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INDUSTRIAL RADIOACTIVE WASTE DISPOSAL

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INTRODUCTION

During late January and early February 1959 the Special Subcommittee on Radiation of the Joint Congressional Committee on Atomic Energy held 5 days of public hearings on "Industrial Radioactive Waste Disposal." These hearings were designed as a followup to the hearings on "The Nature of Radioactive Fallout and Its Effects on Man," held 2 years ago by the same subcommittee. It was the intent of the hearing to emphasize the technical aspects of the waste-disposal problems and to determine whether the present scale of research and development is adequate to meet the coming needs.

The hearings covered in detail the nature of wastes, waste-management operations, the various research and development programs, estimates of the future magnitude and economics of waste disposal, and concluded with a discussion of the activities of various Federal, State, and international agencies in the regulation of disposal of wastes. Thirty-three scientists and engineers covering the entire spectrum of scientific disciplines interested in the problem presented oral testimony and approximately 50 papers were received for the record. Selected papers from the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958, are also included in the record. All sessions were open to the public.

On July 29, 1959, the special subcommittee held an additional hearing on the specific subject of disposal of low-level radioactive wastes into the ocean.

The written record of the hearings represents the most comprehensive collection of technical information on the subject that has been compiled. The nature of the problem was characterized and the data submitted on the operation of the various systems in use were extensive. The research and development program was thoroughly reviewed as were the economic aspects and the probable growth of the problem. Each of these subjects is summarized briefly in this report.

SUMMARY-ANALYSIS OF HEARINGS

ON

INDUSTRIAL RADIOACTIVE WASTE DISPOSAL

SUMMARY AND CONCLUSIONS

1. The management or disposal of radioactive wastes from the nuclear energy industry is not a single problem with a single solution. It varies widely, depending on the specific nature, concentration, and quantity of radioactive materials involved, and on the specific environment in which it must be considered. In the nuclear fuel cycle, wastes are produced at each step: from the mining of ore, the production of fuel elements, the operation of reactors, the chemical-reprocessing of fuels, and from the research activities associated with each of these steps. The wide variety of wastes encountered can be categorized into two classes which, if not sharply delineated, at least do have major differences in their nature, in their volume, in their hazard, and in their control: "low level" and "high level" wastes.

"Low-level wastes" were defined during the hearings as those having a radioactivity concentration in the range of one microcurie per gallon.¹ By way of contrast, some "high-level wastes" have concentrations of hundreds or thousands of curies per gallon—and thus can be more than a million times more concentrated than "low-level wastes." In terms of volumes of wastes generated, billions of gallons of low-level wastes are produced each year (which are treated and dispersed as described below), whereas the volume of high-level wastes produced is much more limited. Since the beginning of the atomic program, 65 million gallons of high-level wastes have accumulated, all contained in underground tank storage as described in paragraph 4 below.

2. According to the best judgment of the scientific experts who testified during the hearings, radioactive waste management and disposal practices have not resulted in any harmful effect on the public, its environment or its resources. Extensive monitoring programs have shown that concentrations of radioactivity released to the environment are well within established permissible limits. To accomplish this has required a major capital expenditure by the Federal Government of some \$200 million and an estimated annual operating cost of \$6 million. Detailed monitoring and control must be maintained in connection with waste management operations on a continuing basis for generations.

3. For low-level wastes, the program has been to disperse them to nature (air, ground, water) with or without treatment as required under careful control and management. The problem may be ex-

¹ A curie is defined as 3.7×10^{10} disintegrations per second—approximately equivalent to the radiation emitted by 1 gram of radium. A μc is one-millionth of a curie.

pected to increase as the nuclear-power industry increases in size or if acceptable limits of radioactivity in the environment are further reduced.

4. The final disposal of high-level wastes associated with the chemical reprocessing of irradiated nuclear fuels represents an aspect of the problem that, while safely contained for the present and immediate future, has not yet been solved in a practical, long-term, engineering sense at the present time. The practice today is to reduce high-level wastes in volume, if possible, and to contain or hold them in tanks. It was the consensus that tank storage is not an ultimate solution in itself but that temporary (2 to 10 years) tank storage will be an integral part of any ultimate system. Although apparently feasible solutions to the problem of ultimate disposal of high-level waste are in various stages of development, at least several years of pilot plant, prototype, and field-scale testing will be required before engineering practicality can be demonstrated.

5. It will always be necessary to use the diluting power of the environment to some extent in handling low-level waste. Present dispersal methods have been demonstrated to result in concentrations well below established permissible limits. The cost of "absolute" processing or containing all these large volumes would be prohibitive. Since the release of even small amounts of high-level waste would use up large amounts of environmental dilution capacity, the reservation of this capacity for the low-level waste where it is needed becomes another reason (in addition to protection of man and other biota) for containing the high-level waste.

6. Suggestions for final disposal of high-level wastes include—

- (a) Conversion to solids by one of several methods;
- (b) Storage of solids in selected geological strata with major emphasis on salt beds;
- (c) Disposal of liquids into geological strata—either deep wells or salt beds;
- (d) Disposal of liquids or solids into the sea.

Although a number of possibilities were described during the hearings, the conversion to solids and storage of these in salt formations seemed to be the most favored at this time. The least favored was disposal of high-level wastes in the sea.

7. Some radioactive wastes have been disposed into the sea, but it should be emphasized that these were of a low-level, solid, packaged variety. Disposal of high-level wastes at sea is not contemplated at this time by the U.S. Atomic Energy Commission. The special subcommittee held an additional hearing on July 29, 1959, on the specific subject of disposal of low-level wastes into the ocean, as summarized in paragraph 15 below.

