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Discharge of Radioactive and Thermal Wastes

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mitted from nuclear power plants should take into account that modern man is exposing himself to additional man-made radioactivity somewhat greater than that to which he has adapted himself through the centuries. A lower standard would clearly seem more appropriate, especially since the only cost is a slightly higher cost for electricity.

Another concept introduced by the Federal Radiation Council is that of a Radioactive Concentration Guide, defined as "the concentration of radioactivity in the environment which is determined to result in whole body or organ doses equal to the Radiation Protection Guide." After a Radiation Protection Guide is established, a concentration can be established for each radioisotope in the environment against which to compare observed concentrations. However, since an individual is usually exposed to more than one radionuclide, reliance on Radiation Concentration Guides could allow an individual to receive a total dose greater than the Radiation Protection Guide even though each radionuclide was within its concentration limit. This fallacy is promoted in the concentration limits set by the Atomic Energy Commission in its regulation 10CFR20. Reliance on concentration guides also ignores the presence of more sensitive targets such as the fetus, and cannot take into account the concentration of radionuclides through the food chain to man.

In the absence of a Federal Radiation Council statement of the risk contained in its standard of .5 rem, one may turn to Publication No. 8 of the International Commission on Radiological Protection (1966). A task group was set up in 1964 "to consider the extent to which the magnitude of somatic and genetic risks associated with exposure to radiation can be evaluated." Estimates are expressed as the number of cases of a specific injury type to be expected from the exposure of a specified number of people to a given radiation dose. Because of the imprecision inherent in the data, upper and lower bounds on the number of injuries to be expected are given rather than a single number. If we assume the population of the Twin Cities metropolitan area to be two million, then a continuing yearly exposure of .5 rem — the FRC standards dose — would be expected to cause from 10 to 100 cases of leukemia per year and about an equal number of other types of neoplasms. Estimates of the genetic damage from this dose are also available. Whether a loss of this magnitude is acceptable to society can only be determined by considering the benefits to be gained from a particular use of atomic energy. The Federal Radiation Council has given no indication of the uses of atomic energy for which *it* feels a loss of this magnitude is acceptable.

It appears unlikely that any single nuclear power plant will discharge sufficient radioactive waste to reach the FRC standard, even if the standard were revised to take into account existing man-made radioactivity.

Conclusion: Open Discussion Necessary

The nuclear power industry is still in its infancy, however, and little operational experience has yet been gained with the present generation of reactors. Indeed the Atomic Energy Commission has felt compelled to point out that it is unwarranted to ask the board to deal only with new features of reactor design because "the new features in these cases are not departures from established standards but from other reactors whose 'old' features remain in many cases untested."

What is wise public policy in this case, especially with so many untested reactors to be installed within a short period of time? The growing concern of both the scientific community and informed segments of the public demands that the problems associated with nuclear power — and indeed all peaceful uses of atomic energy — be subject to open discussion and further evaluation before irrevocable decisions are made.

Discharge of Radioactive and Thermal Wastes

ABRAHAMSON AND POGUE

ABSTRACT — A combination of several economic factors, together with growing concern about air pollution associated with conventional, fossil-fuel electric generating facilities, has contributed to the increase in size and number of nuclear-powered plants. Although these nuclear plants are "clean" from the standpoint of conventional air pollutants, they must dispose of thermal and radioactive wastes. This paper outlines the sources and quantities of these wastes, based on technical data for the boiling-water reactor proposed for Monticello, Minnesota.

Total electrical power production is expected to about double in the next ten years, with the biggest part of the increase coming from nuclear plants (U.S. Atomic Energy Commission, 1967).

A nuclear generating plant, Figure 1, is schematically similar to a conventional steam plant. Exceptions are that the heat source — the reactor core — depends on the fission reaction in uranium, and the wastes are radioactive fission and activation products. The waste heat from a nuclear plant also is considerably greater than from a conventional plant of the same generating capacity.

