0.18	0.13	6.9×10^{-2}	7.1×10^{-2}	0.10	0.10	8.7×10^{-2}
	Inh.	3.7×10^{-4}	1.2×10^{-4}	6.9×10^{-5}	4.0×10^{-5}	2.4×10^{-5}	1.7×10^{-5}	8.2×10^{-6}	6.9×10^{-6}	6.4×10^{-6}	6.0×10^{-6}	5.7×10^{-6}
7	Ing.	0.54	0.18	0.10	5.8×10^{-2}	3.6×10^{-2}	2.4×10^{-2}	1.2×10^{-2}	1.2×10^{-2}	1.5×10^{-2}	1.4×10^{-2}	1.3×10^{-2}
	Inh.	7.7×10^{-5}	2.5×10^{-5}	1.4×10^{-5}	7.4×10^{-6}	4.5×10^{-6}	2.7×10^{-6}	1.2×10^{-6}	2.0×10^{-7}	7.0×10^{-7}	6.3×10^{-7}	6.5×10^{-7}
14	Ing.	0.37	0.12	6.9×10^{-2}	3.9×10^{-2}	2.4×10^{-2}	1.5×10^{-2}	7.6×10^{-3}	7.1×10^{-3}	8.3×10^{-3}	7.7×10^{-3}	6.4×10^{-3}
	Inh.	5.0×10^{-5}	1.8×10^{-5}	9.0×10^{-6}	5.0×10^{-6}	3.0×10^{-6}	1.8×10^{-6}	8.1×10^{-7}	6.1×10^{-7}	4.6×10^{-7}	4.3×10^{-7}	4.0×10^{-7}
21	Ing.	0.32	0.11	5.9×10^{-2}	3.3×10^{-2}	2.0×10^{-2}	1.3×10^{-2}	5.8×10^{-3}	5.4×10^{-3}	5.7×10^{-3}	5.5×10^{-3}	4.5×10^{-3}
	Inh.	4.4×10^{-5}	1.4×10^{-5}	7.7×10^{-6}	4.2×10^{-6}	2.4×10^{-6}	1.5×10^{-6}	6.2×10^{-7}	4.7×10^{-7}	3.4×10^{-7}	3.1×10^{-7}	2.8×10^{-7}
30	Ing.	0.29	9.7×10^{-2}	5.4×10^{-2}	2.6×10^{-2}	1.8×10^{-2}	1.1×10^{-2}	5.3×10^{-3}	4.5×10^{-3}	4.4×10^{-3}	4.1×10^{-3}	3.3×10^{-3}
	Inh.	3.7×10^{-5}	1.2×10^{-5}	6.7×10^{-6}	3.2×10^{-6}	2.1×10^{-6}	1.2×10^{-6}	4.9×10^{-7}	3.6×10^{-7}	2.5×10^{-7}	2.3×10^{-7}	2.0×10^{-7}
60	Ing.	0.25	8.3×10^{-2}	4.6×10^{-2}	2.5×10^{-2}	1.5×10^{-2}	9.8×10^{-3}	4.3×10^{-3}	3.3×10^{-3}	2.7×10^{-3}	2.4×10^{-3}	1.8×10^{-3}
	Inh.	3.2×10^{-5}	1.0×10^{-5}	5.4×10^{-6}	2.9×10^{-6}	1.7×10^{-6}	1.1×10^{-6}	3.7×10^{-7}	2.6×10^{-7}	1.7×10^{-7}	1.5×10^{-7}	1.4×10^{-7}
90	Ing.	0.24	8.0×10^{-2}	4.4×10^{-2}	2.4×10^{-2}	1.4×10^{-2}	9.2×10^{-3}	3.8×10^{-3}	2.9×10^{-3}	2.1×10^{-3}	1.7×10^{-3}	1.3×10^{-3}
	Inh.	3.1×10^{-5}	1.0×10^{-5}	5.4×10^{-6}	2.9×10^{-6}	1.7×10^{-6}	9.7×10^{-7}	3.6×10^{-7}	2.4×10^{-7}	1.5×10^{-7}	1.3×10^{-7}	1.2×10^{-7}

* Ing. = ingestion; Inh. = inhalation.