8. It was generally agreed that separation of specific fission products (in particular Sr^{90} and Cs^{137}) only for their industrial utilization would not affect appreciably the waste disposal problem nor significantly aid in its solution.

9. The long term responsibilities, particularly those associated with the protection of public health and safety and natural resources, must be borne by agencies of the public, probably at several levels of government, but primarily the Federal. However, industry, under proper regulations, can and must ultimately assume greater responsibilities and initiative in connection with actual physical handling and disposal operations.

10. International aspects of the problem are important considerations, particularly in connection with disposal into the seas and operation of nuclear-propelled vessels and aircraft. It is essential that competent international agencies attack these problems at an early date and on a continuing basis. The Joint Committee is pleased to learn that the International Atomic Energy Agency is studying this problem and hopes that it will continue and increase its efforts in this field.

11. Although a substantial, coordinated waste-disposal research and development program exists, it is essential that it must be vigorously pursued on an expanded basis in order to (a) achieve better understanding of the behavior of radioactive materials in the environment; (b) anticipate the informational requirements in this field for an expanding nuclear energy industry; and (c) develop safe, practical systems for handling presently unsolved problems within a reasonable period of time. Because of the nature of the overall problem many aspects of the research and development must of necessity be long-range.

12. Initial costs associated with waste disposal, though large in absolute numbers, appear to be a relatively small fraction of unit nuclear-power costs and within the realm of economic practicality. It must be emphasized that these economic conclusions are, at the present time, based on calculation rather than on demonstration. There does not appear to be anything inherent in the general waste problem that need retard the development of the nuclear-energy industry with full protection of the public health and safety, if a bold and imaginative, yet realistic research and development program is carried out.

13. The scientific evidence before our committee indicates that manmade radiation to the average man is derived from several sources: medical use of X-ray machines; industrial applications of radioactive materials and atomic energy; radioactive fallout from weapons tests; and radioactive waste materials. The evidence indicated that, at the present time, medical exposure from X-rays constitutes the major source of radiation to man, and that the contribution from radioactive wastes at the present is substantially less than that from worldwide fallout. As an example, in the environs of Hanford, where controlled quantities of wastes are dispersed into the air from the Hanford plant, the deposition of radioactive isotopes on local vegetation from fallout exceeds that which originates from the waste products of the Hanford plant. Even at that location in the area of a major atomic plant, the combined radiation exposure from all sources, including fallout and waste products, is estimated by most experts to be between 3 and 15 percent of currently established permissible limits.

14. From an environmental health and safety standpoint, the types of potential waste-management problems which will require continued efforts and supervision in the future are as follows:

a. Controlled releases of low-level wastes under careful supervision to protect the environs from various nuclear energy operations;

b. Possible leaching or relocation of small fractions of high-level wastes from underground storage sites; and

c. Accidental, irregular releases from nuclear energy operations.

Based on projections of the growth of nuclear power in the United States, it was estimated during the hearings that it would be 20 to 25 years before the national waste-storage demand for high-level wastes from the nuclear power industry would equal the present volume in storage at Hanford alone (about 50 million gallons). With improved or new chemical processing and waste-treatment systems, there are reasonable prospects for reduction of these estimated waste volumes. Vigorous efforts should be continued in the research and development program to find a "foolproof" method for fixation of high-level wastes into solids before the end of this 20- to 25-year period.

The technology for effluent control of low-level wastes appears to be sufficiently straightforward so that the contribution of radiation exposure from waste-dispersal operations can continue to be a small percentage of the total exposure of man from all radiation sources. Nonetheless, care should be taken to control buildup of contaminants in individual links of the food chain from particular environmental concentration factors that might prevail.

The ICRP-recommended maximum permissible radiation exposure for the population at large from environmental contamination of all sources is about one-third of the average radiation exposure from medical sources.² Testimony during the hearings indicated that it is not expected that waste-disposal activities alone will use up all of this in the foreseeable future.

15. On July 29, 1959, the Special Subcommittee on Radiation held an additional public hearing on the specific subject of disposal of low-level radioactive wastes into the ocean. In particular, the meeting was called to receive expert testimony on the NAS-NRC report entitled "Radioactive Waste Disposal Into Atlantic and Gulf Coastal Waters" (reprinted at pp. 1428-1488 of vol. II of the hearings). This report had suggested 28 possible locations for disposal of low-level wastes in "in-shore areas," in some cases less than 15 miles from shore and in waters less than 50 fathoms (300 feet) deep.

The hearing was also held to consider H.R. 8187 and H.R. 8423, bills introduced in July and referred to the Joint Committee which

² See "Recommendations of the International Commission on Radiological Protection" (Pergamon Press 1957), which states at p. 15:

"Maximum permissible genetic dose.—It is suggested that the genetic dose . . . to the whole population from all sources additional to the natural background should not exceed 5 rems plus the lowest practicable contribution from medical exposure."

