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Discussion of Questions by Senator Gravel

Question 1

It seems that the AEC is responsible only for the dilution of contaminants, but that no one is responsible for controlling or even for keeping track of the total amounts of radioactivity created and released to the environment.

Is this true?
Does anyone know to what extent man-made radioactivity has already contaminated this planet?
Is there an inventory of the total number of curies from all sources and for all purposes?
Can anyone estimate, for instance, how many curies were created by Americans in 1968?

Answer

Under the Atomic Energy Act of 1954, as amended, the Atomic Energy Commission is responsible for assuring that all of its activities are carried out in such a way that the health and safety of the public is protected. The Act provides that the Commission shall regulate the possession, use and transfer of source, byproduct and special nuclear materials and the construction and operation of nuclear facilities (such as nuclear power reactors and irradiated fuel reprocessing plants), in accordance with safety standards established by rule, regulation or order of the Commission. The Act prohibits the possession, use and transfer of such materials except as authorized by license issued by the Commission or by exemption from licensing requirements.

AEC regulations governing the issuance of a license to possess, use and transfer byproduct material are set forth in 10 CFR Parts 30-36; for source material and Part 40; for special nuclear material Part 70 and for nuclear facilities Part 50. Licensees are subject not only to safety requirements set forth in their licenses but also to general health and safety

standards, limits on releases of radioactivity in liquid and gaseous effluents, precautionary procedures, waste disposal requirements and recordkeeping and reporting requirements set forth in 10 CFR Part 20, "Standards for Protection Against Radiation". Atomic energy activities carried out by the Commission and its contractors are also subject to comparable health and safety requirements and rules. In reference, then, to the first part of the statement in Question 1, the Atomic Energy Commission is responsible for imposing whatever controls are necessary on atomic energy activities to protect public health and safety, including such limits on quantities of radioactivity that may be released to the environment as may be necessary.

Periodic evaluation of data on the overall radiological situation in the U. S. by the Federal Radiation Council and a similar evaluation on a worldwide basis by the United Nations Scientific Committee on the Effects of Atomic Radiation indicate that radioactive contamination from man's use of nuclear energy is much less than the radiation from naturally occurring radionuclides. All AEC sites and licensees carry out environmental radioactivity monitoring and related exposure evaluation as necessary to verify that population exposures resulting from their activities are within the standards. The scope and complexity of each program naturally varies with the nature of the site. In some cases, relatively simple monitoring is sufficient to verify that radioactivity content of effluents is well within appropriate limits at point of release. At other sites, highly sophisticated evaluation techniques have been developed to assure that exposure to peop e

in the environs, considering all possible sources, are within limits.

The AEC's Health and Safety Laboratory (HASL) conducts a radiological monitoring and surveillance program on a wide geographical scale and for a variety of components of the bioenvironment. Among the surveillance activities are: (1) worldwide deposition of strontium 90 (Precipitation) Program; (2) the radionuclides in surface air program, and high altitude balloon air sampling program; (3) the radiostrontium in milk and tapwater program; (4) the HASL diet studies; and (5) the program on concentrations of strontium-90 in human vertebra. The U. S. Public Health Service (USPHS) operates (1) a Pasteurized Milk Network consisting of 63 sampling stations, 61 of which are located in the U. S., one in Puerto Rico and one in the Canal Zone; and (2) the Radiation Alert Network (RAN) for routinely sampling air at ground level on filters, consisting of 73 stations throughout the U. S.. In addition to these routine network programs, the USPHS conducts periodic surveys for radioactivity in food and diet, and semiannual analysis of water for tritium at 10 surface water sampling stations in the U. S. Various other national and international health agencies also operate extensive programs to evaluate exposures to the public from the environment via air, water and diet sampling programs. The USPHS has also, as a matter of perspective, developed data on the very much larger exposures to the public from diagnostic and therapeutic medical exposures. Such exposures are largely from X-ray equipment not under AEC regulation.

There is no single inventory of the total number of curies that have been created from all sources for all purposes. While this could be collected, continuous surveillance of important areas of the bioenvironment

with particular attention to significant nuclides and critical pathways by which the various nuclides reach man is considered to be the best policy to pursue. There are about 200 radionuclides formed by the fission process. Fortunately for analysis, most of the radionuclides are of little health consequences because of their short radiological half-lives or other physical or chemical characteristics such as being highly insoluble. It is possible to estimate the radiation doses to various organs of the body primarily by considering 5 significant radionuclides that are deposited internally, i. e., iodine-131, strontium-90, cesium-137, carbon 14 and tritium.

Question 1A

Can the 1968 estimated total be subdivided into meaningful categories according to half-lives?

X curies of nuclides with half-lives of less than 1 day?
X curies with half-lives between 1-10 days?
X curies with half-lives between 10-365 days?
X curies with half-lives between 1-100 years?
X curies with half-lives between 100 and one million years?
X curies with half-lives over a million years?

Isn't such data essential in order to meet our future needs for containment and storage, to calculate the accumulation of uncontained nuclides, and to comprehend the ecological consequences, if any?

Answer

A curie is a unit of radioactivity and is defined as the quantity of any radioactive species in which 3.7×10^{10} nuclear disintegrations occur per second. However, the definition says nothing about the types of radiation given off or their biological effectiveness to cause injury to a biological system. Categorization by half-life is inadequate for hazards evaluation

since exposures to people depend not only on half-life but also the pathway of the radioactivity from the air or water into and out of the body and the effectiveness of the radiation given off. Further, there are many radionuclides formed in the fission process with a very short half-life (i. e., a few seconds, minutes or hours). The half-life is so short that it is not meaningful to relate half-life to exposure.

The problem with such categorizations is illustrated by the following Table of relative radiotoxicity taken in part from International Atomic Energy Agency (IAEA) documents. This radiotoxicity classification is based upon the radiological and biological half-life as well as other factors related to inhalation. The classification of radiotoxicity changes when the radionuclides enter man by other routes such as ingestion.

Table*

Radiotoxicity	Nuclide	Half-life	Grams per curie	Type of radiation
High	Plutonium-239	24,360 years	16.2	alpha
	Strontium-90	27.7 years	6.96×10^{-3}	beta, plus yttrium 90 gamma**
Medium upper	Iodine-131	8.08 days	8.06×10^{-6}	beta and gam
	Strontium-89	50.5 days	3.44×10^{-5}	beta, plus yttrium 89 gamma*
Medium lower	Phosphorous-32	14.22 days	3.49×10^{-6}	beta
	Iron-59	45.1 days	2.03×10^{-5}	beta
Low	Tritium	12.26 years	1.02×10^{-4}	beta
	Uranium-235	7.1×10^{8} years	4.65×10^{5}	alpha

*daughter products

Derived from IAEA Technical Report Series No. 15, A Basic Toxicity Classification of Radionuclides, 1963

With respect to storage, the inventory of radionuclides in a closed system, when added at a known rate, can be calculated from half-lives, but the hazards, as indicated above, cannot. Radioactive waste storage facilities must resist corrosion and handle any heat generated within the wastes. Their design thus require inventories of the specific radionuclides and data on the physical and chemical properties of the non-radioactive components of the wastes. An inventory categorization by half-lives would be neither essential nor adequate.

Question 1B

Can the 1968 estimated total be subdivided also into categories of initial location?

X curies without location; decayed 100% in less than 1 day.
X curies released into the air.
X curies released into the rivers.
X curies buried at sea (if any).
X curies dribbled into the ground.
X curies contained in tanks.
X curies solidified and stored.
X curies released directly into the oceans
X curies trapped underground in cavity glass.
X curies in underground water.
X curies buried in land.

Every curies has to be somewhere initially, and isn't some idea of initial disposition indispensable for ecological calculations?

Answer

The cited categories appear to be a mixture of places where radioactivity is stored indefinitely and places from which activity is released or where it is unconfined. However, in most AEC operations the initial location can be considered to be a nuclear reactor or the point of nuclear detonation. In reactors the radionuclide build-up over a period of time varies with the type of fuel and the half-life of specific radionuclides produced. Some

radionuclides (such as the radioiodines) reach an equilibrium condition where the rate of formation and rate of decay are approximately equal in a few days or a few weeks after start-up, while others (such as strontium 90) do not reach equilibrium during the normal fuel cycle. In fuel reprocessing plants the longer half-lived material is present and must be contained; however, the short-lived materials are soon below detectable levels. In regards to underground nuclear weapons tests, radionuclides from fissioning are formed simultaneously and then decay with their characteristic radioactive half-lives.

The value for "curies buried at sea" by the United States was zero in 1968. The three categories "contained in tanks","solidified and stored", and "trapped underground in cavity glass" contain almost all the curies in the totals.

Question 1C

Can the 1968 estimated total be broken down a third way: into categories of source?

X curies directly from reactor operation?
X curies from fuel reprocessing?
X curies from explosive fabrication?
X curies from Plowshare excavation tests?
X curies from Plowshare buried tests?
X curies from all military tests combined?
X curies from medical and industrial operations?
X curies of natural radionuclides liberated in fuel mining and in the burning of coal?

Isn't such data essential in order to match a particular benefit with its appropriate risk?

Answer

The intent of this categorization is not clear. For example, in the activities of nuclear reactors, large numbers of curies of radionuclides are generated but few curies are released. In underground nuclear tests, large numbers of curies of radionuclides are generated and remain buried forever. Fuel reprocessing operations generate none and release few, but store almost all of those generated by the reactors. Finally radionuclides used in medical and industrial operations are generated in a nuclear reactor and a certain small quantity is released to the environment.

The reference to "natural radionuclides liberated in fuel mining" is subject to several interpretations. It may refer either to underground uranium mining operations releasing radon and its daughters to the mining environment; or to the radioactive tailing residues from such mining operations; or to the natural radionuclides liberated in burning fossil fuels such as coal. If this refers to release of radon and its daughters in underground mining operations AEC is a purchaser of uranium oxide but does not have regulatory control over mining operations. Radon-222 and its daughters are released into the mine atmosphere during these operations and the unit concentration must be controlled through ventillation to protect uranium miners. Federal regulations require maintenance of records of the concentration of radon and its daughters in the underground work spaces. In the event of increased concentration above a stated level of radon and its daughters work will cease in the area until restoration to safe radiation levels for the miners to work. Radon in mines is primarily an occupational problem. If this refers to radioactive tailing residue from such operations,

the tailings are permanently stored at uranium mill sites. Air sampling has demonstrated that there is no health hazard to the population surrounding the mill sites. Stabilization of the tailings is required in Colorado, and other uranium milling states are considering such control. If this refers to the natural radionuclides liberated in burning fossil fuels the AEC does not have responsibility for measuring natural radionuclides released in this process.

Inventories of radionuclides by source do not bear a direct relationship to risk-vs-benefit balances. The inventory of radionuclides deeply buried underground following nuclear weapons test events must be considered as unavoidably associated with these events which are conducted as part of the U. S. national security program as were former weapons tests in the atmosphere. The risk of contamination of ground water is minimal since it is known that movement of ground water on the Nevada Test Site is very slow, i. e., it is believed to be significantly less than 100 feet per year. At this slow rate of movement, it would require several hundred years for the water to move to a point of known use as a public water supply. During this time radioactive decay continues. The potential dose commitment to the user would then be considerably lower than the guidance for radiation protection provided by the Federal Radiation Council. No Plowshare feasibility experiment is conducted until the AEC, through a series of safety studies in all known areas of the environment in which there could be problems of health and safety to the population, has assured itself that

there are adequate provisions for protection of the public.

Thus, there is no logical way to equate inventories of indefinitely-stored radioactive wastes with human exposures (potential risks). Even equating released inventories with human exposures requires many assumptions. Conversely, at the low exposure levels which are presently being observed in the environs, it may not be always possible to ascertain the relative contribution of different sources. Finally, and most important, the Federal Radiation Council never has attempted a "benefit-vs-risk" breakdown among different phases of the peaceful uses of nuclear energy, some of which are interrelated, such as power production and fuel reprocessing. This is due to the need to temper broad estimates of biological and other risks and of benefit with factors involving medical, social, economic, political and other considerations.

Question 1D

Can the 1968 estimated total be broken down a fourth way, into significant nuclides by name?

X curies of tritium?
X curies of carbon 14?
X curies of tungsten-187?
X curies of krypton-85?
X curies of "others"?

Isn't such data basic to the computation of consequent doses and ecological transfer?

