ECOLOGICAL HAZARDS FROM NUCLEAR POWER PLANTS

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INTRODUCTION

The growth of the nuclear industry in the United States has been the natural consequence of an increasing need for electrical power coupled with governmental programs dedicated to success in peaceful exploitation of nuclear energy. More than one hundred nuclear-fueled electric power plants are already planned. In addition to the growing nuclear power industry in the United States, the United States Atomic Energy Commission is pressing plans for major nuclear plants in other countries. These plans are summarized in a recent AEC news release:[1]

> ". . .A typical industrial complex such as those studied could include interrelated industrial processes for the production of fertilizers, aluminum, phosphorus, caustic-chlorine and ammonia. The agro-industrial complex would be located on the sea coast and include large scale desalting of sea water for highly intensified irrigated agriculture. Nuclear reactors producing low cost power would serve as the energy source for the electrical and other energy requirements of the complexes.
>
> The study indicated that the energy center concept might have application in Australia, India,

Mexico, the Middle East, Peru, and the United States. Included are a number of locations where agro-industrial complexes could be attractive and provide needed food supplies to the regions. It is expected that the energy center concept may be attractive for other areas not specifically identified in the report. . . ."

Detailed discussion of these plans has already been held with the governments of India, Mexico, and other nations of less industrial development. In another recent AEC news release these agro-industrial complexes are discussed with particular reference to the Middle East:[2]

". . .The study group, including experts from Government, industry, foundations and universities, will estimate the power and water requirements of the Middle East: survey the sources and availability of raw materials for industrial products; survey the domestic and export markets including price and demand relationships for the products from such a complex; identify specific locations where the soil, climate and other conditions are suitable for agricultural development using desalted water for irrigation; design and estimate costs for agro-industrial complexes at specific locations; and define the need for experimental or pilot projects to assure the success of larger projects. . . ."

In view of the tremendous potential for ecological change which would result from these complexes, it might be expected that the advice of ecologists and other biologists would be sought in the planning of these technological programs. Little mention is found, however, in the releases of the Atomic Energy Commission or its associated industries and agencies. One does find remarks such as were made by AEC Commissioner James T. Ramey at a recent meeting:[3]

> ". . .Today the engineers have command (of the fast reactor development) and are busily seeing to it that a solid technical base is laid for the construction of demonstrations plants. The day is near at hand when the executives, the financers, and the lawyers will begin to play a key role in providing the management initiative, the indispensable dollars, and the sound arrangements for building these demonstration plants."

And later in the same address:

> "The potential of nuclear desalting is international--covering the whole rim of the Mediterranean including Spain, Italy, Greece, Israel, and the Arab countries, together with India and Pakistan, as well as our own Southwest and Latin America--and I am sure we will ultimately see this potential realized. However, the problems of management may be further complicated by the addition of foreign countries, international organizations, and all of the other complexities associated

with international relations."

Although these remarks were made at a meeting of the Federal Bar Association, and perhaps the emphasis on management and financing was appropriate, it does seem that mention might have been made of the bio-system which might be affected by these giant industrial complexes.

The environmental implications of the nuclear industry are not being entirely ignored. The transcript of a series of hearings before the United States Joint Committee on Atomic Energy contains a section headed "ecological considerations."[4] The entire section reads:

"Representative Holifield. But it [the reactor] would require more extensive cooling towers, and therefore it would be more expensive?

Mr. Ramey. To that extent, yes, sir.

Representative Hosmer. These are fads. Coming into the climate of economics of these plants are some sociological considerations, I gather. Thermal effects must be technologically zero, plants must be pretty and out of sight, and heaven knows what else, as we develop all of these things.

Regulation must be contended with in ever-increasing degrees. Doesn't that throw some variables in your economics of plants that you have to consider?

Mr. Ramey. I think these would have some effects, yes.

ECOLOGICAL CONSIDERATIONS

Representative Hosmer. Let us try to get into this thing. I would like to get a feeling for this ecological basis.

When Senator Aiken's ancestors came up to Vermont they took all of the pretty stones and took them out of the fields, and piled them up to make fences out of them. And they cut down and burned up the trees, and they dragged their wagon wheels all over the countryside and chased the Indians away and made other changes and they have been doing it ever since.

Mr. Ramey. There are some who love it, though.

Senator Aiken. They weren't ecological at that time. Ecology is a recent part of a lot of people's vocabulary.

Representative Hosmer. It is a fad.

Senator Aiken. I think so.

Representative Hosmer. We have gone through these dialogs and these other semantics around here, but I guess it is important. Some people think it is.

How much of this nature is going to have to be left unchanged in relation to a constantly increasing population and industrialization, and all of the other things?

We can talk about ecology all we want but who is going to make the rules as to what changes are within the ballgame and what are not?

NUCLEAR REACTORS

A nuclear generating plant, Figure 1, is similar to a conventional steam plant. Exceptions are that the heat source, the reactor core, depends on the fission reaction in uranium, instead of burning coal, oil or gas.

Heat is generated in the reactor core and is transferred to the primary coolant water surrounding the core. This water is heated, converted to steam and passed through a pipe into the turbine-generator where electricity is generated. After passing through the turbine, the water is recondensed in the condenser and is pumped back into the primary reactor vessel to complete the primary coolant loop. In some reactors there is an intermediate heat-exchanger so that the primary coolant does not itself pass through the turbine. The single-cycle system described here is characteristic of a boiling-water reactor.

The primary coolant water, which is in direct contact with the core, is contained in a closed system. However, the turnover rate of this water is on the order of one month. Approximately once a month this water is exchanged, not all at once, but in a gradual process of leaks and purposeful removal.

Cool water, the secondary coolant, passes into the condenser and removes the waste heat. For every three units of heat in the steam, one unit is converted to electricity and two units are waste. The secondary coolant may pass to and from the environment without any particular restrictions. The radioactive discharges are not necessarily contained in the secondary coolant, but are put there in the systematic turnover and deliberate release of primary coolant water and gases which have been in direct contact with the reactor core.