The contribution to the genetic exposure of the population at large from medical sources has been estimated at 4.5 rems and from natural background radiation also at 4.5 rems. The illustrative apportionment of the 5 rems for additional sources is given by the ICRP as follows, quoting again at p. 15 of its report:

"Illustrative apportionment.—The Commission does not wish to make any firm recommendations as to the apportionment of the genetic dose of 5 rems but, for guidance, gives the following apportionment as an illustration:

	Rems
(A) Occupational exposure.....	1.0
(B) Exposure of special groups.....	.5
(C) Exposure of the population at large.....	2.0
Reserve.....	1.5"

For a further breakdown of the 2 rems for the genetic exposure for the population at large, the ICRP states at pp. 15-16 of the report:

"Exposure of the population at large.—The apportionment of 2 rems (with a long-term reserve of 1.5 rems for possible eventualities) for the genetic exposure of the population at large is intended for planning purposes in the development of nuclear energy programs (with the associated waste disposal problems) and more extensive uses of radiation sources. In the case of internal exposure, the radioisotopes of interest are those that contribute to the gonad dose directly (by local concentration) or indirectly (by radiation produced elsewhere in the body). In either case the maximum permissible concentrations in air and water of these isotopes recommended by the Committee II for continuous occupational exposure ('168-hour week') are based on an average yearly dose of 5 rems in the gonads or the whole body. If for these isotopes the average concentrations in public air and water supplies are lower than the values recommended for continuous occupational exposure by a factor of 1/100, the genetic dose to the population would amount to 1.5 rems (5 x 1/100 rems/year in the gonads x 30 years = 1.5 rems). In this case the contribution from external sources should be limited to 0.5 rem in order not to exceed the total of 2 rems."

would impose certain statutory restrictions on disposal of radioactive materials into the Gulf of Mexico or into the Atlantic Ocean.

During the hearings, representatives of the Atomic Energy Commission indicated that the AEC has not yet approved the locations suggested by the NAS-NRC report, and that the subject would be studied further. The Commission indicated that it would continue to follow a policy of disposing of radioactive wastes in depths of not less than 1,000 fathoms (6,000 feet), which in most cases would mean sites at distances from 70 to 150 miles offshore.

In furtherance of this policy, the Commission is amending one license which had permitted disposal of some wastes in Massachusetts Bay to require future disposal only at sites in deep waters off the Continental Shelf.

The Chairman of the NAS-NRC Working Group testified during the hearing. He described the methods in which the working group arrived at its conclusions and recommendations, and emphasized that a considerable amount of survey work must be done to provide greater detail on local conditions before these sites could be finally recommended as disposal areas.

The NAS-NRC report had also stated that, prior to disposal, there should be a preuse survey to provide more detailed information. In addition, the NAS-NRC report emphasized that there should be *monitoring* of the disposal area at intervals following the start of disposal operations which would be essential to the safe and efficient use of the area.

As a consequence, the AEC indicated that it would not grant licenses for disposal in "in-shore areas" without first notifying the Governor of the contiguous State and providing opportunity for public hearings on the proposed license, as required by the AEC Rules of Practice.

The Commission stated that it has not made a decision to use or approve the use of these in-shore sites even if the results of the studies and investigations are favorable from a safety standpoint. Such a decision is a question for future consideration.

The Commission assured the Joint Committee that the present policy of disposing wastes in not less than 1,000 fathoms would be continued until scientific evidence had clearly demonstrated, after further studies and research, that disposal in lesser depths and nearer to shore could be made without injurious effects upon fisheries, or upon man and his environment. The Commission further testified that before any such decision was made effective, it would notify the Joint Committee on Atomic Energy for its consideration.

NATURE OF WASTES

The nuclear-energy industry has developed in a period of less than 15 years. As in every other industry, the disposal of its wastes has posed problems and hazards. A characteristic distinguishing these wastes from the more common industrial wastes is that their active components are not detected by human senses. However, with appropriate instrumentation, their nature, character, and concentration may be determined with high accuracy. In addition, the toxicity of some of these wastes to humans is greater than that of any hitherto familiar industrial poison.

Of even more significance is that these wastes become inactive only by natural decay. Since many of the radionuclides have long half-lives,¹ the supervision and control of some of the wastes must be viewed, not from the standpoint of temporary expediency, but from the necessity of guaranteed supervision and control for hundreds of years.

The radioactivity with which we are concerned may be either naturally occurring or produced by fission or by neutron activation in nuclear reactors. The naturally occurring radionuclides are shown in table 1.

The fission products resulting from the nuclear fission of any of the three isotopes uranium 235, uranium 233, plutonium 239 are similar in their distribution between the elements starting with atomic No. 30 (zinc 72) and ending with atomic No. 66 (dysprosium 161). From the standpoint of waste disposal those of most interest possess long half lives and/or have a high hazard potential for man as defined by their allowable concentrations in the human body. The more significant fission products are shown in table 2.

TABLE 1.—Naturally occurring radionuclides *

Radionuclide	Natural abundance in nature	Half life *	Radionuclide	Natural abundance in nature	Half life *
	<i>Percent</i>			<i>Percent</i>	
Uranium 238.....	99.26	4.5×10 ⁹ y	Thorium 232.....	100	1.4×10 ¹⁰ y
Thorium 234.....	(b)	24.3 d	Radium 226.....	(d)	6.7 y
Protactinium 234.....	(b)	6.7 h	Thorium 230.....	(d)	1.9 y
Thorium 230.....	(b)	8.0×10 ⁴ y	Radium 224.....	(d)	2.6 d
Radium 226.....	(b)	1,600 y	Radon 220.....	(d)	54.0 s
Radon 222.....	(b)	2.8 d	Bismuth 212.....	(d)	1.0 h
Uranium 235.....	0.71	7.1×10 ⁸ y	Polonium 212.....	(d)	Very short
Uranium 234.....	0.006	2.5×10 ⁵ y	Thallium 208.....	(d)	3.0 m

* "Nature of Radioactive Wastes," F. L. Culler, ORNL-CF-59-1-106, Jan. 26, 1959. Paper prepared for the record of the JCAE hearings on "Waste Disposal," January 1959.