Answer

Yes the nuclides can be broken down by name. As previously stated there are approximately 200 radionuclides created in the fissioning process but it is possible to estimate the radiation doses to the population primarily by considering 5 significant radionuclides that may be deposited internally. The latest values for the dose commitments for populations in the North Temperate Zone from nuclear tests carried out before 1968 are given in the following Table taken from a recent report of the United Nations Scientific Committee on the Effects of Atomic Radiation.

TABLE I. DOSE COMMITMENTS FROM NUCLEAR TESTS CARRIED OUT BEFORE 1968

Tissue	*Source of radiation*			*Dose commitments (mrad)*		
				North temperate zone	*South temperate zone*	*Whole world*
Gonads	External	Short-lived		36	8	23
		^{137}Cs		36	8	23
	Internal	^{137}Cs		21	4	21[a]
		^{14}C[b]		13	13	13
			Total[c]	110	33	80
Cells lining bone surfaces	External	Short-lived		36	8	23
		^{137}Cs		36	8	23
	Internal	^{90}Sr		130	28	130[a]
		^{137}Cs		21	4	21[a]
		^{14}C[b]		16	16	16
		^{89}Sr		<1	<1	<1
			Total[c]	240	66	220
Bone marrow	External	Short-lived		36	8	23
		^{137}Cs		36	8	23
	Internal	^{90}Sr		64	14	64[a]
		^{137}Cs		21	4	21[a]
		^{14}C[b]		13	13	13
		^{89}Sr		<1	<1	<1
			Total[c]	170	51	140

[a] The dose commitments due to internally deposited ^{90}Sr and ^{137}Cs given for the north temperate zone are considered to represent upper limits of the corresponding dose commitments to the world population.

[b] As in the 1964 and 1966 reports, only the doses accumulated up to year 2000 are given for ^{14}C; at that time, the doses from the other nuclides will have essentially been delivered in full. The total dose commitment to the gonads and bone marrow due to the ^{14}C from tests up to the end of 1967 is about 180 millirads and that to cell lining bone surface is about 230 millirads.

[c] Totals have been rounded off to two significant figures.

Several points can be made: a) these values are based on the collection of large amounts of data and highly refined interpretations of analytical nature, b) for comparison it should be noted that the dose from natural background radiation is about 120 mrads for a single year and about 5000 mrads for a comparative period of time (i. e., to year 2000), c) none of the other radionuclides dispersed in the fallout produced radiation doses anywhere near those indicated in the Table. However higher doses than these indicated in the table for external and internal (to year 2000) were sustained to the thyroid gland of some individuals during the time atmospheric nuclear testing was in progress but these dose commitments can only be estimated for local groups.

In respect to radioactive waste management, inventories of specific radionuclides are a basic tool, particularly for the large quantities involved in fuel reprocessing. The long-range planning for such reprocessing is based in part on highly complex computer codes for the generation of radionuclides under various parameters of reactor operation, combined with economics-based forecasts on the growth of the industry. This detailed breakdown is most useful in sizing and designing the reprocessing and waste storage facilities (for example, in evaluating heat output from stored wastes). In evaluating planned or accidental releases to water, the radionuclide curie values must be weighted according to potential dose contribution to be significant in terms of human exposure. For mixed fission products from fuels in general, strontium-90 will be the controlling radionuclide and precise breakdowns are not so important as in the storage design.

Environmental water analyses usually assume unidentified beta activity to be strontium-90 for this reason.

Comparable effort is devoted to predicting radionuclide yields from nuclear devices. For both nuclear devices and reactor fuel cycle activities, exposure estimates based on radionuclide releases are supplemented and verified by evaluations based on actual measurements.

Question 1E

If this data does not exist, even an estimate, do you think we ought to start keeping such inventories?

Answer

We do not feel that total inventories for all radionuclides need be kept. However, there are certain radionuclides for which inventories have been determined so that the information would be available for research or other investigative purposes. The present approach of careful surveillance of the environment and developing data in a meaningful manner to evaluate potential hazards to man is sufficient. If new and unusual potential problems present themselves, evaluations and procedures will be modified to meet the need.

As the nuclear power industry grows it will continue to be AEC policy to provide long-term storage for the high-level wastes at a relatively small number of Federal repositories. For design and planning purposes, it will become increasingly important to have inventories of these types of wastes at a central point.

Question 2

It seems that every American already carries a "body burden" of man-made radionuclides.

What is the present average American body-burden?
What fraction of it is from naturally occurring nuclides, and what fraction from man-made nuclides?

How does the total 1968 body-burden compare, numerically, with 1944? With 1951? With 1958? With 1963? Is this known data?

From currently known data, could anyone provide or assemble charts which would show American body-burdens of radioactive nuclides:

by year?
by area/region?
by age groups?
by source (Natural vs. man-made)?
by nuclide (e. g., potassium-40, tritium, carbon-14, radium-226)?

Won't such data kept up to date, be necessary in order to see the big picture and to assess future risks?

Is better understanding of low-dose radiation effects presently hampered by an insufficiency of historical data, or is sufficient data available to the scientific community?

Answer

The simplest approach to this question is to detail the body burdens for individual nuclides. These burdens can then be summarized on the basis of dose and compared with doses from natural radioactivity. Thus the reply to this question will show the amounts of individual nuclides in the body with an indication of how they vary by year, region and age.

The data presented are the results of continuing programs of measurements and it is expected that they will be kept up to date. The nuclides emphasized are those that are considered to present the greatest hazard

to man. Lesser programs are in effect to look at other nuclides, both natural and artificial, and these are only mentioned briefly.

Potassium-40 (Natural)

Potassium-40 is a natural component of the element potassium and its radioactivity amounts to about 800 pCi/gram of potassium. The average man contains approximately 140 grams of potassium, so there are about 100,000 pCi of potassium-40 in the body. The measurements of body potassium are very widespread because the data can be obtained when measuring whole-body cesium-137 from nuclear fallout. The potassium concentration, however, is controlled by the body and varies within narrow limits, as shown in the diagram. The total potassium content is proportional to the lean body weight. There is no variation with time or with geographical location. The average man with 140 grams of potassium in his body would be represented by the horizontal line in the diagram.

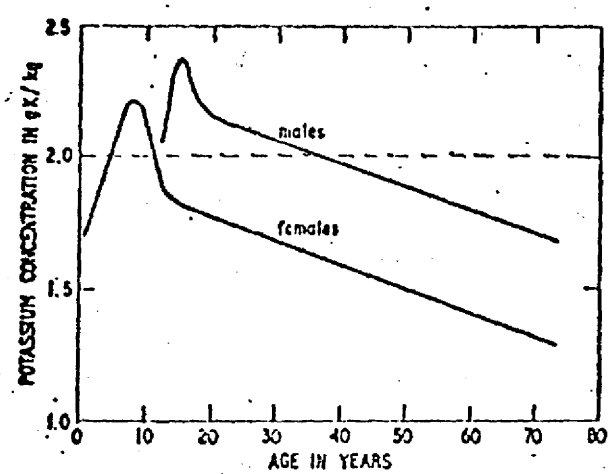

Diagram from Anderson and Langham, Science, 130, 713 (1959)

Tritium (Natural and Man-made)

Tritium (H-3) is produced in the atmosphere by cosmic rays. The natural level is about 16 pCi/liter of surface water, also expressed as 5 tritium units.

There are very few reported measurements of tritium in the body. The concentration of tritium in the body water follows the concentration of tritium in the environment and these latter measurements are readily available. The following table indicates the concentrations of tritium in precipitation for the one site with the longest history of measurement and the corresponding burdens of tritium that would be expected in man if the water is used for drinking.

Concentration of Tritium in Precipitation and Estimated Body Burden (Ottawa, Canada)

Year	Precipitation (Tritium Units)*	Precipitation pCi/liter**	Body Burden (Picocuries)
Natural Level - to 1952	5	16	700
1953	20	64	2,700
4	130	416	17,000
5	45	144	6,000
6	140	448	19,000
7	110	352	15,000
8	800	2,560	110,000
9	350	1,120	47,000
1960	140	448	19,000
1	180	576	24,000
2	900	2,880	120,000
3	3,000	9,600	400,000
4	1,600	5,120	200,000
5	900	2,880	120,000
6	500	1,600	67,000
7	400	1,280	54,000
8	200	640	27,000

*1 Tritium Unit equals 1 atom of tritium in 10^{18} atoms of hydrogen or 3.2 picocuries of tritium per liter of water.
**For convenience of comparison, and not included in original table.

Precipitation data from the Quarterly Health Physics Reports of Atomic Energy of Canada, Limited.

The source of the elevated tritium in this table is the thermonuclear testing carried out from 1952 through 1961. Tritium from the more recent thermonuclear tests has not yet appeared in precipitation samples.

There is some variation in the excretion pattern of tritium with age following a single exposure. This has no effect in the case of continuous exposure from the environment and the body burdens reflect the amount of body water times the concentration in the environment.

The geographical pattern of tritium in precipitation in the United States is available for 1963. The data are shown in the following table.

Tritium in Precipitation-United States, 1963 Average
(U. S. Geological Survey Data)

Palmer, Alaska	2950 Tritium Units
Menlo Park, Calif.	480
Salt Lake City	3670
Denver	3110
Albuquerque	1870
Lincoln, Neb.	2280
Madison, Wis.	2510
Bismark	4370
St. Louis	1560
Baton Rouge	830
Boston	1410
Washington	1130
Ocala, Fla.	620
San Juan	240

Data from Stewart and Hoffman, Geological Survey Circular 520 (1966)

Carbon-14 (Natural and Man-made)

Carbon-14 is produced in the atmosphere by cosmic-ray bombardment. The isotope has a long half-life (over 5000 years) and is mixed uniformly with the carbon compounds of living matter to give an activity of about 6 pCi/gram

of carbon. The C-14 produced in thermonuclear weapons testing is usually expressed as a percentage increase over the natural level.

The concentration of carbon-14 in the normal carbon compounds of the body follows any change in the concentration of carbon-14 in the environment with a time lag of one or two years. Thus there have been only a few measurements of carbon-14 in man and attention has been directed towards measurements in air. The following table shows the percentage of excess carbon-14 resulting from thermonuclear weapons testing. The data for 1968 are not yet available.

Inventory of C-14 in Tropospheric Air - Northern Hemisphere
(Data Abstracted from UNSCEAR Reports)

1956	5	% over normal
7	11	
8	16	
9	24	
1960	23	
1	25	
2	30	
3	65	
4	92	
5	90	
6	78	
7	65	

There is no indication of any variability in the concentration of carbon-14 with age or with geographical location over the United States.

Radium-226 (Natural)

Radium-226 in man comes largely from the diet except for a few locations where the water contains high concentrations of radium. Fairly extensive measurements on human bone are available for three cities, New York, San Francisco and San Juan. The respective values of radium are 35 pCi, 29 pCi

and 19 pCi in the adult whole body. Other measurements also seem to indicate that the range of body burden in the United States is only a factor of about 2. It should be noted that the concentration of radium in the body is independent of age, although the absolute body burden will increase with the growth of the skeleton.

More extensive measurements are available on the dietary intake of radium-226. These include data from the Health and Safety Laboratory for the three cities mentioned above and the Public Health Service for eleven other cities. These data are given as an illustration in the table below.

Radium-226 in Total Diet from 1964 to the Middle of 1967
(from December 1969, Radiological Health Data and Reports)

Sampling Location	Mean pCi/kg
Boston	0.52
Palmer, Alaska	.54
Chicago	.58
Idaho Falls	.58
Seattle	.61
Denver	.61
Cleveland	.62
Burlington, Vt.	.62
Honolulu	.64
Wilmington	.70
Pittsburgh	.73

Radium-226 in Total Diet in 1966
(Health and Safety Laboratory, AEC)

New York	0.91
San Francisco	.63
San Juan	1.0

The range of dietary intakes is also less than a factor of 2. Measurements from year to year are not necessary since the concentration of this

naturally occurring radionuclide in the environment does not change with time.

A smaller number of measurements of Ra-228 are made from time to time. The data are not listed here, but the estimated doses are given in the reply to Question 3.

Strontium-90 (Man-made)

Strontium-90 appears to have the greatest biological significance of the radionuclides produced in weapons tests. There have been many studies of its deposition and transfer through the food chain to man. A large number of bone samples are analyzed each year by the Atomic Energy Commission and the Bureau of Radiological Health. A summary of these measurements for 1958, 1963 and 1968 are given in the following table.

Mean Body Burden of Sr-90
United States

Age (years)	pCi in the Body 1958	1963	1968
0 - 4	260	540	420
5 - 19	600	1800	1900
over 19	200	1300	900

Since strontium-90 essentially did not exist in 1944 it could not have been present in the skeleton. Measurements were not made in 1951 but our knowledge of fallout and the transfer mechanisms mentioned above would indicate that the levels were below 100 pCi of strontium-90.