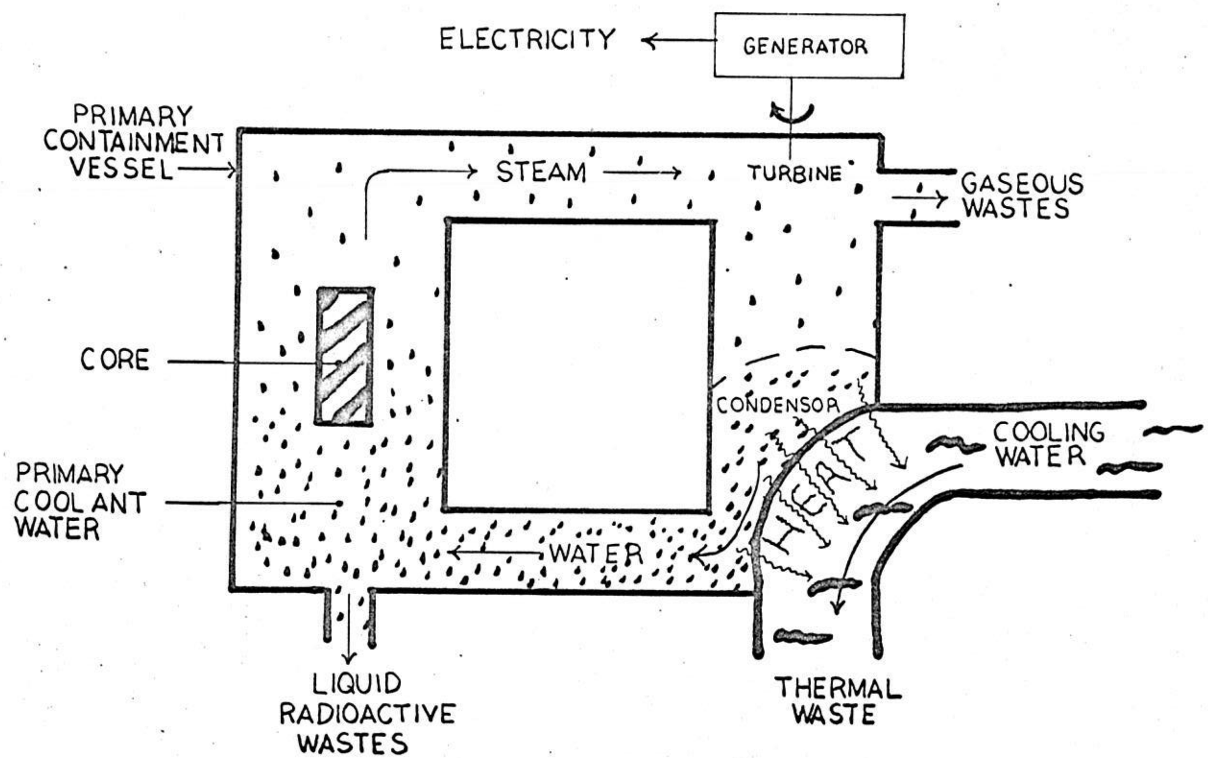

Figure I

BOILING WATER NUCLEAR POWER STATION

QUANTITY OF THERMAL WASTE

Thermal waste is the pollutant common both to conventional and nuclear plants. The lower efficiency of nuclear plants, however, means that they must disperse about fifty percent more heat into the environment. The quantity of waste heat from electric generating plants can easily be computed: It is directly proportional to the size of the plant (at least for the new, large plants), and is produced at the rate of 6000 BTU per kilowatt capacity for a conventional plant, and 8500 BTU[5] per kilowatt capacity for a nuclear plant. Thus a nuclear plant with a capacity of 1,000,000 kilowatts of electric power must dispose of approximately 2.4 million BTU per second. If this quantity of heat were released into a river having a flow rate of 1000 cubic-feet per second, the entire river temperature would rise by 33 degrees Fahrenheit. This is also sufficient heat to furnish the entire heating needs of approximately 300,000 two-story houses in a sub-Arctic climate such as is found in Minnesota.

EFFECTS OF THERMAL POLLUTION

The biological and other effects associated with thermal pollution have been discussed at length in several recent publications, some of which are listed in the bibliography. Some of the frequently mentioned effects are:

Thermal death--The sudden death of aquatic life due directly to increased temperature.

An increased predation rate, due for example to changes in avoidance reactions induced by temperature changes, decrease in swimming speed and stamina, etc.

Increased susceptability of aquatic organisms to chemical or physical toxins.

Disruption of normal biological rhythms.

Disruption of migration patterns.

Decreased oxygen concentrations in heated waters at the same time as oxygen requirements of the organisms are increased because of the increase in temperature.

Increase in anaerobic organisms with putrification of sludge, etc.

Increase in rooted plant growth leading, for example, to decreased flow rates, increased siltation, and a total disruption of the biosystem.

Increased susceptability to pathogenic organisms.

Decreased spawning success and decrease in survival of young fish.

Death from thermal shock caused by rapid changes in water temperature.

Increased growth of taste and odor producing organisms such as blue-green algae.

Changes in efficiency of water purification and treatment methods.

Effects on various industrial processes which are temperature dependent.

Replacement of cold water species by other species.

Effects on swimming and other recreational used; increased decomposition of sludge, increase in sludge gas, increase in saprophytic bacterial and fungi, increase in algae formation.

Increase in incorporation of radioactive wastes into organic material and hence into the food chains when radioactive wastes are discharged along with thermal wastes (for example in association with a nuclear power plant).

Arecent report of the National Technical Advisory Committee to the Secretary of the Interior includes a tabulation of provisional maximum temperatures for fish and their biota, Table I

Table I

Provisional maximum temperatures for fish and their biota. From summary of NTA report, Environmental Science and Technology, Volume 2, Number 9, September 1968 pages 662-663)

Temperature	Maximum for
93 °F	Growth of spotted bass, white or yellow bass, gar, catfish, buffalo, carp, sucker, gizzard shad
90 °F	Growth of largemouth bass, drum, bluegill, crappie
84 °F	Growth of sauger, walley, perch, pike, smallmouth bass
80 °F	Spawning and egg development of gizzard shad, catfish, buffalo, threadfin shad
75 °F	Spawning and egg development of largemouth bass, white bass, yellow bass, spotted bass
68 °F	Growth or migration routes of salmonids and for egg development of perch and smallmouth bass
55 °F	Spawning and egg development of salmon and trout (except lake trout)
48 °F	Spawning and egg development of lake trout, walleye northern pike, sauger, Atlantic salmon.

It is possible that the vast quantities of heat from power plants be used in a constructive manner. Several such possibilities have been suggested, and are discussed in some of the articles cited on thermal pollution. Once again, however, it has been an economic question in most instances; is there more immediate economic gain from utilizing the waste heat in a constructive manner or from releasing it into the river, lake or estuary? It is only relatively recently that the true costs associated with thermal pollution have been considered. If other nations follow the pattern set by the United States--the construction of ever-larger central power stations--they may benefit by counting those costs in their planning.

RADIOACTIVE WASTE PRODUCTION

To understand the processes by which the radioactive wastes can escape into the local environment, it is necessary to consider briefly the construction of a reactor. The reactor fuel, usually uranium dioxide, is formed into small pellets, Figure 2. These pellets are stacked into a long, thin-walled tube, the cladding, to make up the fuel rods. Each fuel rod is approximately one-half inch in diameter and twelve feet long.