^b More important decay products of U²³⁸.

^c Decay products of U²³⁵ and U²³⁸ not very important due to low concentration of parent.

^d More important decay products of Th²³².

* s=second, m=minute, h=hour, d=day, y=year.

¹ A period of time characteristic of each nuclide during which one-half of the initial quantity of activity undergoes decay.

TABLE 2.—Principal fission products of interest in waste-disposal operations *

Radionuclide	Half life ^b	Maximum allowable concentration ^c		Approximate percent of total activity after decay of—		
		In body μc	In water $\mu\text{c/ml}$	100 days	3 years	30 years
Strontium 90.....	28.0 y	1.0	2.0×10^{-1}	<2	15	~40
Cesium 137.....	26.6 y	90.0	1.5×10^{-2}	<2	15	~40
Promethium 147.....	2.6 y	120.0	1.0	8	15	<1
Cerium-praseodymium 144.....	290.0 d	2.0	4.0×10^{-1}	45	50	.....
Krypton 85 (gas).....	10.3 y	.....	.....	<1	1	<1
Iodine 131 (gas).....	8.1 d	3	2.0×10^{-1}	<1	.....	.....
Zirconium-niobium 95.....	63.0 d	90.0	4.0×10^{-1}	29	.....	.....
Barium-lanthanum 140.....	12.8 d	5.0	2.0×10^{-1}	<1	.....	.....
Ruthenium-rhodium 103.....	41.0 d	5.0	1.0×10^{-1}	5	.....	.....
Ruthenium-rhodium 106.....	1.0 y	4.0	0.1	2	3	.....
Strontium 90.....	54.0 d	2.0	7.0×10^{-1}	7	.....	.....
Xenon 135 (gas).....	5.3 d	300.0	4.0×10^{-1}	<1	.....	.....

* "Nature of Radioactive Wastes," F.L. Culler, ORNL-CF-50-1-106, Jan. 26, 1959. Paper prepared for the record of the JCAE hearings on "Waste Disposal," January 1959.

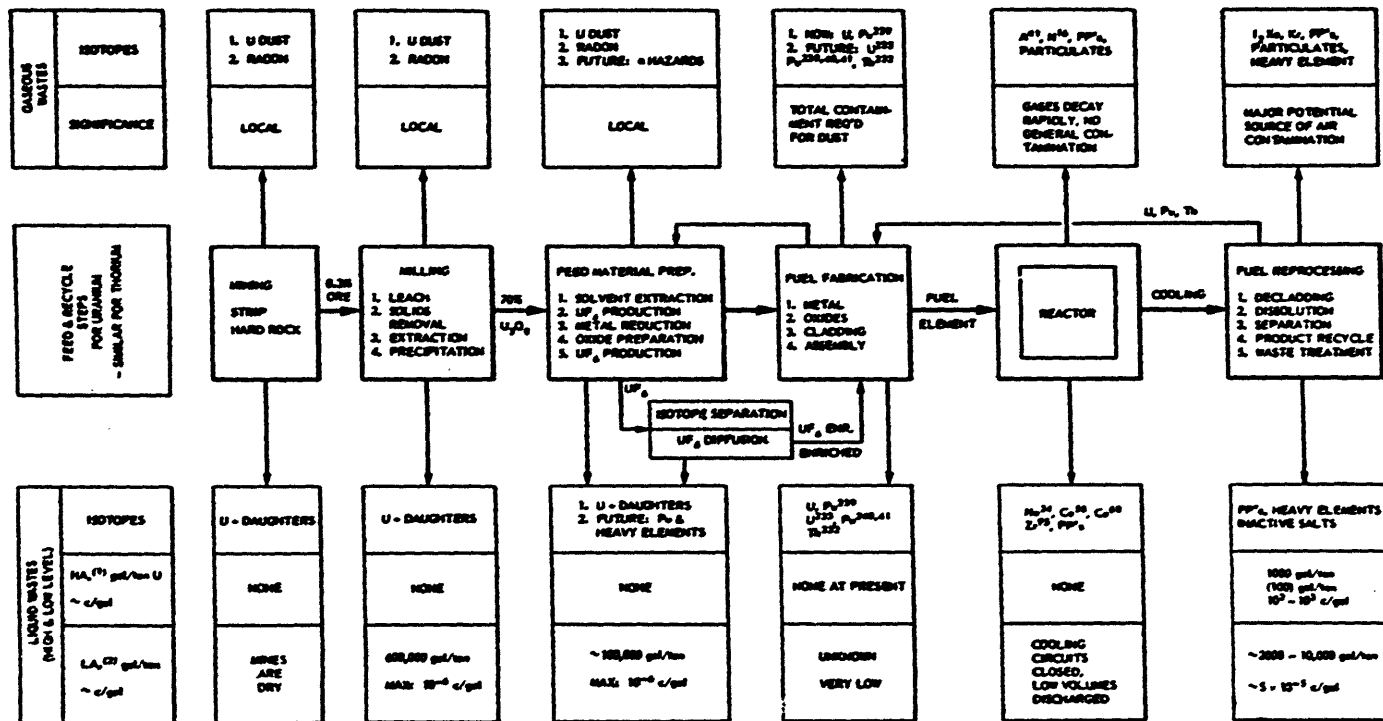
^b d=days, y=years.

^c U.S. Bureau of Standards Handbook #2.