Heat is generated in the reactor core and is transferred to a primary coolant, usually water, surrounding the core. This water is heated, converted to steam and passes through a pipe to operate the turbine-generator. The water is then recondensed and pumped back into the primary reactor vessel to complete the primary coolant loop. In some reactors there is an intermediate heat-exchanger

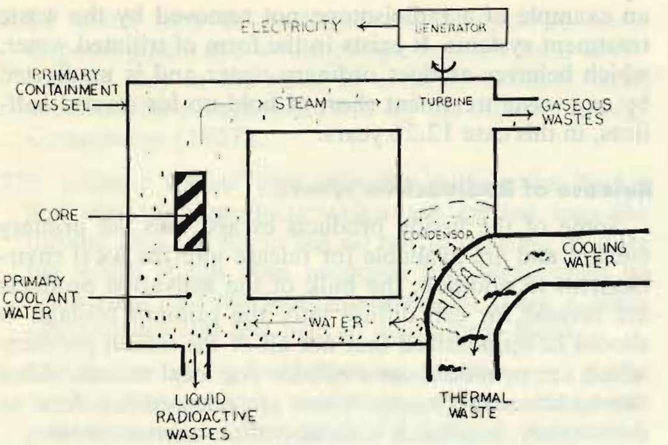

FIGURE 1.

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 proposed for Monticello, Minnesota. (The plant is now under construction).

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, being exchanged in a gradual process of leaks and purposeful removal.

Cool water, the secondary coolant, passes into the condenser and removes the waste heat. The thermal efficiency of a nuclear power plant is approximately 33 per cent. Thus, for every three units of heat generated, 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 due to the systematic turnover and deliberate release of primary coolant water and gases which have been in direct contact with the reactor core.

The Path of Waste Escape

To understand the processes by which the radioactive wastes can escape into the local environment, it is necessary to consider briefly the construction of the reactor core. 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.

The fuel rods are assembled into fuel elements which in turn are stacked into a larger mechanical structure to form the reactor core, Figure 3B. The core of the Monticello reactor 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 elements in a rectangular array with a control rod between them, Figure 3A. 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 (starting of the chain fission reaction) the control rods are pulled out a certain distance.

The reaction itself is fission of, for example, uranium-235 (Leachman, 1965). 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 [1] for each fission is also released and appears as heat in the primary coolant.

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

The fission product spectrum peaks in the vicinity of nuclear masses 95 and again near 140 (Leachman, 1965). Radioactive isotopes, which are particularly significant from the environmental and health standpoints,

[1] One Mev (million electron volts) equals 0.152 x 10-15 Btu (British thermal unit). One Btu/second equals 1.055 kilowatt.

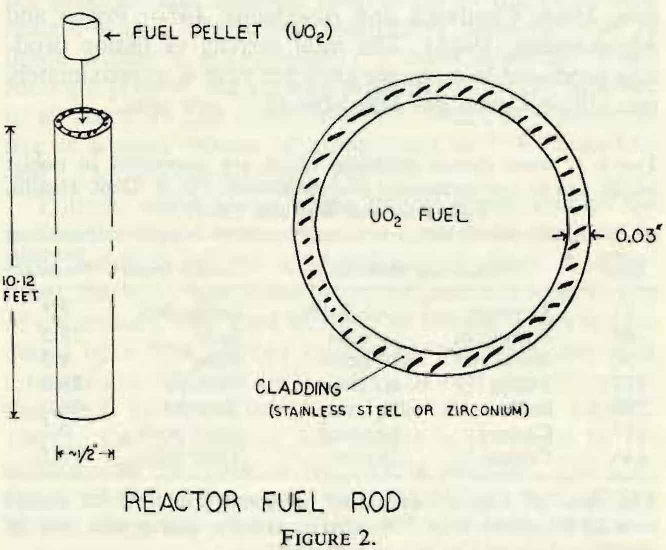

FIGURE 2.

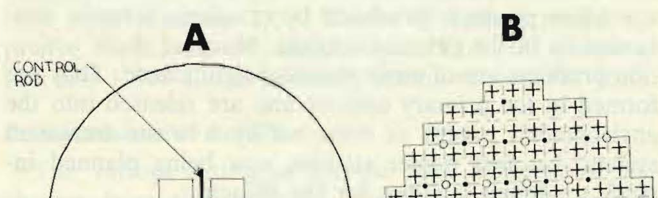

FIGURE 3.

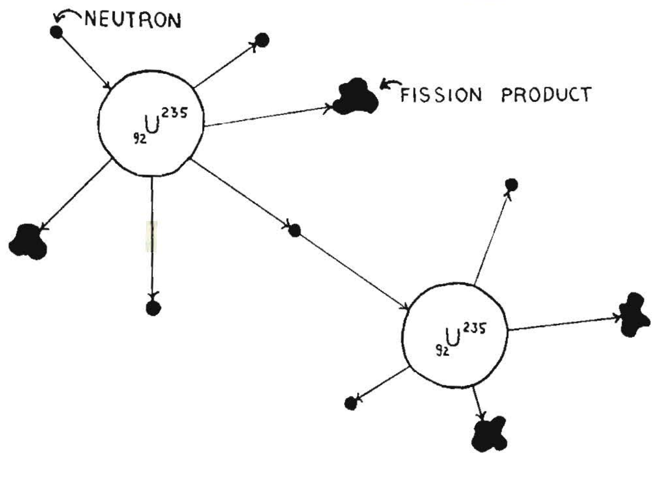

FIGURE 4.