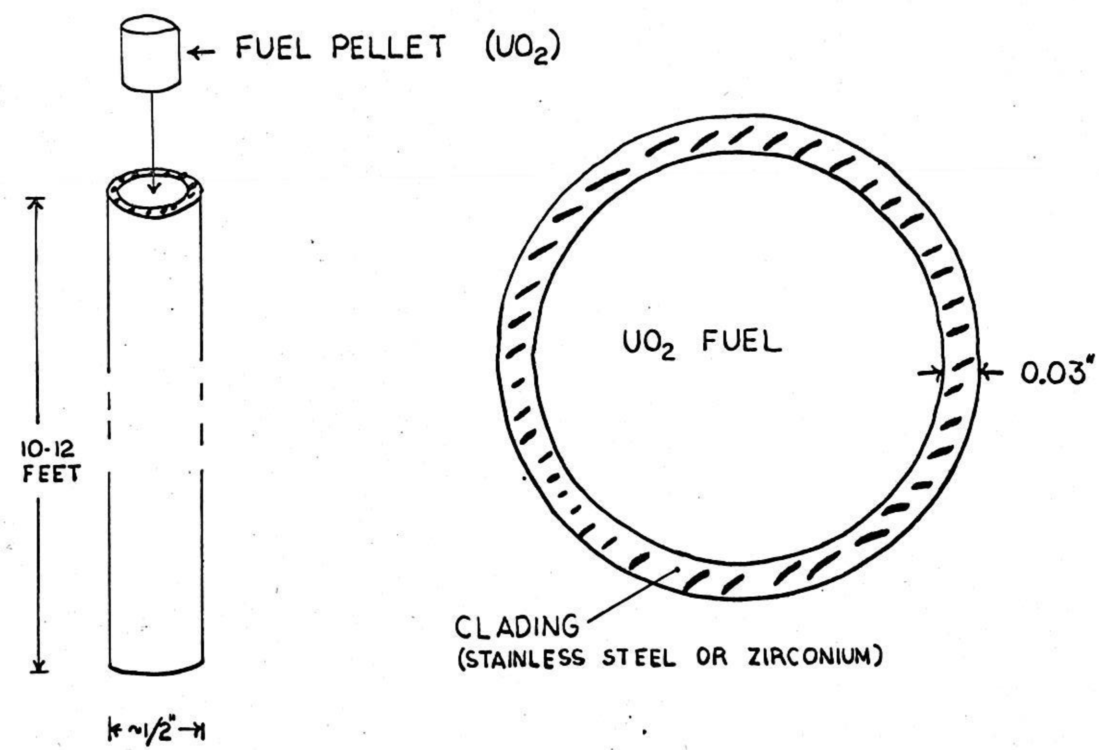

Figure 2

REACTOR FUEL ROD

The fuel rods are assembled into fuel elements which in turn are stacked into a larger mechanical structure to form the reactor core, Figure 3A. The core of a typical 500,000 kilowatt nuclear plant contains approximately 23,000 fuel rods. The primary coolant circulates through the spaces between the individual fuel rods. A configuration often used in the reactor core is four fuel assemblies, each containing dozens of rods in a rectangular array with a control rod between them, Figure 3B. A control rod is a long steel assembly which contains a substance, such as boron-10, having a high affinity for neutrons. With the control rods fully inserted into the core, enough neutrons are absorbed so that a chain reaction cannot take place. When the reactor is to go critical (the chain fission reaction is to begin) the control rods are pulled out a certain distance.

The reaction itself is fission of uranium-235. A neutron is absorbed by the uranium nucleus resulting in an extremely unstable product which splits, producing on the average 2.5 neutrons and two new nuclei, the fission or daughter products, Figure 4. Approximately 200 Mev[6] for each fission is also released and appears as heat in the primary coolant.

The fission products cause difficulties both regarding the operation of the reactor and the contamination of the environment. Many of the fission products have a high affinity for neutrons and can ultimately poison the reactor by absorbing

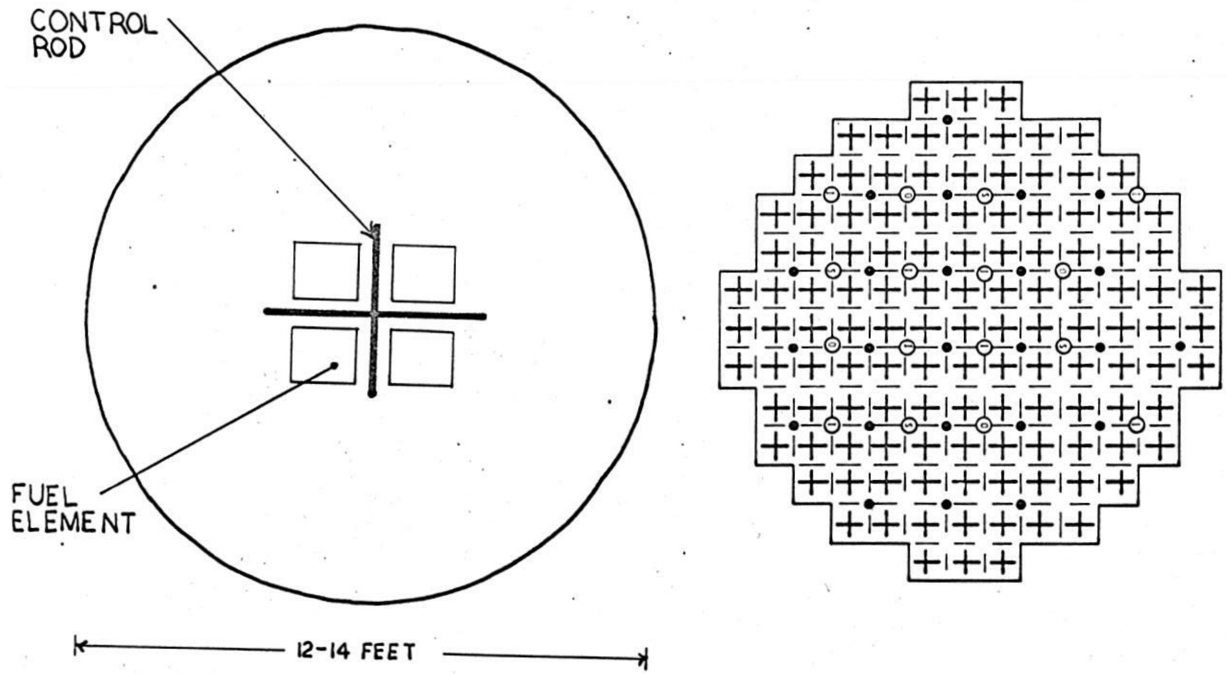

Figure 3

REACTOR CORE

sufficient neutrons so that the chain fission reaction can no longer take place. The fission products are also highly radioactive with half-lives between fractions of a second and millions of years.