In the operation of a nuclear reactor some of the neutrons do not effect collisions with fissionable materials but rather are absorbed by the coolant, its contained impurities, and by structural components to form radioactive isotopes of the absorbing elements. These are referred to as activation products and form a third class of radionuclides which must be considered in waste disposal. A list of some of the principal coolant and impurity activation products is given in table 3.

A nuclear fuel cycle complex is shown schematically in figure 1 with particular reference to types of wastes encountered. Some wastes are produced at each step: from the mining of ore, the production of fuel elements, the operation of reactors, the chemical reprocessing of fuels, and from the research activities associated with each of these steps. The problem varies considerably from step to step, the level of activity ranging from fractions of microcuries per milliliter in low-level waste to hundreds of curies per liter in high-level waste. They occur as liquids, solids, and gases and the various types of activity levels are generally treated separately.

In the mining and feed materials steps, only naturally occurring radioactive elements are encountered and the activity levels in wastes are very low. During the operation of a reactor, fission and activation products are formed. Except in the case of an accident, the activation products form the normal waste at this step and the concentrations, while higher than in mining and milling operations, are quite moderate. Of the three classes of radioactivity discussed, the fission products represent by far the greatest potential problem as far as total quantity of continuing radioactivity is concerned. Under normal circumstances they do not become a waste-disposal problem until the spent fuel is processed chemically.

FIGURE 1. SCHEMATIC FLOWSHEET FOR ORIGIN OF WASTES—NUCLEAR FUEL CYCLE^a

(1) HIGH ACTIVITY WASTE; ACTIVITY IS ORDER OF MAGNITUDE ESTIMATE, CURIES/GAL
(2) LOW ACTIVITY WASTE.

^a "Nature of Radioactive Wastes," F. L. Culler, ORNL-CF-59-1-106, January 26, 1959. Paper prepared for the record of the JCAE hearings on Waste Disposal, January 1959.

TABLE 3.—Coolant and impurity activation products

Radionuclide	Half life	Mechanism of formation
Water reactors:		
Coolant activity:		
Nitrogen 16.....	7.0 s	$O^{16}(n,p)N^{16}$
Nitrogen 17.....	4.0 s	$O^{17}(n,p)N^{17}$
Oxygen 19.....	30.0 s	$O^{19}(n,\gamma)O^{19}$
Fluorine 18.....	1.9 h	
Impurity activity:		
Sodium 24.....	15.0 h	$Al^{27}(n,\alpha)Na^{24}$
Aluminum 28.....	2.0 m	$Al^{27}(n,\gamma)Al^{28}$
Argon 41.....	110.0 m	$A^{40}(n,\gamma)Ar^{41}$
Manganese 56.....	2.6 h	$Fe^{56}(n,p)Mn^{56}$
Cobalt 58.....	71.0 d	$Ni^{58}(n,p)Co^{58}$
Cobalt 60.....	5.2 y	$Co^{59}(n,\gamma)Co^{60}$
Iron 58.....	2.9 y	$Fe^{57}(n,\gamma)Fe^{58}$
Iron 59.....	45.0 d	$Co^{59}(n,p)Fe^{59}$
Chromium 51.....	27.0 d	$Cr^{52}(n,\gamma)Cr^{51}$
Copper 64.....	12.8 h	$Cu^{63}(n,\gamma)Cu^{64}$
Tantalum 182.....	111.0 d	$Ta^{181}(n,\gamma)Ta^{182}$
Tungsten 187.....	24.0 h	$W^{186}(n,\gamma)W^{187}$
Sodium reactors:		
Sodium 24.....	15.0 h	$Na^{23}(n,\gamma)Na^{24}$
Sodium 22.....	2.6 y	$Ne^{20}(n,\alpha)Na^{22}$
Rubidium 86.....	19.8 d	$Rb^{85}(n,\gamma)Rb^{86}$
Antimony 124.....	60.0 d	$I^{127}(n,\alpha)Sb^{124}$

Mining

Uranium is recovered from many mines, large and small, in the United States at a rate of about 65,000 pounds per day. This is equivalent to about 10 curies of uranium 238, which at equilibrium would mean 10 curies of each of the daughter products. Altogether about 100 curies of solid radioactive elements are delivered to the mills each day.

The waste products of uranium mines are not of major significance in the overall waste-disposal picture. The principal problems are protection of miners from radon gas and radioactive dust. Harmful concentrations of these airborne radioactive materials are prevented by sufficient ventilation. The exhaust air is discharged to the atmosphere without presenting a problem of general atmospheric contamination. The total quantity of radon discharged to the atmosphere from uranium mines is very small compared to that which is naturally produced from the surface of the earth.

Milling

At the mills, the ore goes through three areas: grinding and crushing, chemical processing, and final isolation. In the crushing and grinding areas dust is produced containing all the constituents of the ore. The primary health hazard in these areas is produced by silicon dust rather than by a radioactive material. Similarly, in the chemical-processing section, waste products are mainly gases from chemicals added to the slurries and solutions—such toxic compounds as hydrogen sulfide, arsine, or acid gases. In the final processing area the primary wastes are uranium compounds which are disseminated into the workroom air. Good ventilation is required.

Since the ore contains a low concentration of uranium, practically all of the material fed to the mills is discarded as wastes, slimes, and sands. In addition, 13 million gallons of water are used each day, most of which is discharged as plant effluent carrying the dissolved and solid waste to the tailing ponds. Most of the 100 curies per day of activity delivered to the mills is discharged in the liquid tailing.