The uptake of strontium-90 is greater in children. This is apparent in the next table, which gives the concentration of Sr-90 rather than the body burden.

Mean Concentration of Sr-90 in Human Bone
United States

Age (years)	pCi/gram of Calcium 1958	1963	1968
0- 4	2.0	4.3	3.2
5 - 19	1.0	3.0	3.2
over 19	0.2	1.3	0.9

1958 and 1963 Data from UNSCEAR Reports.
1968 Data from Health and Safety Laboratory Reports.

The geographic variability is apparently only a factor of two from the mean. This should be less than the variability in fallout deposition itself, due to the wide distribution of many food products.

Cesium-137 (Man-made)

Continuing measurements of the whole body cesium-137 content of humans have been made in the states of California, Idaho, Illinois, Massachusetts, New Mexico, New York and Washington for many years. Additional measurements have also been made in other areas. Cesium-137 can be measured in living subjects with a whole-body counter, in contrast to the other radionuclides which can only be measured in autopsy material. The following table shows the average adult whole body burdens as estimated for the United States.

Mean Body Burden of Cs-137
United States

Year	Body Burden	
1953	280	picocuries
4	1000	
5	2000	
6	4400	
7	5100	
8	6400	
9	8000	
1960	6700	
1	4600	
2	6000	
3	11000	
4	19000	
5	16000	
6	9700	
7	5700	
8	3500	

Data from Gustafson and Miller, Health Physics 16, 167-83 (1969)

As in the case of strontium-90, Cs-137 did not exist in the environment in 1944. No measurements are available for 1951.

The variability with geographic location is similar to that for fallout in general and a factor of 2 would cover most areas. An exception is the small group of Eskimos living off a diet high in reindeer meat. Their body burdens are 50 to 100 times higher than the ones shown in the table. This is caused by the peculiar food chain of lichen-reindeer-man which transfers cesium-137 with great efficiency. It is of interest to note that lead-210, which represents natural fallout, is also concentrated in these individuals.

The body burdens of cesium-137 in children are uniformly less than adults in the same area due in part to the half-time of retention.

Polonium-210 (Natural)

Polonium-210 is a daughter of radon-222 and occurs naturally in the air. Human exposure, however, occurs largely through the food chain rather than by inhalation. The data are too scattered to present a tabulation of body burdens but UNSCEAR has assumed burdens of 200 pCi in soft tissue plus 200 pCi in the skeleton. A dose estimate is given in the answer to Question 3.

Other Nuclides (Man-made)

A few additional nuclides have been studied sufficiently so that their contribution to radiation exposure can be evaluated. These are plutonium, iron-55, krypton-85 and strontium-89. None of these have made a significant contribution.

We do not consider that our understanding of low-dose radiation effects is hampered by an insufficiency of historical data on exposures of either individuals or population groups to man-made radioactive nuclides. We do not believe that in the foreseeable future epidemiological techniques would be capable of providing information on the effects of exposures of the general public to radiation doses within the range of "permissible doses." Even with experimental animals, which afford a much more feasible basis for relating effects of radiation, the numbers of animals required to establish significant differences between irradiated and unirradiated populations make the studies prohibitively expensive long before we get down to the range of "permissible dose". The "permissible dose" is derived by extrapolation from doses where statistically significant effects can be detected. The assumption has to be made that nothing unusual happens at the very low dose. The data

now available give no indication that the extrapolation is not justified for making a "safe" estimate of amount of effect produced at low dose.

Question 3

If the average American body-burden for 1968 is known, what is the consequent whole-body dose which it delivered in 1968?

Would that figure represent only the dose from internal radiation?

What was the average additional whole-body dose in 1968 from external radiation, and from nuclides passing in and out of the lungs, and straight through the gastrointestinal tract?

In your opinion, is the public accurately enough informed if the high, wet-zone doses are averaged together with the lower dry-zone doses? And then further averaged out over a 70-year life span?

Answer

The 1968 body burdens of individual radionuclides tabulated and described in reply to Question 2 are converted to doses in the following table. It should be noted that the doses from radium and from strontium-90 are not whole body doses but are the doses to bone and cannot be added to the other doses.

Internal Whole-Body Radiation Doses from All Sources

Natural Radioactivity	
K-40	20 mrads/year
C-14	0.7
Ra-226	0.6
Ra-228	0.7
Po-210	0.3 (2 mrad/yr to bone)
Rn-222 (dissolved in body)	0.3
Artificial Radioactivity-1968	
Cs-137	0.5
Sr-90	9.
H-3	0.4
C-14*	0.5

*1967 dose rate, 1968 should be lower.

The whole-body dose from external radiation in 1968 was essentially due to natural background radiation. An estimate of this dose is given in the table below. The variability with geographic location should be within a factor of 2. The higher doses occur in mountain areas where man is subjected to both higher levels of cosmic radiation and to higher levels of terrestrial radiation because of the rocky nature of the environment.

Dose Rates of External Irradiation from Natural Sources

Source	Whole Body Dose Rate
Cosmic Rays	
Ionizing Component	28 millirads/yr.
Neutrons	0.7
Terrestrial Radiation (including air)	50
Total	79

The whole-body dose rates from fallout in the northern hemisphere ranged from 1 to 2 mrad per year in the period 1965-1967. Measurements in the United States in 1968 yielded estimates of one-half to one mrad per year.

The highest dose rates to any part of the body from natural sources come from inhalation of the short-lived daughter products of radon. Current estimates give local dose rates of several hundred millirads per year to the bronchi, with other portions of the lung receiving smaller doses by factors of 10 (bronchioles) to 100 (alveoli). No other natural or artificial radionuclide produces any significant exposure to lung tissue. It should be noted that the whole-body dose from inhalation is negligible, since the weight of irradiated tissue is very small.

There are no continuing measurements of exposure of the gastrointestinal tract by material passing through. An indication of the magnitude of the dose can be obtained from the following quotations from the 1962 UNSCEAR report.

"The dose to the GI tract is determined by the quantity of fission products entering the body by ingestion and inhalation. No direct measurements of this quantity are available, however. Some gamma spectrometer measurements of faecal samples were carried out in the United Kingdom in April-May 1959, which was the period of highest fallout contamination in air in that year. The United Kingdom measurements show an average daily excretion of 150 pCi/day in 214 g faeces in addition to the total natural potassium activity of 577 pCi/day. Allowing for there being some beta-active nuclides that are not gamma-emitters, the dose-rate in the faecal material would be about 10 μrad/day, 3.7 mrad/year and about half this for the adjacent tissue in the lower large intestine, which is the part of the GI tract sustaining the greatest dose."

"The measurements suggest that the dose-rate to the lower large intestine was less than 2 mrem/y during this period of very high air contamination and that the average dose over the five-year period 1955-1959 was less than 1 mrem per year. These calculations suggest that the dose to the lower large intestine from this cause is negligible."

Within the United States, almost any exposure to a particular nuclide has fallen within a range of a factor of 2 regardless of annual rainfall or any other climatological characteristics. Thus, when an average value is used to describe the broad exposure of the people of this country it should be satisfactory for public health purposes. First the individual response to radiation or other stimuli is probably more variable than a factor of 2 and second the

present levels of radiation are sufficiently low that variation by such a factor is not critical. If the radiation levels were to approach applicable guidance of the FRC it would be necessary to define the exposure of individual population groups much more closely.

On exception to the geographical uniformity described is the localized distribution of iodine-131 from atmospheric weapons testing or substantial venting of underground explosions. This has not produced significant exposure in 1968. Similar local contamination is also possible from nuclear facilities. These are monitored, and there are no data indicating significant exposure in 1968.

Question 4

According to the H. E. W.'s Radiological Health Data and Reports, American Air, rain, and river-water is regularly monitored for gross radioactivity.

Is anyone monitoring the sea? Especially on the Continental Shelf?

What has made the average level of gross beta contamination in American air chronically ten times higher than the average gross beta contamination in Canadian air for the past 12 months?

Is it true that, during the atmospheric tests, Canada received more fallout than we did? If so, then why is our air more contaminated now?

According to the Radiation Alert Network, gross beta radioanalysis of the air is "insufficient to assess total human radiation exposure from fallout." Apparently, gross beta analysis fails to detect tritium, carbon-14, iron-55, beryllium-7, manganese-54, chromium-51, argon-57, and krypton-85, as well as all the alphaemitting nuclides like uranium, thorium, plutonium, radium, radon, and polonium-210.

In your opinion, do the present systems of environmental monitoring provide sufficient data for anyone to comprehend the extent to which we are contaminating our environment?

Answer

There are no routine radiological monitoring programs for radionuclides in the ocean. The volume of water in the ocean is so large and the input rate of radionuclides is so small that day-to-day changes in concentration are infinitesimal. However, for the past several years there has been considerable effort to determine levels and distribution of radionuclides in ocean water samples collected at selected locations at various periods of time. This effort is part of the oceanographic programs conducted at locations such as the Woods Hole Oceanographic Institute, Woods Hole, Massachusetts; (strontium-90 and cesium 137); Scripps Institution of Oceanography, La Jolla, California (tritium and cesium-137); the University of Miami, Miami, Florida (tritium); the University of Washington, Seattle, Washington (carbon-14); and the Naval Oceanographic Office, Washington, D. C. (strontium-90, etc.). In addition, a number of oceanographers are measuring the radioactivity in marine organisms, which reflect the radioactivity in the water. Examples of locations where these investigations are being conducted and the organisms being studied are: the Oregon State University, Corvallis, Oregon (benthic organisms, Plankton, mesopelagic fishes, estuarine organisms, and the University of Washington, Seattle, Washington (mostly fishes).

Since 1963 the U. S. Coast Guard (USCG) vessels on location at Latitude 35° N, Longitude 48° W, in the Atlantic Ocean have measured precipitation amount and collected fallout using a funnel and ion-exchange column unit supplied by the AEC's Health and Safety Laboratory.

A larger sampling program was initiated in the summer of 1965 for the purpose of extending our knowledge of strontium-90 fallout and precipitation over the sea. Ion-exchange column collectors and rain gauges have been placed on the 23 Coast Guard vessels assigned to Ocean Station duties; these vessels maintain continuous weather observation stations at four locations in the Atlantic Ocean. These locations are: Latitude 56° 30' N, Longitude 51° 00' W; Latitude 52° 45' N, Longitude 35° 30' W; Latitude 44° 00' N, Longitude 41° 00' W; Latitude 35° 00' N, Longitude 48° 00' W. Normal scheduling of the ships results in "on station" periods of about 21 days; thus, the deposition samples are not monthly as is usual for land sampling.

The factor of ten difference between the data reported by the Canadian Air Surveillance Network and that of the U. S. Public Health Service Radiation Alert Network is a result of difference in equipment and procedures used by the two countries in making these measurements.

Air filter samples collected at sampling stations in the United States are surveyed with field instruments and a field estimate of the gross beta concentration in air is made. Samples collected for the Canadian Air Surveillance Network are mailed to a central laboratory for analysis. Levels of gross beta concentration in air, identified by laboratory equipment, are consistently lower than field estimates of gross beta concentration in air made by field instruments.

Prior to August 1967, all air filter samples collected for the USPHS Radiation Surveillance Network (presently the Radiation Alert Network) were sent to the Radiation Surveillance Network Laboratory for analysis. The

gross beta air concentration reported by the USPHS Radiation Surveillance Network and the Canadian Air Surveillance Network prior to August 1967, were almost identical.

Answer 4C

In response to the first question, the answer is yes. In 1961 and 1962 the USSR conducted its atmospheric nuclear testing program primarily at Novaya Zemlya (approximately 72°N Latitude) above the Artic Circle. As described by Dr. Lester Machta, Director, Air Resources Laboratory, ESSA, before the Joint Committee on Atomic Energy Congressional Hearings in June 1962, the meteorological parameters of the earth's atmosphere lead to the following situation.

A portion of the radioactivity from atmospheric tests is injected into the stratosphere and is dispersed and diffused around the world before it is finally deposited on the earth's surface. Fallout from this source would be expected to be rather uniformly deposited over a wide range of latitudes and over a period of years. Another portion of this radioactivity is injected into the troposphere and will essentially all be deposited on the earth's surface in about 30 days. Since the tropospheric or near surface air travels west to east, it follows that the radioactivity injected into the troposphere at the polar regions will be deposited in the more northern latitudes; hence, during the 1961-1962 USSR atmospheric tests the Canadian air contained more radioactivity than the U. S. air and there was more deposition of debris from this source in Canada than in the U. S. It would not be expected that there would be any correlation between past deposition

levels and current ground level deposition in ground level air concentration in Canada and the U. S.