The fission product abundance spectrum peaks in the vicinity of nuclear mass 95 and again near 140. Radioactive isotopes which are particularly significant from the environmental and health standpoints, such as strontium-90, iodine-131, and cesium-137, are produced in large quantities, Table I. These fission products must be kept out of the environment because of the well known dangers associated with ionizing radiation. The total activity of fission products produced in a typical reactor core per year is approximately one billion Curies per year.[7] For comparison, theexplosion of the nuclear bomb at Hiroshima released only a few hundred thousand Curies of long-lived radiation.

A further source of radioactive wastes are the activation products produced by reactions between contaminants in the primary coolant and the high neutron flux present in the coolant. Many of these activation products are of environmental significance. The activation products are formed directly in the primary coolant and are released into the environment, except as they are removed by the waste treatment system. Nuclear power stations now being planned include some treatment facilities for the effluent streams.

Radioactive hydrogen, tritium, is not included

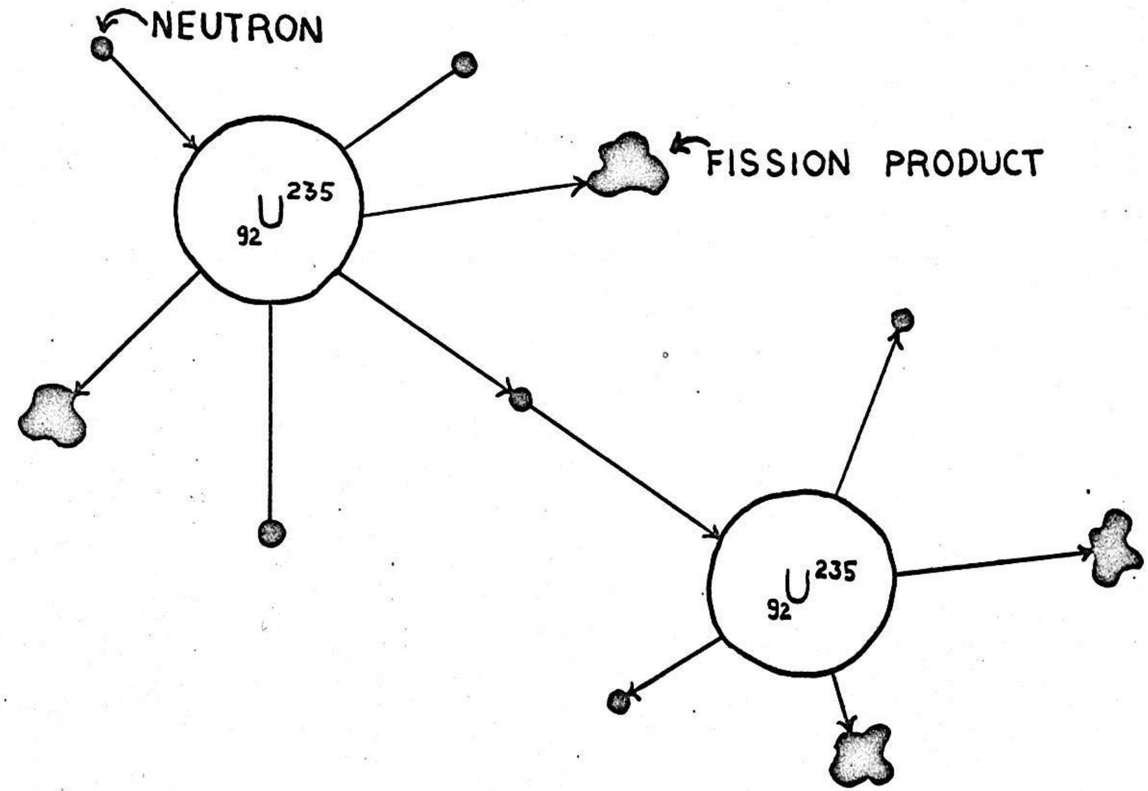

Figure 4

NUCLEAR FISSION

in Table II although it is a fission product. More tritium is formed via other reactions than via fission. The quantity of tritium produced and released is considered later as an example of a radioisotope not removed by the waste treatment systems.

TABLE II

Some fission products which are important to public health and to environmental contamination. (U.S. Dept. Health, Education and Welfare, 1966)

MASS	NUCLIDE AND HALF-LIFE		CRITICAL ORGAN	QUANTITY PRODUCED*
85	Krypton	10.6 years	Lung, skin	0.3
89	Strontium	51 days	Bone	58.5
90	Strontium	28 years	Bone	1.5
131	Iodine	8.1 days	Thyroid	36.0
133	Iodine	21 hours	Thyroid	36.0
137	Cesium	30 years	Total body	0.5
141	Cesium	33 days	Total body	76.5

* Millions of Curies (excluding daughter products) of fission product produced in a 500 Mw(e) reactor during one year of operation followed by one day of decay.

RELEASE OF RADIOACTIVE WASTE INTO THE ENVIRONMENT

Some of the fission products escape into the primary coolant and are available for release into the local environment. In addition, the bulk of the activation products are formed, or can diffuse into, the primary coolant. It should be emphasized that not all of the fission products which are produced are available for local release. Also, those radioactive wastes which are released are done so deliberately. They are released because it is cheaper to do so than to retain them; the only gain because of their release is a slightly (and to date unspecified) reduced power cost to the consumer.

The fission products are produced in the uranium oxide fuel pellets. The cladding surrounding the fuel is 0.02 to 0.04 inches thick and is surrounded by the primary coolant water, Figure 5. Fission products can pass through intact cladding by diffusion, and other processes, or they can pass through defects in the cladding. There are approximately 250,000 linear feet of cladding in a typical reactor core. It is difficult to fabricate this amount of thin-walled tubing without leaks either initially or developing after prolonged exposure to high temperatures and high neutron flux.

The waste disposal system of a power reactor is designed on the basis of a maximum of one percent of the fuel rods having cladding defects. This does not imply that one percent of each of the fission products necessarily escape, or that there will be one percent defects in each reactor core. Some initial cores have had high leak rates, and others have not had significant leaks after a year or more of operation. Nevertheless, passage of fission products into the primary coolant is the major source of radioactive wastes which are available for release into the local