Radioactive isotopes in uranium mill tailings include natural uranium, thorium 234, thorium 230, and radium 226. From a potential stream pollution standpoint, the concentration of radium 226 is the most significant isotope.

Feed materials operations

Ore concentrates contain on the average 70 percent U_3O_8 . They are further chemically purified to produce uranium hexafluoride for the gaseous diffusion plants or reduced to uranium metal or converted to uranium compounds such as uranium dioxide for use as reactor fuel. The radiochemical nature of the wastes from these operations is similar to that of the mill wastes containing natural uranium and its decay daughters. For each ton of uranium processed, approximately 1,000 gallons of solvent extraction wastes are produced. Gases from the reduction and hydrofluorination operations are scrubbed to remove chemical fumes and entrained uranium. Waste materials from uranium metal production are leached to remove contained uranium. The leach liquors are treated by the solvent extraction purification cycle or by ion exchange.

Diffusion plant operations

Diffusion plant feed is prepared from two sources: (1) concentrates from milling and (2) recycled uranium from production reactors, such as those at Hanford, Savannah River, or the Idaho Chemical Processing Plant. The latter products are stored long enough to allow decay of uranium 237. They have a plutonium content of less than 10 parts per billion parts of uranium. Fission products have been removed almost completely. The wastes from this operation are monitored and discharged to the environment at levels below tolerance.

Fuel-element manufacture

Manufacture of fuel elements involves the use of uranium, its alloys and uranium oxide (UO_2). Operations involved include melting, casting, rolling, machining, and metal cleaning. These operations produce varying quantities of uranium-bearing wastes in the form of alloy scrap, liquids, contaminated pieces of metal, paper, rags, and a certain amount of airborne dust. The volume of liquid waste generated during cleaning and etching operations at one plant was only 5,000 gallons per year. The solution is dilute acid containing small amounts of dissolved uranium. The level of radioactivity contained is so low that it can be monitored, diluted and discharged to a river. At the same plant 7,000 pounds per year of slightly contaminated copper and steel were produced by hot-working operations.

Reactor operation

The radioactive wastes stemming from reactor operation are produced by two general processes: (1) fission and (2) neutron activation of the coolant, its impurities, and structural components. Reactors are generally classified into two broad categories: heterogeneous and homogeneous. Heterogeneous reactors are typified by a core lattice of solid fuel elements clad with a structural material (aluminum, zirconium, stainless steel) to protect the fuel from the coolant (water, liquid metal, organic, air) and to contain the fission products. They feature elaborate electronic devices designed to detect clad ruptures so that a failed element may be removed before significant amounts of fission products are released into the coolant stream. Bypass

coolant purification systems provided for the removal of corrosion and impurity activities are also capable of retaining the fission products.

Homogeneous reactors have fuel dispersed in the coolant-moderator which is cycled through an integrated primary and secondary heat-removal system. The entire coolant system is the primary container of both induced activities and fission products. Homogeneous reactors are now in an early stage of development.

Since the waste problems vary somewhat with reactor type, a number of examples will be described briefly. Operating heterogeneous reactors are at present predominantly water cooled. During operation the major source of radioactive waste is the short-lived isotopes produced by nuclear reactions in the bulk coolant. After a very short period, however, the impurity activation products are of prime concern. (See table 3.) To these induced activities may be added fission-product activities introduced into the coolant by fuel-element failure. These fission products seldom markedly increase the difficulty of the waste problems. The activity level of coolant is, in any case, low.

The Hanford production reactors are designed for low-pressure, single-pass water cooling. Cooling water is taken from the Columbia River, treated by coagulation, settling, filtration, chlorination, addition of corrosion inhibitors, and pH adjustment. Effluent water from the reactor flows by gravity to retention tanks for a holdup period of approximately an hour to permit partial decay of the short-lived radioisotopes. More than 60 radioisotopes have been identified in the effluent. Under normal circumstances the discharge is then put into the river. At the time of discharge approximately 90 percent of the gross activity consists of Mn^{55} , Cu^{64} , Na^{24} , Cr^{51} , Np^{239} , As^{76} , and Si^{31} . By the time the effluent has traveled to the vicinity of Pasco, Wash. (24 hours), the isotopes of greatest abundance are Cu^{64} , Na^{24} , Cr^{51} , Np^{239} , and As^{76} . Of the total number of isotopes detected in the effluent, 24 are of sufficient interest that their concentration is measured on a routine basis. On occasion the retention basin monitoring system may register an abnormally high level of radioactivity. In this event the contents may be pumped to a storage basin where advantage is taken of the adsorptive properties of the Hanford soils to retain the radioactive materials as the water percolates into the ground.

The Materials Testing Reactor (MTR) at Idaho uses a recirculating water system. The feed water is pretreated by ion exchange to reduce impurities to less than one part per million. The total flow through the core and reflector is about 22,000 gallons per minute. Sources of waste are (1) a continuous bleedoff of demineralized primary coolant, (2) canal overflows, (3) waste water from test loops, (4) waste streams from various laboratories, and (5) primary coolant purges at the time of shutdown.

During the first 2 years of operation of this reactor, very minor fission-product activities were released to the cooling system. The activity near the piping after nitrogen 16 had decayed was about 50 to 100 mr per hour during operation and 10 to 20 mr per hour during shutdown. Corrosion product and other activities identified included aluminum 28, sodium 24, cobalt 60, and trace amounts of nine other isotopes. In 1954 a series of fuel element ruptures occurred which gradually increased the activity levels to as high as 3 r per hour.