In response to the second question, a Health and Safety Laboratory Report (HASL-207 App) of gross gamma concentrations in surface air during 1968, observed at 21 stations in both the Northern and Southern Hemispheres, indicated that the gamma radioactivity at Moosonee, Ontario, was only slightly lower (approximately 25%) than three stations in the U. S., namely, New York City, New York, Sterling, Virginia, and Miami, Florida. The analysis on all of these air samples was done in the Health and Safety Laboratory; thus, the results were comparable. As previously stated, gross beta air concentrations presently reported from Canada and U. S. Air Surveillance networks are not comparable due to difference in equipment used for analysis. Further, it would not be expected that there would be any correlation between past levels of deposited radioactivity and current levels of radioactivity in ground level air.

Question 4D

According to the Radiation Alert Network, gross beta radioanalysis of the air is "insufficient to assess total human radiation exposure from fallout." Apparently, gross beta analysis fails to detect tritium, carbon-14, iron-55, beryllium-7, manganese-54, chromium-51, argon-57, and krypton-85, as well as all the alphaemitting nuclides like uranium, thorium, plutonium, radium, radon, and polonium-210.

In your opinion, do the present systems of environmental monitoring provide sufficient data for anyone to comprehend the extent to which we are contaminating our environment?

Answer 4D

Information obtained from the U. S. Public Health Service Radiation

Alert Network may be used to identify any intrusion of unexpected quantities of radioactivity in the environment and is not intended to be used to estimate human exposure. There are other routine monitoring activities besides this nationwide network that provide information for specific areas and specific radionuclides. The Radiation Alert Network is adequate for the purpose intended.

Gross beta activity in air, as indicated by air filter samples collected at ground level, indicate to monitoring and surveillance personnel, whether there should be increased sampling of milk, water and vegetation in that area. The specific quantities and kinds of radionuclides found in the samples may then be used to estimate population exposure.

The current radiation surveillance and monitoring networks in the U. S. provide quite adequate data upon which scientists may evaluate the extent of contamination of the environment and the potential exposure to man. For your information, a summary of the various Radiation Surveillance Networks is enclosed which identifies the major radiation monitoring programs in the United States. In addition to these programs there are numerous research studies or programs which provide a vast amount of additional information and data relating to radioactivity levels in the environment.

Question 5A

If a man absorbs a curie of radioactive substance, will it kill him?

Answer 5A

The biological effects of a curie of radioactive substance taken into the body will depend upon many factors and may be expected to differ from

one radionuclide to another. Factors that may be of importance in determining the quantity (measured in curies or in fractions of a curie) of a particular radionuclide that would result in serious injury if taken into the body include: the chemical element of which the material is a nuclide; the chemical form of the substance; the radioactive half-life of the nuclide; the average energy emitted per disintegration; the manner in which the substance is introduced into the body; and, especially for materials of relatively short half-lives, the interval of time over which the substance is introduced into the body.

Factors enumerated above determine the retention and distribution of a given radionuclide in the body, total radiation doses to various organs and tissues, and rates at which these doses occur. Because different individuals respond differently to dangerous doses of radiation, as they do to other severe biological stresses, one cannot state with confidence the minimum quantity of a given radionuclide that might be required to kill a particular individual.

Some of these considerations are illustrated by the following examples:

Radiation doses resulting from the inhalation of a curie of tritium as a gas (i. e., as $^{3}H_{2}$ or ^{3}HH) would be too small to produce observable effects. A curie of tritium oxide ($^{3}H_{2}O$ or ^{3}HHO) would result in a whole body radiation dose of about 200 rads. Even if this amount were inhaled within a short period of time, consequent irradiation of body tissues would be spread over a period of weeks. A person exposed at this level probably would experience no symptoms

of radiation exposure. The inhalation of 10 curies might produce recognizable symptoms of exposure but would have a very small probability of being fatal.

One could select a number of radionuclides of which a curie might be taken into the body under conditions which would not be lethal. One may also select radionuclides of which the intake of a curie under credible circumstances would be fatal. However, nature of the damage to the body and the length of time that might elapse before death occurs could vary greatly from one such radionuclide to another. Familiar radionuclides of greater than average hazard are strontium 90, barium 140, cesium 137, radium 226, thorium 230 and plutonium 239.

Question 5B

Apparently less than a curie of strontium-90 would be lethal. How much less? Half a curie? 1/4 of a curie? 1/100th?

Answer 5B

The answer to this for man is undetermined since man is not used for such experimental investigations. There have been many studies in which rodents and larger animals have been given various amounts of strontium-90 either by feeding or injection, in single or multiple doses. Some of these studies have been reviewed by McClellan and Jones (^{90}Sr Induced Neoplasis: A Selective Review, in Delayed Effects of Bone-Seeking Radionuclides, edited by Mays, Jee and Lloyd, University of Utah Press, Salt Lake City, Utah, 1969). At the University of California - Davis, beagle dogs have been fed various levels of strontium-90 for long periods of time. At a level of 12 μCi/day for 1-1/2 years, which gives an average skeletal dose of 6.0 rads/day, no significant

alterations were noted in serum chemical tests. There was leukocyte depression of about 50%. It was estimated that a feeding level of approximately 22 μCi per day would have been required to achieve a 25% depression in the neutrophil level at four months of age (L. K. Bustad et al, Hematopoietic Changes in Beagles Fed ^{90}Sr, reference as above).

At Battelle-Northwest Laboratory, Richland, Washington, miniature swine were exposed to strontium-90 feeding levels ranging from 1 to 3100 μCi/day. At ingestion levels of 25 μCi or less per day for 7 to 10 years, definitive changes were infrequently observed in the formed elements of the blood except for swine showing true leukemia. The cumulative skeletal radiation dose received by these animals ranged from 300 to 14,000 rads. At levels greater than 25 μCi/day there was a progressive decline in leukocytes and platelets, and a terminal precipitous drop in red blood cells, noted at 3 to 64 months post-initiation of strontium-90 feeding at average accumulated skeletal radiation doses of 5,000 to 19,000 rads (W. J. Clarke et al, Strontium-90 Induced Neoplasia of Swine, reference as above).

Beagle dogs have been injected intravenously with strontium-90 by scientists at the University of Utah College of Medicine (Dougherty and Mays, Bone Cancer Induced by Internally-deposited Emitters in Beagles, Annual Report COO-119-240, Radiobiology Division of the Department of Anatomy, University of Utah, College of Medicine, March 1969). Of twelve dogs that were given a single injection of 32.7 μCi/Kg of body weight at an age of 1.4 years, six are still living some 10 years later. Of the six that died, the average survival time was 9.7 years. From this, one can surmise

that it would require greater than 32.7 μCi/Kg to cause an acute death. Indeed, 14 dogs injected with ~ 98 μCi/Kg lived an average of 4.06 years from time of injection until death.

In these studies referred to above, the animals have been followed until death and the cause(s) of death determined. Six of fourteen beagle dogs that died after an i. v. injection of 98 μCi/Kg had osteosarcoma, 2 had hemangiosarcoma, 1 had squamous cell carcinoma. In the case of the miniature swine on continuous daily feedings of various levels, there have been a large number of myelo-lymphoproliferative disorders after cumulative skeletal Radiation doses of 300 to 19,000 rads. In addition, 5 animals have shown giant cell tumors or osteogenic sarcomas a bone doses of 8,000 to 14,000 rads. On the basis of the data from dog studies, Dougherty and Mays (Ibid, above) predict lifetime doses above which bone cancers may occur in adult humans from irradiation by strontium-90 of 5,000 to 17,000 rads. The results reported for dogs and swine are generally similar and resemble those reported in other species, thus lending a firm basis for extrapolation to man. Studies on radium-226 toxicity have indicated a similar response for dogs and man after equivalent doses, lending further confidence in extrapolation of strontium-90 data to man. The collective dog and swine data indicate that strontium-90 irradiation does not possess any special feature that is not a function of its radiation quality and metabolic characteristics. As a bone-seeking radionuclide, its effects to date appear to be limited solely to bone and hematopoietic tissue. At toxic levels, not only are neoplasms of bone and blood induced, but depression of some of the blood cell concentration suggests a direct dose rate effect on hematopoiesis.

Because the uptake of strontium-90 is related to dietary calcium, and because the metabolism is complex, it is not possible to state what minimum quantity of strontium-90 would be lethal to man. Certainly the animal studies show that at feeding levels many times higher than the ICRP maximum permissible body burden for humans (strontium-90) effects in animals are difficult to detect.

Question 5C

Some nuclides have more, and some have less destructive energy per disintegration than strontium-90. Would a curie of tritium, for instance, be lethal?

Answer 5C

Tritium, ingested as tritiated water, mixes with the total body water and is comparatively rapidly excreted in urine, sweat, feces, and via the lungs with an effective half-life of 10-12 days. Although the physical half-life is relatively long, 12.4 years, the short effective half-life means that it does not remain in the body for a long period. The average effective energy of the beta particles per disintegration is 6×10^{-3} Mev. Because of these factors, the total dose from a curie of tritium would not be expected to be lethal. Based on calculations published by the United Kingdom (Publication AHSB (RP) R-20, 1962) the dose would be about 200 rems. Of this, approximately 90% would be received during the first month. For comparative purposes, total body gamma doses of 250 rems have been given to humans in cancer therapy.

Question 5D

Is there any radionuclide which would not be lethal if one curie were absorbed by a man?

Answer 5D

Yes. These nuclides would be determined by various factors including the effective half-life, the critical organ and the route of entry into the body. Such nuclides would include tritium and cesium-131 (by inhalation), and tritium, chlorine-38 and cobalt 58m (by injection).

Question 6

Is it accurate to say that, ounce for ounce and gram for gram, radioactive substances are a million times more harmful to life than any other environmental pollutants?

If not, what is a reasonable comparison?

Answer 6

Table I shows that for most radioisotopes the mass required to produce short term toxic effects may be greater than that required for some chemical toxins. On the other hand, Table II shows that, for severe long term effects which eventually result in death, the mass required for the most effective radiocarcinogens (radiation sources that produce tumors) is much less than that required for the more effective chemical carcinogens; the radiation sources would appear to be as much as 100,000 or more times more effective on a gram basis. These large ratios do not apply to the more common and important radioisotopes such as tritium, cesium-137, or strontium-90, which, as the following discussion points out, may not be more effective on a gram basis than potent chemical agents.

There is very great interest in determining the body burden levels that induce subtle long term effects, although at present there is little experimental data available in mammals. A simple proportional interpolation of high level burdens is probably not valid because it appears that many radiatic effects exhibit threshold properties; that is, radiation doses below a threshold level produce essentially no detectable effect. The present explanation for this response is that cells are capable of repairing many forms of radiation damage provided the exposure is delivered at a low enough rate. The existence of similar repair mechanisms which protect cells from chemical carcinogens or mutagens (mutation producing agents) is not well

established. Furthermore, it is not known what fraction of an ingested chemical carcinogen is actually retained in the body cells in a chemically potent form. If one takes a speculative viewpoint and assumes that less than 10% of a chemical carcinogen is retained in potent form and that cells can repair more than 90% of the initial radiation damage when delivered at low dose rate, then it becomes conceivable that for the more important radiocontaminants (tritium, radium, strontium-90, cesium-137, etc.) long term detrimental effects on a gram for gram basis may not be appreciably greater than those for the most potentent chemical agents.

The estimates presented in Tables I and II are based on various sources of data. Animal studies were applied to man by assuming that the same concentration of agent would produce the same effect. This is common pharmacological practice and suggests that if man weighs 100 times more than the test animal then the total amount of agent required for man is 100 times that of the test animal. No correction has been made for the relative lifetimes of man and the test animals. It is obvious that if man lives longer than the test animal he will be exposed to the detrimental effects of the agent for a longer period of time and therefore may be able to tolerate only a correspondingly lower concentration level. Indeed this appears to be the case for tumor induction in mice, dogs, and man by radium-226. It is found that the necessary body burden concentration levels are in inverse ratio to the relative life span (or exposure periods) of the different animals.

It is obvious that many uncertainties becloud our ability to specify a body burden level for the production of long term effects. This is particularly true for very low exposure levels where it is unknown how effectively the body can negate or repair initial damage. The uncertainties occur for

both chemical and radioactive contaminants. Current population body burden levels of the common radiocontaminants are generally considerably less than one ten-thousandth of the levels listed in Table II. The highest relative level is for potassium-40 which is present at a level of about one thousandth that estimated to produce severe long term effects. Potassium-40 has been a part of all individuals since the origin of life. It is a naturally occurring form of potassium and makes up 0.01% of the potassium of the earth. It may be that some chemical agents are present in the body at levels much closer to that expected to produce severe long term effects.