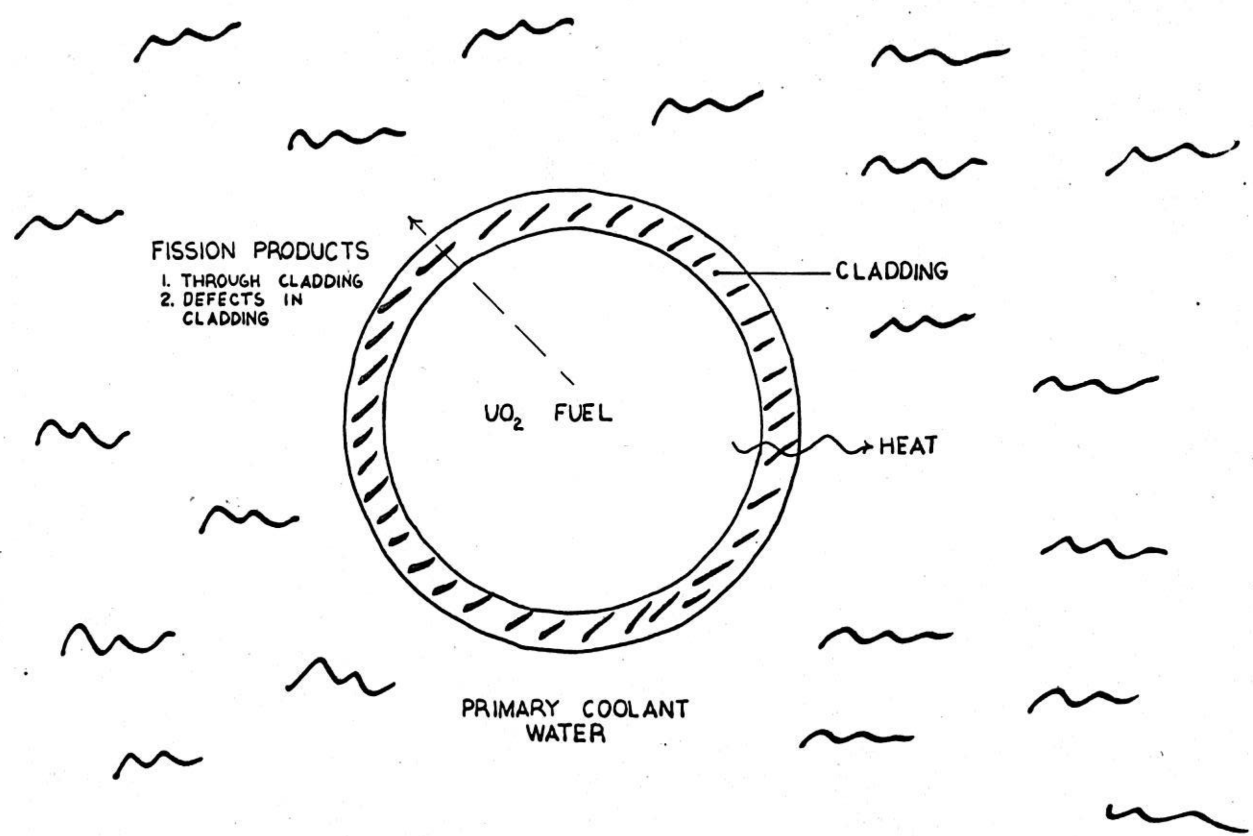

Figure 5

PASSAGE OF FISSION PRODUCTS TO PRIMARY COOLANT environment. The fission products which are retained in the reactor fuel are transported to waste reprocessing plants. The treatment and storage of these high level wastes, each gallon of which contains more radioactivity than all the radioactive material that has ever been shipped from the Atomic Energy Commission's laboratory at Oak Ridge for scientific purposes, is also a very serious problem.

The radioactive wastes take three forms; solid, liquid and gaseous. The solid wastes are packaged and shipped to waste disposal plants. These wastes escape into the local environment only in the event of an accident.

The gaseous wastes are primarily radioactive fission and activation products which are carried over into the turbine with the steam, but do not recondense as does the water. These gases are discharged into the local environment, using an approximately 300 foot stack to aid in their dilution.

Leaks in the primary containment structures, drains from the laboratories and purposeful removal of the primary coolant give rise to the liquid radioactive wastes. It is usually proposed to treat this water and then to add it to the condenser cooling water (the secondary coolant) in the discharge canal. The secondary coolant does not contain significant quantities of radioactive wastes; however, prior to its return to the river, these wastes are added to it.

THE QUANTITY OF RADIOACTIVE WASTE

The quantities of radioactive wastes which are discharged into the local environment are not as well known as are the quantities of thermal waste. The quantities of fission products produced in the reactor are known, and it is possible to estimate the quantities of activation products. To be produced is not, however, equivalent to being released. Much of the current controversy regarding nuclear power plants is due to the uncertainties in the quantities of the radioactive wastes expected from the current generation of nuclear power plants. Not only have measurements in existing reactors not been adequate to predict waste quantities, but the design features of these plants are changing. Many features of the current generation of nuclear plants have not been tested in existing reactors. This apparently includes the waste treatment systems as well as engineering features of the reactor itself.

To be able to predict the environmental or public health danger due to the radioactive releases from these plants, it would be necessary to know the quantities of each nuclide in the waste and also the chemical form of the nuclide. These data are not available. The release of a given quantity of strontium-90 or iodine-131 cannot be equated with the same quantity of, for example, one of the radioactive noble gases.

The manufacturer does estimate the quantities of wastes from nuclear power reactors. These estimates should probably be interpreted as lower limits. Although these estimates are made for nuclear electrical generating reactors, they would probably also apply for a large reactor used, for example, for desalinization. A large boiling-water reactor (1,000,000 kilowatts electric capacity) would discharge a minimum of 12,000 Curies of gaseous waste per year. In the case of one percent fuel leaks, the gaseous waste would be made up primarily of fission products and would be discharged at a rate approaching 20,000,000 Curies per year. In making these estimates, it is assumed that over 99 percent of the gaseous halides would be removed by filtration so that the bulk of the gaseous discharge would be noble gases. A review of the research and development efforts of the Atomic Energy Commission shows that several of these efforts are associated with the removal of iodides from reactor effluents. That such research is necessary, and that all of the gaseous wastes released are not noble gases is suggested in the conclusion stated in the report of a study done at the University of Nevada:

> "This constant level [of iodine-131 in the thyroid glands of cattle] in the absence of [nuclear weapons] testing indicates that all the I-131 in the biosphere is not from nuclear explosions. Some other processes must be producing I-131 at a reasonably constant rate and in copious quantities. The principal known source of I-131 that could contribute to this level is exhaust gasses from nuclear reactors and associated fuel

Radioactive iodine is one of the most noxious of the wastes being produced by nuclear reactors. The various radioactive isotopes of iodine are also among the most abundent of the reactor wastes. Approximately 72,000,000 curies of I-131 alone are produced per year in a 1,000,000 kilowatt (electrical) nuclear reactor.

The radioactive wastes in the liquid effluent from a plant of this size can also be estimated, but the quantity of these wastes depends critically on the extent of the waste treatment employed. The only component of the liquid waste which can be estimated with reasonable accuracy is tritium, radioactive hydrogen. No waste treatment yet proposed will remove tritium from the liquid or gaseous effluents from nuclear reactors. The total quality of tritium which is produced by a 1,000,000 kilowatt (electrical) nuclear plant has been estimated at 130,000 curies during its first year of operation and somewhat less in subsequent years. With present practice, all of this tritium is released either at the reactor site or at the site of the fuel reprocessing plant. The United States Public Health Service has estimated that about half of the tritium is released at the reactor site.