such as strontium-90, iodine-131 and cesium-137, are produced in large quantities, (Table 1). These fission products must be kept out of the environment because of the well-known dangers associated with ionizing radiation (International Commission on Radiological Protection, 1966; Chadwick and Abrahams, 1964; Pogue and Abrahamson, 1968). The total activity of fission products produced in a reactor core per year is approximately one billion Curies per 500 Mw(e) [2] per year.

TABLE 1. 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.

A further source of radioactive wastes stems from the activation products produced by reactions between contaminants in the primary coolant. Many of these activation products are of environmental significance. They are formed in the primary coolant and are released into the environment, except as removed by a waste treatment system. Nuclear power stations now being planned include treatment facilities for the effluent.

Radioactive hydrogen, tritium, is not included in Table I, 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. It exists in the form of tritiated water, which behaves as does ordinary water and is unaffected by any waste treatment short of hold-up for several half-lives, in this case 12.26 years.

[2] Quantity of radiaoactivity is measured in Curies, one Curie being the amount of radioactivity in one gram of radium. Mw(e) (megawatt-electrical) is the unit used to describe the size of an electrical power plant.

Release of Radioactive Waste

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, because it is cheaper than to retain them.

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

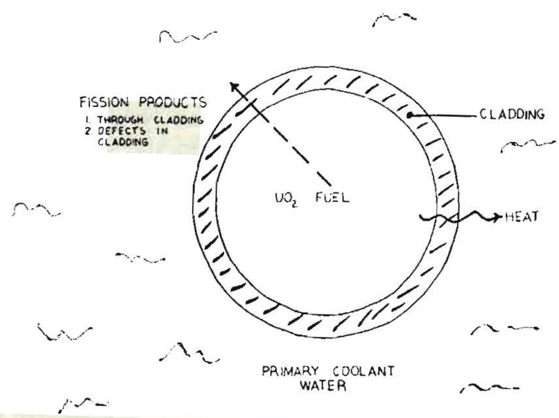

FIGURE 5.

intact cladding by diffusion and other processes, or they can pass through defects in the cladding. There are approximately 250,000 lineal 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 power reactors is designed on the assumption that one per cent of the fuel rod cladding will have defects. This does not imply that one per cent of each of the fission products escapes or that there will be one per cent defects in each reactor core. Nevertheless, passage of fission products into the primary coolant is the major source of radioactive wastes which became available for release into the environment. Fission products retained in the reactor fuel are transported to high level waste reprocessing plants. The treatment and storage of these high level wastes, each gallon of which contains more radioactivity than has all the radioactive material shipped from Oak Ridge for scientific purposes (Peterson, 1968), is also a very serious problem (Snow, 1967), but it is not in the province of this paper.

The radioactive wastes take three forms: solid, liquid, and gaseous.

Solid wastes may be packaged and shipped to waste disposal plants and would escape into the local environment only in the event of a major accident. Such accidents have been evaluated by the Atomic Energy Commission (1957).

The gaseous wastes are primarily radioactive fission and activation products which are carried into the turbine with the steam but do not recondense as does the water. It has been proposed that these gases be discharged into the local environment, using a stack approximate 300 feet high to dilute these gases.

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 before adding 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.

There is a direct relationship between the cooling water and the radioactive wastes. At present, the federal regulations applicable to radioactive wastes (Code of Federal Regulations Title 10) specify *maximum concentrations* of radioactive isotopes at the point of their discharge into public waters. Thus, a large volume of cooling water, 645 cubic-feet per second for the Monticello reactor, is depended upon to dilute the radioactive wastes to meet applicable regulations.

Lower Efficiency, Greater Heat

Thermal waste is the pollutant common both to conventional plants and nuclear power plants. The lower efficiency of nuclear plants, however, means that they must disperse considerably more heat into the environment. A 1,500 Mw(t) or 500 Mw(e) nuclear plant (the proposed Monticello plant is rated at 1,479 (Mw(thermal) or 490 Mw (electrical); each of the two units proposed for Prairie Island, Minnesota, is 1,650 Mw(t) or 560 Mw(e) must dispose of approximately one million Btu per second. If this quantity of heat were released into a river having a flow rate of 1,000 cubic-feet per second [3] the river temperature would rise by sixteen degrees F. It is also sufficient heat to furnish the entire heating for approximately one hundred thousand houses during a Minnesota winter.