TABLE I
Short Term Killing Effects

Estimated Single exposure (acute) body burdens for man (170 pounds) which result in killing 50% of the exposed individuals within 30 days.

Agent	Source of Data	Body Burden	
		Micrograms	Microcuries
Botulinus Toxin (Spiled Food)	Guinea Pig	0.1	
Tetanus Toxin (Lock Jaw)	Guinea Pig	0.1	
Diptheria Toxin	Guinea Pig	100	
Phosgene (War Gas)	Man	1,000	
Crotoxin (Rattlesnake venom)	Mouse	10,000	
Bufotoxin (Toad Poison)	Cat	20,000	
α-napthol-thio-urea (Rat Poison)	Rat	700,000	
DDT (Insecticide)	Estimate for Man	35,000,000	
Phosphorus-32	Man	0.6	170,000
Iodine-131	Man	8	1,000,000
Cesium-137	Dog	3,000	250,000
Tritium-3H	Mouse	7,000	70,000,000

TABLE II

Long Term Effects

Estimated continuous (chronic) body burdens for man (170 pounds) for induction of tumors in 50% of the exposed individuals within a lifetime.

Agent	Source of Data	Body Burden	
		Micrograms	Microcuries
1 Lymphoma Cell	Tumors in Mice	0.3	
Aflatoxin (moldy peanuts)	Liver tumors in turkey and fish	1,000	
Methyl-Azoxy-Methanol	Liver tumors in mice	50,000	
3-hydroxyxanthine	Various tumors in mice	100,000	
DDT (insecticide)	Liver tumors in mice	5,000,000*	
Thorium-228	Bone tumors in dog	0.002	1.5
Plutonium-238	Bone tumors in dog	0.02	1.3
Iodine-131	Thyroid tumors in rate	0.03	4,000
Radium-226	Bone tumors in man	5	5
Tritium (in thymidine)	Various tumors in mice	3	30,000
Tritium (in water)	Theoretical estimate	10	100,000
Cesium-137	Theoretical estimate	12	1,000
Strontium-90	Bone tumors in dog	50	7,000
Potassium-40	Theoretical estimate	15,000,000	100

*This is not a body burden but daily feeding intake.

Question 7A

It seems that there is great uncertainty about the biological effects of chronic low doses of radiation on man. "Permissible levels" are set nevertheless. Man is a fairly large animal. Is it known what biological and genetic effects the same levels of air and water contamination which are presumed "safe" for man, are having on animals smaller than man? On plants? On plankton? On the oxygen-producing diatoms?

Answer 7A

A number of lines of evidence indicate that exposures "safe" for man are "safe" for other forms of life. It is generally true that lower organisms are progressively less sensitive to radiation than man or other mammalian species. Radiation doses required to kill some of the simpler forms of life are from hundreds to thousands of times those required to kill mammals.

Radiation effects on man are closely related to the sensitivity of the germ cells, of the cells of the bloodforming tissues, and of the cells of the lining of the gut. Because these cells of man are as sensitive as any that have been found in animals or plants, we have no reason to expect that any organism, regardless of size, would be more sensitive to radiation than man.

For radiation doses to man to be considered "safe", probabilities of serious effects must be extremely small. It would not be consistent with our view of the value of animal and plant life to require that exposures to radiation should carry equally small probabilities of serious effects to be considered "safe". Our interest in the safety of the multitude of species of animal and plant life in any portion of the environment is that exposures

to environmental conditions should not threaten the vigor and viability of the species. This consideration alone affords a wide margin of safety when considering possible ecological effects of environmental levels of radiation .

Question 7B

In your opinion, is there any threat to animals or plants if present nuclear policies continue indefinitely, unchanged?

Answer 7B

As long as environmental levels of radiation limit risk to man to acceptable levels, most biologists would consider that they represent no threat to other species.

Question 7C

In other words, can we increase the use of Plowshare explosives and nuclear reactors indefinitely, without needing to consider any additional controls over consequent environmental contamination?

Question 7D

If we cannot, how soon do you think we should start discussing additional controls?

Answer 7C and 7D

At present, the use of Plowshare explosives and nuclear reactors is subject to the guidance of the FRC and regulatory agencies. Any increased use in the future would also be subject to this guidance.

Should changes in the controls concerning environmental contamination be necessary for any reason, these organizations would undoubtedly initiate suitable precautions for protecting the public health and safety.

Question 8

Already, the Mississippi River dumps about 800,000 curies of tritium every day into the Gulf of Mexico. About 4% of that tritium is produced by cosmic rays, but the other 96% is man-made tritium.

Do you have any ideas about how that amount of tritium might affect marine life in the Gulf of Mexico?

Answer

The Mississippi River discharges nowhere near 800,000 curies of tritium per day into the Gulf of Mexico. The present value is on the order of 100,000 curies per year. This is lower than in 1963 and 1964 when the concentration of tritium in atmospheric precipitation, as well as in the river, was higher. During the 6-month periods April-September 1963 and 1964, it averaged 64,300 and 82,100 curies per month, respectively.[1]

It is the concentration of tritium in water, not the total amount discharged, that would determine its possible effect on marine life. The average concentration of tritium in the Mississippi River at New Orleans during January through June 1969, as reported by the U. S. Public Health Service, was 0.2 nanocuries per liter (nCi/l).[2] Assuming that the specific activity in an organism is the same as in the water, this average concentration corresponds to an estimated whole-body dose of 0.034 mrem/year in man, less than 0.02% of the FRC's Radiation Protection Guide for a suitable sample to the population (170 mrem/year).

1. Stewart, G. L. 1965. Experiences using tritium in scientific hydrology pp. 643-658. In Radiocarbon and Tritium Dating, Proceedings of 6th International Conference held at Washington State University, Pullman, Washington. USAEC Report CONF - 650652.
2. Radiological Health Data and Reports, Vol. 10, No. 11 (Nov., 1969)

The concentration of tritium in the Gulf of Mexico is lower than it is in the Mississippi River, and the radiation dose to the marine life due to tritium is also lower because organisms do not concentrate tritium appreciably.

No harmful radiation effects on the marine life in the Gulf of Mexico are expected because as far as is known, aquatic organisms are much less sensitive to ionizing radiation than human beings, for whom the FRC's Radiation Protection Guides were established.

Question 9A

How do you reconcile the rehabilitation of Bikini Island with all the dire predictions about extinction of life there, and genetic monstrosities and irremediable harm to the ecology?

Answer 9A

As anticipated, there is no evidence the radioactive materials in the environs of the Bikini Island have resulted in genetic monstrosities or irremediable harm to the ecology.

The decision on rehabilitation of Bikini Atoll was made only after a careful evaluation of levels of radioactivity that are present in the environment. These levels were measured throughout a wide range of samples including dietary items collected in 1964 and again in 1967. Also included in the 1967 data are an extensive collection of external radiation measurements taken throughout the atoll.

Question 9B

Who possesses the studies which must have been made on the present contamination levels of Bikini flora and fauna? How do they compare with levels in the United States?

Answer 9B

Reports containing the technical data and exposure estimates are availabl for examination at the Public Document Room in AEC's Washington office at 1717 H Street.

There are measurable levels of some of the longer lived radionuclides in edible plants and animals at Bikini Atoll. However, a number of the items in the Bikini diet are unique to that environment with no direct comparison possible in the United States. More appropriate is a comparison of daily

dietary intake for a given radionuclide. For instance, the average daily strontium-90 intake for residents of New York City for the month of May, 1967 (Bikini was resurveyed in April-May 1967), published in Radiological Health Data and Reports, Volume 9, Number 6, June 1968, was 18.9 picocuries per day. The associated intake of calcium was about one gram per day. For the projected diet expected to apply to the Bikini population if they return in 1970, the intake would be about 114 pCi/day of strontium-90, provided the daily calcium intake is one gram. The returning population is to be provided a dietary supplement to bring calcium intake up to one gram or more per day. This is a worthwhile health measure independent of any radiological consideration. The daily intake of strontium-90 associated with the Federal Radiation Council guide for the general population is 200 pCi/day per gram calcium (top of Range II). However, the daily intake of strontium-90, associated with a one gram per day intake of calcium, which averaged over a year would lead to a dose equivalent to the level of the FRC's Radiation Protection Guide is 600 pCi. FRC adopted the lower level of 200 pCi intake per day because it found no operational need for releasing larger quantities to the environment under normal operating conditions.

Question 9C

Since all the nuclides on Bikini obviously did not decay in 20 years, where did they go? Were they washed by the rain from Bikini into the ocean?

Answer 9C

As to where radionuclides on Bikini have gone, the action of weathering

undoubtedly has caused an increased reduction in levels over and above radioactive decay. The action of rain with subsequent runoff would carry some amounts into the ocean.

Question 9D

Apparently some nuclides--like uranium and thorium--sink to the ocean floor, where they concentrate. What other fission products do that?

Answer 9D

Uranium, Thorium, and Actinium comprise the three major series of naturally occurring radionuclides. All three series end up, following radioactive decay through a number of daughter products over many thousands of years, as stable isotopes of lead. A review of the behavior of these elements in sea water and occurrence in marine sediments can be found in reference 1.

Although fission products comprise more than 200 nuclides of elements ranging from zinc to dysprosium, the major ones of interest in oceanography are listed below.

TABLE

Principal Fission Products

Nuclide	Half-life	Fission yield from fission of ^{235}U by thermal neutrons (%)	Radioactive daughter product	Half-life of daughter
Strontium-89	50.4 days	4.8	--	--
Strontium-90	28 years	5.8	Yttrium-90	64.4 hours
Yttrium-91	58.0 days	5.8	--	--
Zirconium-95	63.3 days	6.3	Niobium-95	35 days
Ruthenium-103	41.0 days	3.0	Rhodium-103m	54 minutes
Ruthenium-106	1.0 years	0.4	Rhodium-106	30 seconds
Tellurium-129m	33.0 days	0.9	Tellurium-129	74 minutes
			Iodine-129	1.6×10^7 years
Cesium-137	30 years	6.0	Barium-137m	2.6 minutes
Cerium-141	32.5 days	6.0	--	--
Cerium-144	290 days	5.7	Praseodymium-144	17.5 minutes
			Neodymium-144	2.5×10^{15}
Promethium-147	2.52 years	2.4	Samarium-147	1.3×10^{11} years

The two major radionuclides with half-lives greater than a year are strontium-90 and cesium-137. Both are soluble in sea water, and tend to remain in the water, rather than sink to the bottom. Introduced as fallout particles, they would sink slowly until dissolved. Measurements show that most of the strontium-90 and cesium-137 that has fallen on the oceans still resides above

1. Burton, J. D. "Radioactive Nuclides," Chapter 22, In Chemical Oceanography, Vol. 2, Edited by Riley and Skirrow, Academic Press, N.Y. 1965.

1000 meters, with the peak in much shallower water. Even in shallow water sediments Sr and Ca are barely detectable. According to Dr. Vaughn Bowen, Woods Hole Oceanographic Institution, no one has been able to measure them in deep water sediments.

Zirconium-95, niobium-95, and cerium-141-144 were found in bottom dwelling sea cucumbers at depths of 2800 meters immediately after the 1961-1962 tests. It is thought that these nuclides, which are not appreciably concentrated in the tissues of organisms (if at all), are carried down in the rain of fecal pellets of animals living near the surface of the oceans[2]. Cerium and promethium isotopes not carried down by biological processes, move downward only very slowly[3].

Assays of sediments from all oceans show that the major radionuclides present are naturally occurring radionuclides of the uranium-thorium series and potassium-40.

Measurements of sea water reveal that practically all of the radioactivity in sea water at the present time is potassium-40, which is universally present in the amount of about 331 pCi/liter. Cesium-137 and strontium-90 can be measured only by special techniques in which the radionuclide is concentrated from rather large quantities of sea water prior to radioanalysis. In compariso natural potassium-40 can be measured easily without pre-concentration. Zirconium-95 and the cerium radioisotopes can be measured in sea water only shortly after foreign atmospheric tests.

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2. Osterberg, C., A. Carey, Jr. and H. Curl, Jr., 1963. Nature, 200 (4913): 1276-1277.

3. Sugihara, T., and V. Bowen, 1962. Radioisotopes in the Physical Sciences and Industry, IAEA, 57.

Question 10A

Articles in the New York Times and "Time" magazine have suggested that fallout is a possible cause of the unexplained starfish plague which is destroying coral reefs and islands in the Pacific and Indian Oceans, and in the Red Sea.