The various estimates for the total radioactive discharges from a 500,000 kilowatt boiling-water reactor now being constructed in Minnesota are listed in

Table III.

The phenomena associated with radioactive materials and the units used to measure quantities of radioactivity are outside of our usual experience and it is difficult to convey a "feeling" for these quantities. Although it is not directly applicable in terms of biological effect, it is useful to compare the quantities of radioisotopes from weapons testing or nuclear reactors with the quantity of radium which would contain the same amount of activity. A Curie is equivalent to the activity in one gram of radium. We can all recall the excitement and intensive searches instituted when a capsule containing a few milligrams of radium had been lost or misplaced. Yet the quantity of radioactivity proposed for release from a single nuclear power plant each year, even under the most optimistic assumptions as to its operation, is several times the activity in the entire world supply of radium. We are being asked lightly to dismiss this discharge of radioactivity.

Tritium discharge can also be used to illustrate another point which has confused discussions fo radioactive wastes and the quantities of radioisotopes already present in the environment. It has been suggested that the added tritium would not be greater than the quantity of tritium already present in, for example, the Mississippi River. However, this tritium is itself due to pollution via the fallout from weapons testing, and <u>does not</u> form a part of the so-called "natural background of radiation present in the environment."

TABLE III

Estimates of the total radioactive wastes to be discharged at the site of a (1500 MW (t), boiling-water, reactor currently being constructed at Monticello, Minnesota.

DESCRIPTION OF WASTE AND ESTIMATE	ESTIMATED ANNUAL DISCHARGE CURIES
Total gaseous, without leaky fuel, as estimated by reactor operator	6,000
Total gaseous, with leaky fuel, as estimated by reactor operator	9,000,000
Tritium in gaseous effluent, with or without leaky fuel	
First year of operation	3,000
Subsequent years	1,500
Total liquid, without fuel leaks, as estimated by reactor operator	0.365
Total liquid, with fuel leaks, as estimated by reactor operator	91.4
Tritium in liquid effluent, with or without fuel leaks	
First year of operation	27,000
Subsequent years	13,500

Prior to the advent of weapons testing and nuclear reactors the surface waters of North America had an average tritium concentration of less than 10 picoCuries per liter.[9] The present tritium concentration in the Upper Mississippi River is in the neighborhood of 2000 picoCuries per liter. It matters little to the environment or to the individuals exposed to this radiation whether it arose from weapons testing or from waste from nuclear power stations. The fact that weapons testing has increased our exposure to radiation seems a poor argument indeed for the creation of an even greater risk by discharging radioactive wastes from nuclear power stations.

In present practice, tritium is not the only radioactive isotope which is released to the environment without any significant control. The noble gasses are also so released, either at the reactor site or at the fuel reprocessing plant. It has been estimated that the exposure due only to one of these isotopes, krypton-85, will approximately equal the exposure from natural sources of ionizing radiation by the year 2000 if the releases of krypton-85 continue from new reactors as they have from existing reactors.

It was not until 1960 that it was recognized that tritium was being produced in nuclear reactors, and very few measurements have been done which indicate the quantities of tritium being released from operating plants. Work is now underway in several places to arrive at realistic estimates of tritium production and release, and the total buildup that would be expected were present radioactive waste practices to continue.

RELEASE OF RADIOACTIVE WASTES--MAJOR ACCIDENTS

It is considered normal in the operation of a nuclear reactor to discharge thousands or millions of curies per year into the local environment. At present, radioactive products such as the noble gases and tritium are always discharged either at the reactor site or at the fuel reprocessing plant. An attempt is made to retain the bulk of the other radioactive wastes, particularly those of long half-life, or of particular biological significance.

The risk associated with a major reactor accident is that these radioactive fission and activation products will be suddenly released into the environment. It is impossible that a reactor accident will resemble the tremendous explosion which is associated with a fission bomb--an atomic bomb such as was used in the latter days of World War II. The accidents which can take place in a nuclear reactor are not these large explosions, but rather are incidents which lead to local release of the fission products from the reactor core.

It was stated earlier that several billion curies of radioactive materials are accumulated during a year of operation in a major reactor. As has been pointed out, a fraction of these wastes are released during "normal operation" of the reactor. Another fraction of these wastes will decay. The bulk of them are, however, retained in the reactor fuel. They are retained with the uranium and held within the cladding of the fuel rods.

Several types of major accidents are sometimes postulated; they are assumed to result in the melting or the physical disruption of the reactor core. This event would probably be accompanied by a steam explosion or a chemical reaction between the coolant, the fuel and the structural metals of the reactor. The net result would be the sudden release of up to several million of curies of radioactive wastes. The dispersion of these materials would depend on the local circumstances, local meteriology, and so forth.

Several years ago, the Atomic Energy Commission published a report which considered these major reactor accidents; this report is "Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants", U. S. Atomic Energy Commission Report Number WASH-740, March, 1957. It must be clearly stated that the type of accident considered in this report, and considered during the safety analysis of each reactor, is highly unlikely. The Atomic Energy Commission and its advisors devote a great deal of effort toward review of nuclear reactors to assure that they are designed such that a major accident will not occur. Various engineering safeguards are incorporated into each plant--safeguards which are said to assure that the probability of a major accident is very small.

However, the probability is not negligably small, and there is evidence for this conclusion. For a complete discussion of this point, the reader is referred to the various documents which relate to the Price-Anderson Indemnity Act and the other documents relating to insurance and indemnity provisions associated with the construction and operation of reactors in the United States. The probability of a major accident with the resultant release of radioactive materials is very small, yet it is high enough that insurance companies will not assume the risk.

For a description of the major accidents and their result, it might be best to quote a fairly large section of the AEC report mentioned above, WASH-740. After a detailed consideration of the various factors which might be involved in a major accident in a then-typical reactor near a large city, the report concludes:

<u>Observations and Remarks</u>

> "The numbers shown in the previous summary are calculated on the basis of what we believe to be the best available assumptions. data and mathematical methods. As has been stressed eleswhere, there is considerable uncertainty about many of the factors, techniques and data, so that these numbers are only rough approximations. Where information is sufficiently complete we have chosen values to represent the most probable situation but where high degrees of uncertainty exist we have

(Continued on Page 29 a)

chosen values believed to be on the pessimistic (high hazard) side. The results shown would be quite sensitive to variations in some of the factors which were used.

The lethal exposures (following an accident) could range from none to a calculated maximum of 3,400. This maximum could only occur under the adverse combination of several conditions which would exist for not more than 10 percent of the time and probably much less.

Under the assumed accident conditions, the number of persons that could be injured could range from none to a maximum of 43,000. This high number of injuries could only occur under an adverse combination of conditions which would exist for not more than 10 percent of the time and probably much less. Depending upon the weather conditions and temperature of the released fission products for the assumed accident, the property damage could be as low low as about one-half million and as high as about $7 billion. For the assumed conditions under which there might be some moderate restrictions on the use of land or crops (Range IV), the areas affected could range from about 18 square miles to about 150,000 square miles."