A bypass cation resin bed was installed and operated at a rate of 1,000 gallons per minute on the bulk coolant. The activity decreased slowly to its original value. This experience indicates that while fuel ruptures can produce an increase in coolant activity, normal levels can be restored with the aid of relatively simple treatment procedures.

Pressurized water reactors produce similar wastes. The increased temperatures cause higher corrosion rates which are reflected in somewhat higher concentrations of corrosion activation products.

Direct cycle boiling-water reactors also generate these same kinds of wastes with perhaps an added importance given to gaseous wastes. Predominant gaseous activities from the Experimental Boiling Water Reactor (EBWR), for instance, are xenon 138 and krypton 88. The normal daily discharge rates to the atmosphere at 20-megawatt operation of EBWR are 0.2 to 0.4 curie of xenon 138 and 0.005 to 0.01 curie krypton 88.

Recirculated heavy water is also used as a moderator and/or coolant in such reactors as CP-5 at Argonne and NRX at Chalk River, Ontario. In addition to the short-lived nitrogen isotopes, tritium is formed in the coolant. The usual problems of corrosion-product activation are encountered in the heavy-water systems and are handled in the same way as in light-water systems (ion exchange).

Liquid metals, such as sodium and NaK, may be employed as coolants in a reactor. Activation of impurities in the sodium is usually negligible compared with that of the bulk sodium. Disposal of waste sodium or NaK is complicated not so much by the radioactivity content as by the vigorous chemical action of the metals with water, oxygen, and carbon dioxide. The several possible methods of disposal all aim at forming water-soluble compounds of the metals. Water, steam, alcohols, and liquid ammonia are used.

Research reactors are sometimes air-cooled. The principal radiation associated with air-cooling of reactors is argon-41 formed from argon-40 in the atmosphere. At the Brookhaven reactor for instance, some 4,000 curies of argon-41 are discharged through the stack each day. This quantity, while troublesome insofar as instrumentation is concerned, causes no problem in regard to the public because of local meteorological conditions and the low radiotoxicity of the argon.

Maintenance of the coolants of homogeneous reactors requires the separation of fission products from the fuel-coolant mixture external to the reactor. The waste problems will be equivalent to those experienced in the operation of a chemical processing plant since the entire system complex becomes contaminated with deposited activities to a degree many orders of magnitude greater than in heterogeneous reactors. In an aqueous homogeneous reactor the radioactive fission products, krypton, xenon, and iodine, are continuously removed from the coolant along with hydrogen, oxygen, and steam. Following recombination of the hydrogen and oxygen, the fission products are physically adsorbed on activated charcoal. The effluent gases are discharged through a stack to the atmosphere.

Chemical processing

Irradiated reactor fuels are taken from the reactor and chemically reprocessed to reclaim the unburned nuclear fuel and recover bred fissionable material. Processing is done at present by solvent ex-

traction in which more than 99.9 percent of the fission products are collected in an aqueous waste stream. Approximately 1,000 gallons of this waste per ton of uranium processed are formed. Specific characteristics of this waste depend on the metallurgical composition of the fuel and on the chemical process used. These wastes are evaporated to smaller volumes and are frequently neutralized before being stored in underground steel and concrete tanks. After 100 days' cooling, high-level wastes may contain as much as 1,000 curies per gallon and emit heat at a rate as high as 20 British thermal units per hour per gallon. The total activity level decreases, and the contribution of specific fission species changes, with time.

High-level wastes now in storage at the major processing plants amount to approximately 65 million gallons. There is a total tank capacity of about 110 million gallons.

In addition to the high-level wastes from chemical processing there is also produced a larger volume of low- and intermediate-level liquid wastes at fuel-processing plants. These derive from second- and third-cycle solvent-extraction operations, fuel de jacketing, laboratory and laundry operations, and cell decontamination.

Research operations

Associated with each production site there are carried out extensive research operations. In addition, there are several National Laboratories whose primary function is research. At these and at every installation at which radioactivity is handled there is a large volume of very lightly contaminated or perhaps only suspect waste of liquid, solid, and gaseous form. These wastes are characterized by wide variability of chemical type and content and by very low concentrations of activity.

Isotope distribution

In 1946 the AEC initiated a program for distributing reactor-produced radioisotopes. Since then nearly 1 million curies of activity have been shipped to over 4,000 institutions throughout the United States. About 98 percent of the isotopes shipped have half lives greater than 30 days. Almost all of this longer lived material is contained in sealed sources.

The amount of radioactive wastes generated through the use of radioisotopes is exceedingly small when compared to the Nation's overall nuclear energy program. At the present rate of use it is estimated that 1 to 200 curies of wastes with a half life greater than 30 days and 400 to 500 curies of wastes with a half life less than 30 days are being generated each year.

WASTE MANAGEMENT

Four witnesses discussed the present management of various types of wastes described in the previous section. In addition, a dozen papers were submitted for the record. The data contained represent an up-to-date and complete record of waste operations in the country. Representative data and information from specific sites is presented in this summary to show how particular types of wastes are handled.

Essentially the same philosophy is used throughout the entire industry. This includes the containment of high-level wastes on the site in underground concrete and steel tanks and the dispersal of low-

level wastes to the environment with or without treatment as needed but under stringent control. Each site maintains an extensive monitoring program to determine that the control of dispersal is adequate.