Answer 10A

The article in the September 12, 1969, issue of "Time" clearly was speculating about possible causes of the starfish infestation and included radioactive fallout as one of several factors to be considered. A similar article appeared in the July 14, 1969, issue of "Newsweek." Dr. Porter Kier, who is quoted in the "Newsweek" article, has recently returned from a month long trip to the Eniwetok atoll and has concluded that radiation damage is not causing the explosion in the starfish population, since no problem was detected in Eniwetok, which was the site of some of our bomb tests and was exposed to higher levels of radiation than many of the areas where the infestation of the starfish is more serious.

Dr. Richard Chesher writing in the July 18, 1969, issue of "Science" discusses the problem and suggests that destruction of reefs by "blasting, dredging and other human activities has provided fresh surfaces, free of filter feeders, for settlement of the (starfish) larvae." He feels that the resulting increased survival of the younger stages of starfish is the most likely explanation for this increases in the adult population.

Question 10B

Do you consider this conceivable?

Answer 10B

Dr. Kier, Smithsonian Institution, is convinced that radiation is not the

cause. Based on the relative lack of sensitivity to radiation of invertebrates, we would not expect any effects.

Question 10C

Do you know who is investigating the radiological implications of the starfish phenomenon?

Answer 10C

In addition to Drs. Kier and Chesher, mentioned above, Dr. Banner of the University of Hawaii is investigating the possible causes of the increase in starfish.

Question 11A

Compared with Americans in the lower-48, many Eskimos carry very high body-burdens of unnatural, man-made radionuclides like strontium-90, cesium-137 and iron-55.

Question 11B

In fact, the mean average American body burden of cesium-137 is calculated to be near 12 nanocuries now. For adult Eskimos, it is 700.

Question 11C

In new York and New Jersey, the body burden of iron-55 is 13 nanocuries, but it is 1,100 nanocuries for fisheating Eskimos.

Answer 11A, B, C

Of the radionuclides to which Eskimos are exposed as a result of fallout from past tests of nuclear weapons, reported burdens of cesium 137 represent the highest radiation doses.* While it is assumed that any small exposure to radiation represent some correspondingly small degree of hazard to human health, the radiation dose rate resulting from a body burden of 700 nanocuries of cesium 137 in an adult is too small to be of great concern. It is also so small that one would expect that any measures that might be effective in substantially reducing the exposure would be expected to represent a greater hazard to the well-being of the Eskimo than does the radiation.

Without attempting an exhaustive justification of these conclusions, the following observations indicate that they are consistent with our evaluation of radiation risks to ourselves and to our families. A body

*The levels of 700 nanocuries is not a mean average for all Eskimos, as implied, but is characteristic of levels in male adults in one or two localities. Levels in women and children are reported to be much lower.

burden of 700 nanocuries of cesium 137 in an adult man corresponds to a whole body dose rate of about 125 millirems (0.125 rem) per year, one-fourth of the limit generally used for controlling exposures of individual members of the public. This is roughly the average radiation dose to inhabitants of the U. S. from all natural sources of radiation inside and outside the body. However, perhaps a million or more inhabitants of the U. S. live in areas where levels of exposure to radiation from natural sources are higher than the national average by an additional 125 millirems per year or more. As far as we are aware, even persons well informed on the risks of radiation do not give appreciable weight to this exposure in considering a move of his family to or from an area in which the higher levels of radiation exist. We know of no reason for greater "worry" about the additional hazards associated with exposures of Eskimos to comparable doses of radiation from cesium 137.

Question 11D

In your opinion, are these figures cause for concern? Would you be worried if your family or your own children carried Eskimo doses?

Answer 11D

We are interested in the health and safety of all individuals, including the Eskimos in remote Anaktuvuk Pass. Our Battelle-Northwest Laboratory and the USPHS laboratories carefully monitor the levels of fallout radioactivity in Eskimos to assure that doses do not exceed levels recommended by the FRC. This situation was recently reviewed by the FRC. The FRC Memorandum for the President on Radiation Protection Guidance for Federal

agencies, dated May 17, 1965, states:

> "Internal exposure from cesium-137 to be taken in through the diet in the conterminous United States during the next 30 years has been estimated to be about 0.01 rad. In Alaska, although the amount of fallout deposited per unit area is about one-fifth as much as that deposited in the 30° -40° latitude band, a combination of ecological conditions and specific dietary habits of some eskimos and Indians causes higher cesium body burdens than are found in the conterminous United States. Average body burdens of cesium-137 in these inhabitants were about three times as high in 1964 as they were in 1962. The estimated annual whole body doses to these individuals ranged from about one-quarter to one-half of the numerical value of the RPG for individuals in the general population.
> On the basis of this information on stratospheric fallout the Council concluded that the health risk from radioactivity in food over the next several years would be too small to justify protective actions to limit the intake of radionuclides either by diet modifications or by altering the normal distribution and use of food, particularly milk and dairy products."

Question 11E

Because relatively few Eskimos marry non-Eskimos, their genetic pool is small; genetic defects are slow to dilute. Will that tend to increase the hazard from contamination?

Answer 11E

The fact that Eskimos predominantly marry Eskimos rather than non-Eskimos indicates a strong and not unusual racial restriction with regard to marriage pattern, but this does not imply a small genetic pool. The overall Eskimo population in Alaska, with numbers estimated at about 27,000, is, under natural conditions, organized into relatively small village units consisting typically of from 10 to 25 families each. Acculturation has, in many instances, led to sizable increases in village populations. There is a strong tendency for marriages to involve individuals within the same village and for this reason there is a degree of consanguinity and thus of inbreeding. However, there are indications from studies of inheritance and of language

differentiation that there has been a significant gene flow between villages so that the villages can by no means be regarded as isolated populations.

The question of "dilution" of genetic effects deserves to be considered in the light of population genetics. Human populations generally carry a number of mutated genetic loci which have accrued from spontaneous mutations in preceding generations. These mutations are generally recessive in their effects, and while they are usually deleterious in their individual effects, they are not all intrinsically bad since they provide the necessary variability in a population to allow it to respond to changing environments, and thus to permit the species to evolve. Although evolution depends on the continued presence of genetic variation, one of its most important immediate consequences in a population is the inevitable production of ill-adapted individuals. This cost, in terms of reduced fitness associated with the production of less than optimally fit indivduals, is called the <u>genetic load</u> of the population. In this sense, genetic load is the cost to the species of the opportunity to engage in evolution.

Most of these continually arising spontaneous mutations are harmful in various degrees, and, by failing sooner or later to be transmitted to the following generations, they are removed from the population at a rate proportional to their harmfulness. A cell carrying the mutation may die, or, being a germ cell, it may fail to be fertilized, or the fertilized egg may fail to be implanted, or being implanted, may die. Loss may also occur

at later stages, depending on the nature of the mutation, and involve what is called hardship in the population, exampled by fetal or infant mortality, or prereproductive mortality.

So far as we know, induced mutations are similar in character to those occurring spontaneously. They, too, are carried in the population as an increment to the genetic load, and, as in the case of spontaneous mutations, are subject to elimination from the population at a rate depending on their harmfullness. Thus, recessive mutations, with relatively slight effects, may be carried for many generations, while dominant lethals and certain types of chromosomal aberrations such as X-chromosome losses are expected to persist only one or no more than a few generations.

The rate with which recessive gene mutations are removed from the population is also dependent upon the mating pattern. For example, in a population where inbreeding is relatively high, such as in the case of the Eskimo, the relative frequency of homozygous recessive individuals in early generations is high but by the same token, so is the rate of removal of the deleterious recessive gene from the population. In this sense then, "genetic defects are slow to dilute" in Eskimo populations, but "dilution" should not necessarily be construed as an advantage to the population since a deleterious recessive gene is expected to persist for a greater number of generations in an outbred than in an inbred population.

Question 11F

The Eskimos have a short life expectancy anyway. Does that suggest that their health may be weak to begin with?

Question 11G

Extensive study of birth defects, fetal mortality, stillborn infants, mental

retardation, blood troubles, and cancer among the irradiated Eskimos might at least provide significant data in the area of greatest ignorance: the effects of low doses.

Do you know anyone making such studies?

Answer 11F and 11G

We have no direct knowledge regarding the health status of the Eskimos. However, for the past twenty years the Arctic Health Research Center of the U. S. Department of Health, Education and Welfare, Public Health Service has been engaged in studying the problems and factors affecting the health of people living in low temperature areas. It is not known whether the Arctic Health Research Center is specifically studying birth defects, fetal mortality, stillborn infants, mental retardation, blood troubles and cancer. However, these health parameters are normally studied and documented by the U. S. Public Health Service.

Question 12A

Do you, or any of your colleagues, have any reason to think that the "acceptable," "safe," "permissible" doses of radiation may not be acceptably safe?

Answer 12A

No.

Question 12B

A study by Warren A. Brill at the National Center for Radiological Health concludes that an acceptable dose of iron-55 to the spleen probably results in a dose two times higher to the red blood cells, and 800 times higher to the blood ferritins. Is this conclusion accepted by other experts?

Answer 12B

The conclusion was drawn by Warren A. Brill, although the information is primarily a summary of work done by other investigators. It is interesting to note that problems related to iron-55 dosimetry in various biological entities have been under study for about a decade. Various organs such as the spleen, tissues such as blood and tissue components such as erythrocytes or ferritin aggregates have been investigated. The conclusion stated in the question is generally accepted by those knowledgeable in the field of dosimetry. We should be aware, however, of exactly by what biological entity the energy is absorbed. For iron-55 the energy available for deposition in biological systems averages about 6 keV (the ICRP uses a more conservative value of 6.5 keV). The energy is emitted either as X-rays or as short-ranged Auger electrons. The Auger electrons account for about 80% of the available energy so that, for cells containing high concentrations of iron-55, most of the decay energy is deposited within the cell. Because of this short range

the highest dose (mrad per picocurie per milligram of iron) is delivered to ferritin aggregates as compared with red blood cell or the whole body. However, the integral dose (gram-rad per picocurie per milligram of iron) is inversely related and the smaller entities, such as ferritin, aggregates receive smaller integral doses than the red blood cells or the entire body. The dose to ferritin aggregates is several orders of magnitude greater than that to red cells whereas the integral dose to ferritin aggregates is less than that to the red cells.

On must also consider the possible effects of radiation on different targets. That is, circulating red cells do not divide and the ferritin aggregates within the entire human body contain roughly 400 milligrams of stable iron.

Calculations were made of the total (infinity) dose to various biological entities of New York residents in 1965 arising from average concentrations of 3.4 picocuries of iron-55 per milligram of iron. The results indicated doses of 1.4, 0.46 and 235 millirad for the red cells, red marrow and ferritin aggregates, respectively. However, the integral doses for the red cells, red marrow and ferritin aggregates were 3.5, 0.69 and about 0.5 gram-rads.

Question 12C

Is it true that in 1960, the ICRP maximum permissible concentration of strontium-90 was 33 picocuries per liter of milk, but that in 1962, the Federal Radiation Council raised the acceptable concentration to 200? If so, what changed the earlier benefit-vs-risk judgment? Had the risk gone down, or had the benefit gone up?

Answer 12C

The basic radiation protection standard for strontium-90 has been the

same in 1960 through 1969 for both the ICRP and the FRC, namely, 5 rems/yr to the bone for occupational workers, and 1/30 of this limit or 0.17 rem/yr for a suitable sample of the exposed people in the general population. To derive an MPC value for water (the ICRP has no milk standards) the ICRP considered the known (in 1960) data on the extent to which strontium-90 taken into the body with water could, through the metabolic chain, make its way to the bone. This is how the value of 33 pCi of strontium-90 per liter of water was derived - i. e., by dividing by 30 the ICRP value of 1×10^{-6} $\mu Ci/cm^3$ for occupational workers. As better metabolic information is developed one would expect the derived MPC value to change and indeed this is what happened. In 1962 the ICRP changed its MPC for water to 4×10^{-6} $\mu Ci/cm^3$, a factor of four higher than the 1960 value.

While adhering to the same primary standard of 0.17 rad/yr to the bone marrow, the FRC used a different model for relating the concentration of strontium-90 in the milk to the dose within the skeletal tissue. Using this new technique of relating to the strontium-90/calcium ratio the daily intake, averaged over a year, was determined to be 600 pCi strontium-90/gm of calcium. However, FRC found no operational justification for releasing this much strontium-90 to the environment under normal operating conditions and therefore reduced its average daily intake value to 200 pCi/day.