Perhaps considerations such as these influence the commercial insurance companies when they consider the question of insuring large, nuclear plants.

In addition to major accidents at the reactor site, the possibility exists for accidents during the transportation of fuel from the site. The new fuel being transported to the site is relatively free from radioactive contaminants. The spent fuel, however, contains the vast quantities of fission products described, and an accident involving it might be depressingly spectacular. A detailed evaluation of this problem would require knowledge of the quantity of spent fuel included in a single shipment, the mode of transport, and the details of the country through which shipment was being made. It is a problem which bears consideration in evaluating the risks associated with a reactor program.

BIOLOGICAL EFFECTS OF RADIATION

Since the advent of the atomic age the evidence regarding effects of ionizing radiation has been increasing. Chadwich and Abrahams begin a paper reviewing these effects with a general review of the situation.[10]

"Knowledge that ionizing radiation is capable of causing deleterious effects in exposed individuals followed closely the discovery of x-rays by Roentgen in 1895. The history of the various unfortunate experiences with x-rays and radioactive materials is a familiar one: repeated severe skin burns suffered by the early physicists and physicians using x-rays, skin cancers occurring in some of these same individuals at the sites of the repeated burns, bone sarcomas occuring among those who used radium-containing luminescent paints on watch and clock dials, and more recently, various neoplasms occurring in some patients receiving x-ray exposures in clinical procedures. Thus it became quickly known that large doses of radiation can cause severe acute symptoms ranging from localized skin burns to generalized severe damage to vital tissues, such as bone marrow, and at high enough doses, death. Soon it began to be noted that some of those who recovered from the acute symptoms of over-exposure went on later to develop serious sequelae such as various kinds of neoplasms including, particularly, leukemia. And finally, perhaps most significant of all, it was noted that various groups who received more than the usual exposure to radiation showed many years later a higher than normal incidence of neoplasms--analogous to the situation of those recovering from acute effects of overexposure to radiation; but this time the longterm effects occurred in individuals who had not experienced any acute amnifestations of overexposure.

It can be seen that evaluation of the effects of radiation on man presents some difficulties.

Of course the acute effects--the acute radiation syndrome--occurring after whole body doses of hundreds of roentgens are relatively well understood. However, much more needs to be known about the long-term effects. These effects are not different from usual disease conditions: genetic defects, various kinds of neoplasms, including leukemia. They are manifest as an increased incidence of these diseases occurring usually many years after exposure. Therefore understanding the long-term effects of radiation involves follow-up of often large numbers of exposed persons and comparing their disease experience with suitable controls.

On the other hand there is a tendency to overemphasize the limitations in our knowledge of the effects of radiation on man. Unquestionably there are gaps in our knowledge. We need to know much more abou the relationships between low-level radiation exposure and disease incidence, about the mechanisms of radiation damage, about subtle biochemical and physiological changes induced by radiation, and the possible relationships between these and later significant pathology. On the other hand the very recognition of these important gaps stems from the considerable body of data currently available."

Basic to the consideration of health hazards from any toxic material is the question of the dose-response relationship and the possible threshold level of exposure--the dose below which the substance has no detectable effects. This question is essential to the establishment of any standards for allowable exposure to ionizing radiation.

Some substances, generally considered to be quite toxic, can be taken in small quantities either acutely or chronically with no detectable effects. As the quantity is increased, a level is reached for which the most susceptable individuals begin to show the effect--this is the threshold dose for that substance. As the quantity taken in is further increased a level is finally reached for which all subjects show the effect. Substances of this nature have a response curve as shown in curve A of Figure 6.

There are other substances which may be taken into the body in small quantities without any detectable effect only so long as there is not chronic exposure. An acute exposure to such substances again have a response as indicated by curve A. If, however, these substances are taken into the body on a chronic basis, the threshold, if it exists at all, is much closer to zero, as shown in curve B. These substances are not rapidly removed by the body, but are stored in some manner such that the exposure on one day adds to that of the next day and so on. An example of such substances is lead for which there is a fairly high threshold for an acute dose, but a very low threshold for a chronic dose especially in children.