Waste Quantity Unknown

The quantities of radioactive wastes which would be discharged into the local environment are not as well known as are the quantities of thermal waste. The quantities of fission products produced are known, and it is possible to estimate the quantities of activation products. To be produced is not, however, equivalent to being released or available for release. 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 plants. Many features of the current generation of nuclear plants, including waste treatment systems as well as engineering features, have not been tested in existing reactors.

To be able to predict the environmental or public health dangers 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 limits estimated for the radioactive gaseous effluent from the Monticello reactor are found in the technical description of this reactor (Monticello Reactor, 1967). Should there be no leaky fuel rods, the gaseous waste would be made up primarily of activation products, and would be discharged at a rate of 6,000 Curies per year. In the case of one per cent fuel leaks present, the gaseous waste would contain fission products, and be discharged at a rate of 9,000,000 Curies per year. It is assumed that 99.9 per cent of the gaseous iodines are removed by the filtration system, and thus the bulk of the discharge would be noble gases.

In like manner, the radioactive wastes in the liquid effluent from this plant are estimated during the licensing process. The technical description of the Monticello reactor states, "Estimated radioactive discharge due to liquid wastes is approximately 1 milliCurie/day. When fuels are present, the activity discharge rate may increase to as much as 250 milliCurie/day, which is representative of a stack release of noble gases of 0.3 Curie/second," (Monticello Reactor, 1967).

Tritium, which is the single largest contributor to the radioactive liquid waste, does not seem to be included in these estimates of the *total* radioactive waste. Furthermore, the waste treatment proposed does not remove any of the tritium. The total quantity of tritium which is produced by a 500 Mw(e) nuclear power plant has been estimated at 68,000 Curies during its first year of operation and 38,000 Curies per year thereafter (Smith, 1967). The majority of this tritium is produced by reactions with the boron in the control elements. The U.S. Public Health Service assumes that 50 per cent of this tritium enters the primary coolant (U.S.P.H.S., 1967).

Ten per cent of the tritium which finds its way into the primary coolant will appear in the gaseous waste (Smith, 1967). Thus, even in the absence of leaky fuel rods, approximately 3,000 Curies of tritium would appear in the gaseous effluent during the first year of operation and 1,500 Curies annually during subsequent years.

Comparisons of Activity

The various estimates for the total radioactive discharges from the proposed Monticello reactor (which should be equally applicable to any 500 Mw(e) boiling-water reactor) are listed in Table 2.

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

[3] Flow rate of the Mississippi River at Monticello, Minnesota, is estimated to be equal to or less than 1,100 cubic-feet per second 10 per cent of the time.

TABLE 2. Estimates of total quantities of radioactive wastes from the proposed Monticello Nuclear Generating Plant.

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, estimated by Smith (1967)	
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, estimated by Smith (1967) and U.S.P.H.S. (1967)	
first year of operation	30,000
subsequent years	15,000

helpful 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 capsules containing a few milligrams of radium were 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.

Tritium discharge can also be used to illustrate another point which has confused discussion of 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. The tritium in the river, however, is itself due to pollution via the fallout from weapons testing. It is not a part of the so-called "natural background of radiation." Prior to the advent of weapons testing and nuclear reactors, the surface waters in North America had an average tritium concentration of less than 10 picoCuries per liter[4]. (Fowler, 1965). The tritium concentration in the Upper Mississippi River at time of this writing was in the neighborhood of 2,000 picoCuries per liter (U.S. Geological Survey, 1968). It matters little to the environment or to the individuals exposed to this radiation whether it arose from weapons testing or from waste discharged by a nuclear power station.

[4] One picoCurie equals 10-12 Curies. Concentration of radioisotopes in waters is usually expressed as pico Curies/Liter pCi/L.

Summary

Although nuclear power plants do not discharge conventional air pollutants, they will discharge vast quantities of thermal and radioactive wastes into the local environment if operated as presently proposed. The quantity of radioactive wastes which is discharged depends on the extent of the waste treatment system. Radioisotopes in the wastes can vary from none to several million Curies per year. There need be no radioactive discharges, since those that are released are the result of deliberate decisions. The only gain offsetting these releases is a slightly lower, and as yet unspecified, electrical cost to the consumer.

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