Question 12D

According to the Federal Radiation Council, all radiation is potentially harmful, and every effort should be made to keep doses as far as possible below even the "acceptable" levels, since they already represent

some compromise with safety. Therefore, it is not clear to me why the potential doses which call for official protective actions (the PAG's) are set 15 to 50 times higher than the normally "acceptable" limits.

What are your thoughts on this matter?

Answer 12D

The Federal Radiation Council's Radiation Protection Guides were developed as guidelines for the protection of radiation workers and the general public against exposures which might result from routine uses of ionizing radiation. In formulating these guides there was a judgment, or balance, between the possible risks associated with a particular radiation exposure and the reasons for allowing the exposure.

The Radiation Protection Guides were set with respect to environmental levels of radioactivity, and they reflect the residual risk considered acceptable after engineering and procedural controls have been applied at the source (i. e., place of origin) of radioactivity to limit releases to the environment. Although radiation doses numerically equal to the Radiation Protection Guides may impose a risk so small that they can be accepted each year for a lifetime if there is significant benefit from the programs causing the exposure, they do not and cannot establish a line that is safe on one side and unsafe on the other.

The Memorandum for the President on Radiation Protection Guidance for Federal agencies, dated May 18, 1960, includes the following recommendation by the Federal Radiation Council:

> "There should not be any man-made radiation exposure without the expectation of benefit resulting from such exposure. Activities resulting in man-made radiation exposure should be authorized for useful applications provided the recommendations set forth herein are followed."

In contrast to the Radiation Protection Guides, the Protective Action Guides, recommended in 1965, provide general guidance for the protection of the population against exposure resulting from the accidental release, or from the unforeseen appearance of radioactive materials in the environment. In introducing the concept of protective actions, the Federal Radiation Council pointed out that caution should be exercised in decisions to take protective actions in situations where the projected doses are near the numerical values of the Radiation Protection Guides, since the biological risks are so low that the actions could have a net adverse rather than beneficial effect on the public well being.

The Protective Action Guides represent a consensus as to when, under what conditions most likely to occur, intervention is indicated to avoid radiation exposure that would otherwise result from transient environmental contamination. This consensus involves health, economic, sociologic and political factors for which relative values are different than for the Radiation Protection Guides.

The Memorandum for the President on Radiation Protection Guidance for Federal agencies, dated May 17, 1965, states:

> "Protective actions are appropriate when the health benefits associated with the reduction in exposure to be achieved are sufficient to offset the undesirable features of the protective actions. The PAG represents the Council's judgment as to where this balance should be for the conditions considered most likely to occur. If, in a particular situation, there is available an effective action with low total impact, initiation of such action at a projected dose lower than the PAG may be justifiable. If only high impact action would be effective, initiation of such action may be justifiable only at a projected dose higher than the PAG."

Question 13

Do you or your colleagues have any reason to think that, due to accumulation and reconcentration in the foodchain, the "acceptable" limits (RPG's):

may have been exceeded in the past?
may presently be exceeded in some places?
will be exceeded in the future if the use of nuclear energy increases without any new controls over the totality of waste released into the environment?

Answer 13

The Radiation Protection Guides of the Federal Radiation Council present the significant factors relating potential radiation risk to man. Some of these factors are: critical segments of the population, critical radionuclides (such as the long-lived nuclides strontium-90, cesium-137, carbon-14 and tritium and the short-lived radioiodines); ecology; total quantity of radionuclide involved; food chains, and consideration of the actual or potential concentrations of radioactive materials in air, water or food. Thus reconcentration in food chains is considered in applying FRC guidance.

There is no evidence that the Radiation Protection Guides have been exceeded in the past from peacetime uses of nuclear energy nor do we believe that they will be exceeded in the foreseeable future due to accumulation and reconcentration of radionuclides in the food chain. There is evidence that the Radiation Protection Guides were exceeded in certain areas and years due to environmental contamination resulting from atmospheric nuclear testing.

However, should this situation change, as might be indicated by the surveillance network and assessments of release of significant radionuclides mentioned in previous answers, it is obvious that the FRC and regulatory agencies would take suitable precautions for protecting public health and safety.

Question 14

Although Ernest Sternglass is talking about a different problem--fallout from bomb tests in the atmosphere--he raises two questions which are most relevant to our present inquiry:

A. Can fetuses and infants die from doses of radiation very much lower than we thought could even hurt them?

B. Are they possibly receiving higher doses than we supposed?

In view of the growing plans for Plowshare detonations, the increasing number of reactors, the continuing fallout from old tests and from French and Chinese atmospheric tests, do you feel that these two questions merit further investigation?

Answer 14

The answer to these questions is no. A large amount of information exists which clearly indicates the sensitivity of the embryo to irradiation. This detailed picture of the dose-effect relationship of irradiation on prenatal development has been obtained from studies in animals. However, sufficient human cases have been studied to indicate that the same pattern occurs in man as in animals. Some of the human information is derived from the survivors of the atomic bombs in Japan; the children from women who were pregnant when exposed to irradiation at Nagasaki and Hiroshima. Most of our knowledge comes from cases described in the medical literature of abnormalities following exposure of pregnant women at a time when radiologists did not know the great radiosensitivity of the fetus. At one time it was believed that any harmful effects would lead to abortion or stillbirth and that the embryonic abnormalities would not give rise to deformed children. Subsequently, a detailed survey showed that when a mother received several hundred roentgens for treatment of cancer within the first two months after

implantation of the embryo, severe maldevelopment was observed in all children; a high proportion of whom lived for many years. A much smaller portion of malformed children were born when the mother was irradiated during the last three months of pregnancy.

With regard to the possibility that fetuses and infants are receiving higher doses of irradiation presumably from ingested radionuclides, the report of the United Nations Scientific Committee on the Effects of Atomic Radiation for 1969 contains the following statement: "The results of extensive and comprehensive surveys carried out in a number of countries have contributed considerably to our knowledge of the levels of long-lived radionuclides in man and food chains in those countries as well as to our understanding of the many and complex processes involved in the transfer of radioactivity to the human body. Although the estimates of the doses ascertained do not differ significantly from the previous ones the Committee now has increased confidence that they are representative of the doses to which humans have been committed, at least for those populations in the countries and areas from which the results of measurements are available."

It is possible to approximate radiation exposures to the fetus from atmospheric fallout. Also, fetuses are known to be affected by radiation at doses lower than those which would cause damage to an adult. Basic research must be continued on both animals and, where possible, man to learn the effects of ionizing radiation on reproductive capacity. The results of animal experiments clearly indicate the complexity involved in determining whether a given system does or does not play a primary role in the response

of another system at low levels of radiation exposure. Continued research into the basic mechanisms involved in these irradiation effects will contribute to even greater confidence in extrapolating studies from animals to man, and in defining the critical cellular or subcellular site.

Question 14B

Many experts are scoffing at the Sternglass hypothesis. But is it conceivable that he is right? Or partially right?

Answer 14B

With regard to Dr. Sternglass' hypothesis, we are convinced that he is wrong. It should be pointed out that those experts who have challenged Dr. Sternglass' hypothesis are extremely knowledgeable and dedicated individuals independent of the AEC who have reviewed the data presented by Dr. Sternglass as well as the interpretation he has given to the data. We have attached for your review rebuttals of Sternglass' thesis which have been published in the New Scientist by Dr. Alice Stewart and Dr. Leonard A. Sagan.

Question 14C

Suppose strontium-90 plus other man-made nuclides produced the effect he seems to attribute solely to strontium?

Are you, personally, 100% certain that Sternglass is 100% wrong? If so, would you please share the basis of your confidences with us?

Answer 14C

With regard to these questions, we are enclosing for your review a summary of the Effects of Radiostrontium based on chronic long-term feeding experiments in dogs and miniature swine and a recent publication by the Atomic Energy Commission's Health and Safety Laboratory explaining the situation with

regard to fallout distribution for the various time periods referred to by Sternglass.

Question 15

Natural radiation, in spite of its low level, is apparently harmful genetically. According to one estimate, one out of every 20 seriously defective (mentally or physically) children is the victim of natural radiation.

Is that the best and accepted current estimate?

If not, what percentage of seriously defective children is now considered to be the consequence of natural (not man-made) radiation? What is the applicable description of "seriously defective"? What studies form the basis of that estimate?

Is there any concomitant estimate for fetal deaths and stillborn infants as a result of natural radiation?

Answer 15

It is not clear where the estimate, "one out of every twenty seriously defective (mentally or physically) children is the victim of natural radiation," was derived. The estimate in question is not considered to be the currently accepted estimate or even an accurate estimate.

To provide an estimate of the percentage of seriously defective children that are produced as a consequence of natural (not man-made) radiation would be an extremely complex exercise. At the present time there is no such estimate available and to our knowledge there is no attempt to derive one.

To define "seriously defective" as it applies to this problem is an arbitrary decision; however, it might be considered to be any mental or physical condition which markedly alters or prevents the affected individual from functioning in society and thus is dependent on society for his maintenance.

Estimates have been made for first generation genetic deaths, which would include fetal deaths, stillborn infants, and any other effect which would lead to a non-reproducing individual for whatever cause. The International Commission on Radiological Protection has published "The Evaluation of Risks from Radiation" in the ICRP Publication No.8. In this publication, all of the available experimental evidence has been considered, assumptions for any estimates made carefully delineated, and estimates made for the frequency of genetic deaths that would be expected to occur naturally -- from mutation without the parents having received any man-made radiation as well as what would be expected under similar conditions but with parents having been exposed to man-made radiation.

Using the information developed for this publication, one can calculate what would be expected if each individual parent in a population that produces one million live born children were to receive a given dose of radiation. It is estimated that each individual in the population today receives on the average 3 rem (roentgen equivalent man) of background radiation over a 30-year period (100 millirem/year). Using data considered by the ICRP, if this dose were delivered acutely, one would expect approximately 633 genetic deaths to be produced in the first generation progeny as a result of this background radiation dose. The total number of genetic deaths expected to occur spontaneously in the first generation progeny is estimated to be 235,000; therefore, of this number of genetic deaths background radiation would be estimated to produce 0.27 percent (633/235,000).

Since this estimate is based on data from acute radiation exposure experiments, the expected number of genetic deaths is too high by a factor of 4-8, because it is well documented that doses of radiation delivered over a long period of time produce less genetic damage than an equal dose delivered acutely. For this reason the contribution to spontaneously occurring genetic deaths expected from mutations which exhibit a small dominant effect in the first generation progeny induced by background radiation (not man-made) would be 0.034-0.068 percent.

Question 16

Nuclear explosives are being developed for peaceful excavation purposes. Apparently, cleaner new explosives have been developed--the SCHOONER experiment in December, 1968 was the first developmental model--which make it possible to conduct a megaton excavation blast from which the fission products released to the environment would be equivalent only to a 0.02 kiloton nuclear explosion.

Part A Question 16

Approximately how many curies are created by a 0.02 kiloton nuclear explosive? Would that be pure fission?

Answer Part A Question 16

A 0.02 kiloton all fission nuclear explosive would produce about 10^7 curies of gamma activity as measured one hour after detonation.

Part B Question 16

Is it correct to presume that a Plowshare explosive would produce additional fission products which might not be released to the environment, but which would be "contained" somewhere in the lip or pit of the crater?

Answer Part B Question 16

Only a small portion of total amount of radioactivity produced by an excavation explosive is released to the atmosphere. The amount of radioactivity released is minimized by scavenging during the venting process, by special emplacement techniques, by utilizing minimum fission explosives, and by employing extensive neutron shielding to reduce neutron activation of surrounding materials. For each individual explosive detonated, the sum of fission products airborne in the fallout can be expected to be as low as the equivalent of 20 tons fission yield. This amount excludes the radioactivity which is scavenged during the venting process and remains buried in the broken rock in the crater and in the crater lip. A small

fraction of the radioactivity produced (but a large fraction of the 20 tons equivalent) becomes attached to large dust particles and is deposited on the surface in the immediate area of the excavation or within a few miles to tens of miles downwind as the wind moves the dust cloud away from the crater. A much smaller fraction of the radioactivity produced (and a small fraction of the 20 tons equivalent) remains airborne for longer periods during which time it undergoes radioactive decay and is diffused and dispersed throughout an increasingly large air mass as the wind moves it away from the site. After a few tens of hours, the radioactivity levels are within the normal variations of background or natural radiation. The area of deposition, the direction and rate of travel, and the diffusion rate can all be predicted as a function of meteorological conditions.