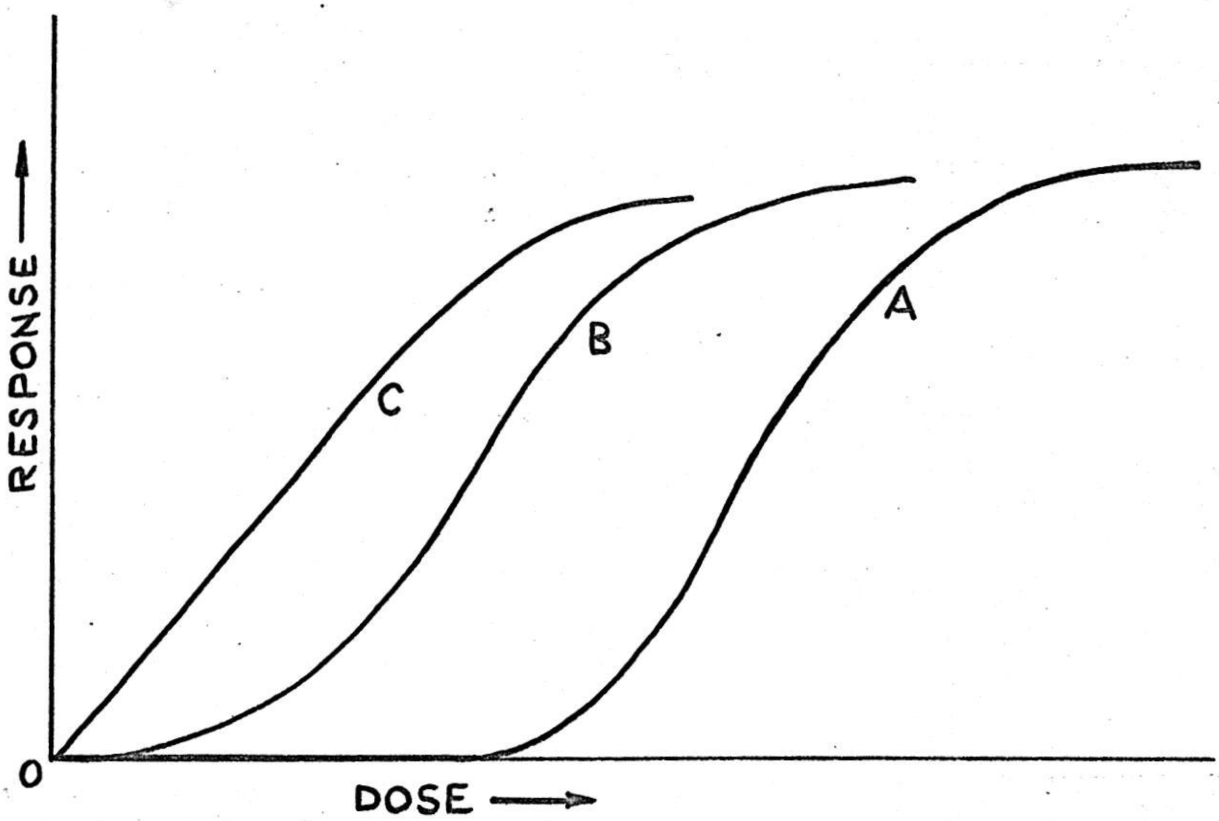

Figure 6

RESPONSE CURVES AND THRESHOLDS FOR RADIOACTIVE SUBSTANCES

In the case of ionizing radiation, it is generally accepted that there is no threshold exposure below which no effects will appear. Although all of the evidence is not yet available, the Federal Radiation Council has adopted the prudent assumption that a threshold radiation dose does not exist, and that". . . every use of radiation involves the possibility of some biological risk either to the individual or his descendents."[11]

The estimates of risks associated with exposure to radiation are often expressed in the number of cases of whatever is being considered per rad of radiation exposure per million people exposed. A rad is one of the units used to measure the quantity of radiation exposure. It has been shown, for example, that the average exposure to humans from naturally occurring sources of ionizing radiation is near 0.1 rad, or 100 millirads. This natural exposure comes from cosmic rays, radio-active isotopes in the ground and building materials, and radioactive materials in our food and water. The 0.1 rad exposure is that which existed prior to the advent of weapons testing with its resultant fallout, and does not include medical use of ionizing radiation.

Many neoplasms have been associated with radiation exposure, and anything approaching a complete review of the current literature is beyond the scope of this paper. The International Commission on Radiological Protection has summarized much of the available data, and has computed the risk of several cancers including leukemia and thyroid carcinoma. The values given for these cancers are:[12]

Leukemia: Twenty fatalities per million persons exposed to one rad. Between forty and two hundred fatalities per million fetuses exposed to one rad.

Thyroid carcinoma: Between ten and twenty cases per million children exposed to one rad.

Fatal cancers other than the leukemias: Twenty fatalities per million persons exposed to one rad.

Difficult as it is to assess the risks of the various cancers, it is even more difficult briefly to consider the genetic risks associated with ionizing radiation. Rather than attempt this discussion, the reader is referred to the International Commission for Radiological Protection Publication No. 8, and to the 1966 United Nations Report.[13] The genetic risks associated with ionizing radiation are of greater importance than are the somatic effects.

A reduction in life-span is also associated with exposure to radiation. If recent studies[14] in beagle dogs can be applied to man they suggest that for each exposure of one rad there would be an approximately two week shortening in life. The irradiated dogs tended to die of the same diseases as did non-irradiated dogs, but there was earlier onset of the diseases. To extend these results to man, however, assumes that the experiments are statistically valid, that they are directly applicable to man, that the percent change in life shortening observed in dogs is the same as it would be for man, and there is no threshold dose below which the effect would not be noted.

The present recommendation is that the general public should not be exposed to greater than 0.17 rads per year in excess of natural background without carefully considering the reasons for doing so. The U. S. Atomic Energy Commission regulations which are applicable to discharges of radioactive wastes from nuclear reactors nevertheless would permit the general public to be exposed to 0.5 rads per year. It is obvious that although the risk to any one individual from these exposures is relatively small, the risk to the population is large.

CONCLUSION

It is apparent that the nuclear industry is creating a major challenge to the environment in the U. S. The thermal wastes are immense in quantity and can cause drastic changes in the bodies of water involved. If the past performance of the nuclear industry is taken as representative of what to expect, there will be vast quantities of radioactive wastes discharged both at nuclear power plant (reactor) sites and at fuel fabricating and reprocessing plants. Even without the catastrophic releases which would result from a major accident, the introduction of these radioactive wastes poses a major threat not only to the current generation but also to the future of the human race. Perhaps the genetic effects which would result from the wastes of the nuclear industry can be tolerated--and perhaps they can not. It is a dangerous game to play, trading potential death and mutation for minor immediate economic gain. There is no reason why the radioactive wastes cannot be contained, but as usual it costs a little more to contain the wastes than to dump them into the nearest public waters or into the atmosphere.

A realistic attempt should be made to evaluate the hidden as well as the direct costs of "going nuclear" before decisions are made in any country that might lead to irreversible changes both in the physical environment and to the life presently existing on this planet.

Perhaps the adverse as well as favorable experience with nuclear technology in the U. S. will be of use abroad. This is certainly a field in which biologists have an obligation to offset the enthusiasm of nuclear developers.

FOOTNOTES

1. "Report on nuclear energy centers for industrial and agro-industrial complexes issued," U. S. Atomic Energy Commission News Release L-197, August 20, 1968.
2. "AEC studying potential of nuclear energy centers in the Middle East," U. S. Atomic Energy Commission News Release No. L-124, June 11, 1968.
3. "The next five years in nuclear development and regulation," James T. Ramey, U. S. Atomic Energy Commission News Release No. S-33-68, Sept. 5, 1968.
4. "Participation by small electrical utilities in nuclear power," Hearings before the Joint Committee on Atomic Energy, Congress of the United States, April 30, May 1, 2 and 3, 1968, part 1, page 37.
5. A British Thermal Unit (BTU) is that quantity of heat necessary to raise the temperature of one pound of water one degree Fahrenheit.
6. One Mev (million electron volts) equals 0.152 x 10^{-15} BTU (British thermal unit). One BTU/second equals 1.055 kilowatt.
7. Quantity of radioactivity is measured in Curies, with one Curie being the amount of radioactivity in one gram of radium.
8. C. Blincoe, AEC Contract No. AT(04-3) 34, Report TID 17229, 1963 and Report CONF-244-1, 1962.
9. One picoCurie equals 10^{-12} Curies. Concentrations of radioisotopes in environmental waters is usually expressed as picoCuries/Liter, pCi/L.

10. D. R. Chadwick and S. P. Abrahams, "Biological Effects of Radiation" Arch. Environ. Health 9, 643-648, 1964.

11. Background Material for the Development of Radiation Protection Standards, Federal Radiation Council, Report No. 1, 1960.

12. The Evaluation of Risks from Radiation, Publication No. 8 of the International Commission on Radiological Protection, Pergamon Press, 1966.

13. Report of The United Nations Scientific Committee on the Effects of Atomic Radiation, General Assembly Official Records: Twenty-First Session, Supplement No. 14 (A/6314) 1966.

14. L. S. Rosenblatt and A. C. Anderson, "Survival of control and x-irradiated female beagles, 1966 Annual Report, Univ. of California at Davis, UCD 472-113, pp. 10-16, 1967.

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