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Teleri at November, 1961

Table 7. Maximum permissible concentration ($\mu c/cm^3$) in water and air of radioactive fallout for five exposure times (n) at eleven different times after burst to deliver a dose to the critical organ of 150 rems *in* 30 days (t)

n	Exposure*	Time after fission										
		3.5 hr	12 hr	1 day	2 days	4 days	7 days	14 days	28 days	105 days	210 days	365 days
1	Ing.	27	8.5	5.1	3.0	2.0	1.4	0.78	0.83	1.2	1.3	1.1
	Inh.	4.1×10^{-3}	1.3×10^{-3}	7.7×10^{-4}	4.5×10^{-4}	2.8×10^{-4}	1.9×10^{-4}	1.0×10^{-4}	9.8×10^{-5}	1.2×10^{-4}	1.2×10^{-4}	1.2×10^{-4}
7	Ing.	5.9	1.9	1.1	0.63	0.40	0.26	0.14	0.14	0.18	0.19	0.15
	Inh.	8.6×10^{-4}	2.8×10^{-4}	1.3×10^{-4}	8.0×10^{-5}	5.6×10^{-5}	3.7×10^{-5}	1.8×10^{-5}	1.7×10^{-5}	2.0×10^{-5}	2.0×10^{-5}	1.9×10^{-5}
14	Ing.	4.3	1.4	0.78	0.43	0.27	0.18	8.8×10^{-2}	8.7×10^{-2}	0.12	0.10	7.9×10^{-2}
	Inh.	7.2×10^{-4}	2.3×10^{-4}	1.3×10^{-4}	6.3×10^{-5}	3.8×10^{-5}	2.5×10^{-5}	1.1×10^{-5}	1.0×10^{-5}	1.1×10^{-5}	1.1×10^{-5}	1.0×10
21	Ing.	3.7	1.2	0.67	0.38	0.23	0.15	7.3×10^{-2}	6.8×10^{-2}	8.1×10^{-2}	6.6×10^{-2}	5.2×10^{-2}
	Inh.	5.4×10^{-4}	1.8×10^{-4}	9.7×10^{-5}	5.5×10^{-5}	3.3×10^{-5}	2.0×10^{-5}	9.8×10^{-6}	8.6×10^{-6}	8.9×10^{-6}	8.6×10^{-6}	8.7×10^{-6}
30	Ing.	3.6	1.1	0.62	0.34	0.21	0.14	6.8×10^{-2}	6.0×10^{-2}	6.3×10^{-2}	5.1×10^{-2}	3.8×10^{-2}
	Inh.	5.4×10^{-4}	1.7×10^{-4}	8.4×10^{-5}	5.3×10^{-5}	2.8×10^{-5}	2.0×10^{-5}	9.2×10^{-6}	7.9×10^{-6}	7.7×10^{-6}	7.1×10^{-6}	6.4×10^{-6}

* Ing. = ingestion; Inh. = inhalation.

Table 5. γ-Field measurements (mr/hr) *for maximum permissible water contamination*

This table applies to any fresh fallout contamination and is for 10 day consumption. Values should be halved for 30 day consumption.

Water body	*Time since bomb burst*			
	12 hr	1 day	2 days	10 days
Reservoir or lake, measured far from shore	100	50	25	12
Reservoir, pond, etc., measured at arms length from shore, close to surface and over water at least 2 ft. deep	50	25	12	6
Water tank, from 150 to 1000 gal measured in contact with center of one surface	50	25	12	6
Water can, from 2 to 4 gal	25	12	6	3

G.W.C TAIT and W.F. Merritt
1958