Part C Question 16

How many curies of fusion products can be expected from a megaton Plowshare explosion, such as the one probably due for detonation next year? What percentage would be released to the environment? Where might the unreleased nuclides be found? Which fusion products do Plowshare excavations create? Tritium? Carbon-14? Iron-55? Tungsten-187?

Answer Part C Question 16

The fusion reaction of the proposed 1 MT Plowshare excavation explosion would probably release something less than 2×10^7 curies of tritium, to the atmosphere. Certain other radionuclides produced by neutron interactions with the medium surrounding the explosion and with the downhole hardware may also be released. The induced activities are dependent upon the chemical composition of the specific underground medium in which the

explosion takes place and the materials making up the device hardware. The following is a representative set of induced radioactivities that might be released to the atmosphere by a 1 MT cratering explosion.

NUCLIDE	KILOCURIES
Sodium-24	800
Phosphorous-32	0.4
Calcium-45	0.03
Manganese-54	0.3
Manganese-56	2000
Iron-55	0.15
Iron-59	0.15
Tungsten-185	10
Tungsten-187	500
Lead-203	7000
Other	20

Note: This list contains the major radionuclides and the upper limits for the amounts produced.

Most of the unreleased tritium would be in the form of water remaining underground in the crater. The fate of the other nuclides is similar to that described for fission products. (See Answer 16B)

Part D Question 16

In April, 1969, H. M. Parker of the NCRP told the Plowshare Symposium that Plowshare technology will produce nuclides not commonly encountered in routine nuclear energy programs. Which are the uncommon nuclides produced by Plowshare explosives?

Answer Part D Question 16

We have reviewed Dr. H. M. Parker's presentation at the April 1969 Symposium on Public Health Aspects of Peaceful Uses of Nuclear Explosives. In the abstract of his paper Dr. Parker makes the statement "... the neutron activation process of Plowshare technology will produce radionuclides not

not commonly encountered in routine nuclear energy programs." Nowhere in his speech, however, does he discuss this point further. You will note that we have discussed neutron activation and listed some of the important nuclides in our answers to Part B and C of Question 16.

Question 17

Another type of Plowshare explosion--the kind used to "mine" natural gas and oil, for instance--is deeply buried, and seems to raise completely different environmental questions.

Part A Question 17

Is there any difference in nuclide production from explosives used for excavation, and explosives used for underground engineering? Or are they equally clean?

Part A Answer Question 17

The AEC is studying the design of nuclear fission explosives which produce minimal amounts of tritium to be used for industrial applications such as stimulation of natural gas and oil. Similarly, special explosives have been designed for excavation applications which produce minimal amounts of fission products. In each case, the explosive is specifically designed to limit to the greatest extent possible the production of radionuclides troublesome to that particular application.

Part B Question 17

Does anyone understand why some tests vent and others do not? If so, why can it not be predicted?

Part B Answer Question 17

Since 1961, no Plowshare experiments designed for complete containment have vented. However, the Commission is continuing its work to refine calculational models to predict the conditions necessary for containment of further detonations. These models, based on theoretical studies of specific parameters such as the type of rock and special emplacement techniques, are

verified by actual field experiments.

Several years of experience in the weapons program and extensive studies into containment failure mechanisms has resulted in a great deal of knowledge of the phenomenology involved. The debris resulting from a venting of radioactivity to the atmosphere can be categorized by the physical nature of the release: That resulting from seepage or that resulting from a "prompt" dynamic release.

In the usual underground explosion a column-shaped volume of broken or crushed rock, termed a chimney, is formed as the initial cavity created by the explosion collapses. The volatile radionuclides produced by the explosion diffuse with cavity gases into the void spaces formed by the collapsed rock. This chimney material acts as a filter so that the only radioactive material which can seep to the surface to reach the atmosphere consists of noble gases and a relatively small amount of iodine. The amount of radioactivity released by seepage is a very small fraction of that formed and can be measured only by very sophisticated laboratory equipment and exacting analytical techniques.

The Commission is continuing its efforts to define containment models which will predict more accurately the effects of various types of rock materials and various chemical techniques designed to reduce the amounts of volatile radionuclides produced. The possibility of seepage of radioactivity to the atmosphere is considered for every underground nuclear test designed for containment. Calculations of the number of curies of radioactivity that credibly could be released to the atmosphere under an accident

situation are made. However, these calculations are made for planning purposes. Tests would not be conducted unless it can be shown that safety of on- and off-site personnel can be assured even if the maximum credible accident should occur. By virtue of experiences gained over the past several years, containment techniques have been vastly improved and further improvement is anticipated.

During the period August 5, 1963, through October 31, 1969, the Atomic Energy Commission announced the detonation of 180 nuclear tests which were designed to completely contain resulting radioactivity underground. Of these 180 underground tests, only 15 (all of low or low-intermediate yield) released radioactivity to the atmosphere which was detected by ground monitors or ground monitoring equipment off the site. There have been no releases of radioactivity from high-yield tests.

Part C Question 17

Is it possible to determine the direction and velocity of contaminated underground water from a Plowshare cavity in an unfamiliar region, when there seems still to be some uncertainty about its direction and velocity even in Nevada?

Part C Answer Question 17

The direction of ground water flow under natural conditions or in the vicinity of a cavity formed by the explosion of a deeply buried nuclear device can be predicted by knowledge of the pressure of hydraulic gradient acting on the water bearing formation. Ground water, like water on the surface of the earth, moves from points of higher elevation or pressure to

points of lower elevation or pressure. The rate of ground water movement is governed by the permeability of the water-bearing formation, which is a measure of the ease with which a fluid will pass through it, and the hydraulic gradient or slope of the water table. The rate of flow of radionuclides in ground water is generally much slower and under no conditions greater than the rate of flow of the water in which that nuclide occurs. Generally, the rate is very much less. This is because many radionuclides become intermittently attached to the minerals that make up the water-bearing formation.

From the considerations described above, it is clear that predictions as to rate and direction of ground water movement are dependent upon a knowledge of geologic and hydrologic conditions at the site under consideration. Early in the feasibility determination for a project, a thorough investigation of the hydrology and geology of the proposed site is under taken.

At and near the Nevada Test Site, the U. S. Geological Survey has compiled water-level and water-flow records on over 100 wells, test holes, and emplacement holes, as well as numerous springs, for use in defining areas of ground water recharge, flow paths underground and discharge points. This information is augmented by chemical and radiochemical analysis of water. On the basis of the composite results of these various studies, underground water movement is known to be from 0.02 to 2.0 feet per day. Taking Yucca Flats as an example, the average rates of movement are believed to be significantly less than one hundred feet per year indicating that the

groundwaters in this region have been there for several thousand years.

Part D Question 17

If a Plowshare explosive is detonated at a depth which takes it very nearly down to sea level, would the contaminated water from the cavity have to migrate all the way to the sea before it could possibly surface? Or are there geological conditions under which it might rise, and surface at elevations above the detonation level?

Part D Answer Question 17

There are geological and hydrological conditions under which ground water occurring at depths of about sea level might move to points of discharge at the land surface. Such conditions could occur if the water bearing formation were so inclined or tilted that it outcropped at the surface and at the same time the water pressure in the formation was lower at the outcrop than at its sea level location. Such factors are investigated and evaluated during review of site hydrology for any proposed Plowshare application.

Part E Question 17

Is it correct to conclude that nuclides like tritium and krypton-85, which contaminate the natural gas from the GASBUGGY experiment, eventually will end up in the air no matter what we do? Is it true that our only choice once we create them, is to flare them into the atmosphere by burning gas at the detonation site, or--after selling contaminated gas and oill--to burn them into the air in our industrial centers, in our automobiles, or in our furnaces.

Part E Answer Question 17

To a degree one can correctly conclude that tritium and krypton-85 which contaminate the gas of a Plowshare natural gas stimulation program will end up in the air. However, the levels of gaseous radionuclides which have been or will be released are well below the accepted guidelines governing

such releases. Much work is also being done to design explosives which will produce minimal amounts of tritium.

Part F Question 17

How many curies are involved per 25 kiloton explosive? Or in a 40 kiloton shot like RULISON? How can the environmental effects be considered unless we know? How can the benefit be compared with the risk?

Part F Answer Question 17

Tritium and krypton-85 are the principal radioactive contaminants related to gas and oil recovery, and tritium is potentially the greater of the two. Approximately 40,000 curies of tritium and 350 curies of krypton-85 were produced by the 26 kiloton GASBUGGY explosion. The 40 kiloton RULISON explosion produced an estimated 10,000 curies of tritium and about 960 curies of krypton-85. Our experience with GASBUGGY has shown that only 5% of the tritium so produced remains in the gaseous phase to be diluted and swept to the surface by the uncontaminated natural gas flowing from the surrounding formation. Subsequent dilution of the gas by the flaring operation and atmospheric diffusion has resulted in barely detectable low concentrations of tritium (about 2.8×10^{-13} curies per cubic foot) at distances of only 1/2 mile from the site. Krypton-85 concentrations were not measured at these distances, since sensors closer to the site detected no krypton-85 concentrations above background.

With this knowledge of concentrations, we are evaluating the effect of such levels of radionuclides on the environment and the resultant radiation dose to individuals. To compare the benefits and possible risks associated with the use of nuclearly stimulated natural gas one must also

recognize the health risks of enduring further exposure to other more common pollutants such as sulfur dioxide, fly ash, carbon monoxide, coal tar residues, etc. resulting from the combustion of conventional fuel. Regulatory limits for radionuclide concentrations in natural gas have not yet been established. Therefore at present, no nuclear stimulated natural gas is being commercially distributed, nor will it be until such regulations are established.

Part G Question 17

Do you have any ideas how this problem should be handled?

Part G Answer Question 17

The problem of radionuclides in the atmosphere is being studied extensively in the plowshare program in an effort to determine the extent of the problem and methods of minimizing it. We are confident that the concentrations of radionuclides predicted from the present technology can be greatly reduced by the variety of continuing efforts discussed previously. The Commission is continuing its research and development programs to reduce the amounts of radionuclides in products proposed for recovery by peaceful nuclear explosions and to determine the effect on the environment and to individuals of trace amounts of radionuclides in such products.

Question 18

The contamination threat would vanish if man figured out how to turn off radiation--how to make an unstable atom stable again. Who is presently sponsoring research into this matter? What are the prospects?

Answer 18

Response to this question requires a brief review of radioactive decay. Whenever a new radionuclide is identified, two properties always investigated by scientists are the method by which the radionuclide disintegrates, or decays, and the rate. For every radionuclide yet found (over two hundred) the method is found to be constant and for any selected increment of time, the fraction of atoms present at the start of the increment which decays during the increment is also constant. (This constant decay fraction is arithmetically related to the physical half-life). In other words, the constant nature of decay method and decay half-life are verified by such a body of evidence that we consider them to be natural laws.

If we are asked to "turn off" radiation we must, in effect, either find that we are mistaken in our understanding of these natural laws, or else find exemption from them. Of course, it was not very long ago that scientists were taught, as a natural law, that matter is indestructible. Hence, it would be unwise to make a categorical statement that no such exemption could ever be found. However, the prospects are not bright for practical application of such an exemption even if the theory were to be developed by continuing basic nuclear physics research. It seems reasonable to assume that a fundamental property of a nucleus (the decay constant) can only be changed, if at all, by some kind of bombardment of the nucleus.

This immediately suggests two limitations:

(1) Actual radioactive wastes are almost never composed of a pure radionuclide or even mixtures of pure radionuclides. There are usually very large numbers of non-radioactive (stable) atoms physically or chemically combined with the radioactive ones. In any nuclear bombardment of an actual specimen of radioactive wastes, there would always be a question whether the desired effect upon the radioactive atoms would be negated by an undesired effect upon the stable atoms.

(2) If neutrons from a nuclear reactor are chosen as the projectile for the nuclear bombardment, they can only be produced by burning (fissioning) nuclear fuel. There would always be a question whether the value of the desired effect from the bombardment would be negated by the significance of the new wastes generated in burning the fuel.

One variation on the thought of "turning off" radioactive decay is to accelerate it so that the radioactive wastes need be stored a shorter time. This is theoretically possible for a number of the fission products which by simple neutron capture are converted to new radionuclides of shorter half-life. This approach has been proposed previously but has not been adopted because of the limitations noted above.

As a final comment, there is a theoretical possibility that under the extreme conditions in a controlled thermonuclear (fusion) process, atoms could be broken down into their subatomic components. In a recent Nobel

Symposium address, Chairman Seaborg mentioned such a process as of possible future use in waste disposal. The AEC sponsors research and development in controlled thermonuclear processes but this has not reached the stage where this process can be explored.