Reactors

Hanford production reactors.—Radioactive wastes generated by the operation of the Hanford production reactors are largely those associated with the cooling water. Since the kinds and amounts of radioactive materials produced in the effluent are partially dependent upon the characteristics of the cooling water fed into the reactor, close control of water quality is maintained. The flow of water through a typical reactor area is illustrated in figure 2. The raw river water is coagulated with alum, filtered through beds of coal and sand, the pH adjusted, and sodium dichromate added to control corrosion.

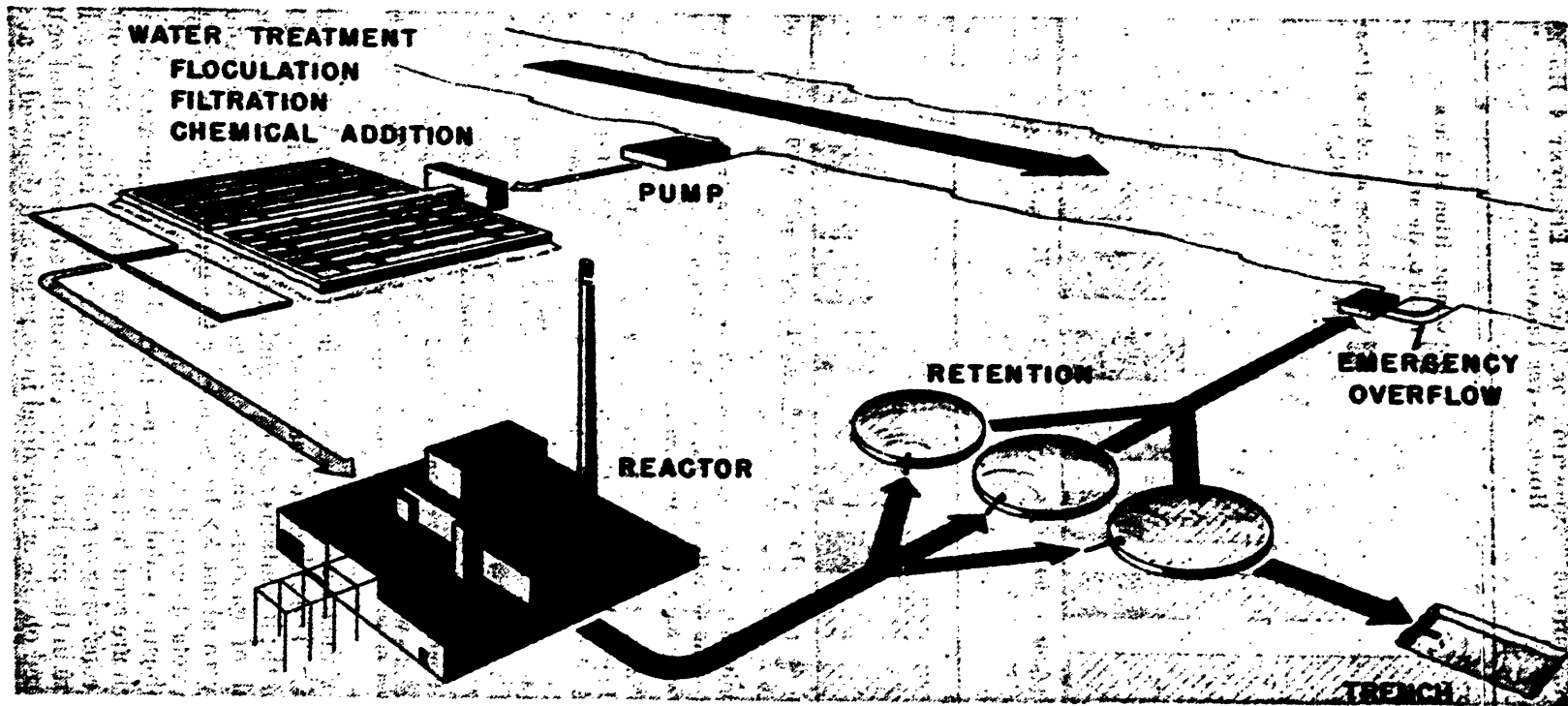
The bulk of the radioactive materials in the effluent are activation products of stable isotopes present in the water, in the film which forms on the reactor tubes and fuel elements, or in the metals of which the reactor components are constructed. Some fission products also occur because of natural uranium dissolved in Columbia River water and as a consequence of occasional ruptures of the aluminum jackets of the fuel elements. The reactor is shut down as soon as a rupture is known to exist and the fuel column containing the rupture is discharged. The total quantity of fission products released varies greatly from one rupture incident to the next. It is estimated that ruptures which occurred during 1958 may have contributed about 5 percent of the radiation exposure received by people in the Pasco-Kennewick area from the drinking of Columbia River water.

More than 60 radioisotopes have been identified in the effluent and figure 3 shows their relative abundance under normal circumstances 4 hours and 24 hours after irradiation (time equivalent to reach Pasco). Of the total number of isotopes detected in the effluent, 24 are of sufficient interest that their concentration is measured on a routine basis.

The effluent is retained in the basins for 1 to 3 hours before release. This reduces the radioactivity by 50 to 70 percent. By the time the effluent has traveled 35 miles, radioactive decay has further reduced the gross activity to less than 10 percent of the level when it entered the basins. The retention basins also serve to intercept effluent which has an unusually high radioactive content. Such situations arise from the occasional rupture of fuel elements and from the periodic purging of the film which forms on the reactor tubes. In some cases effluent which contains purged material or ruptured debris is diverted into trenches or cribs where it seeps into the ground. This provides decontamination by filtration and ion exchange before the liquid reaches the river.

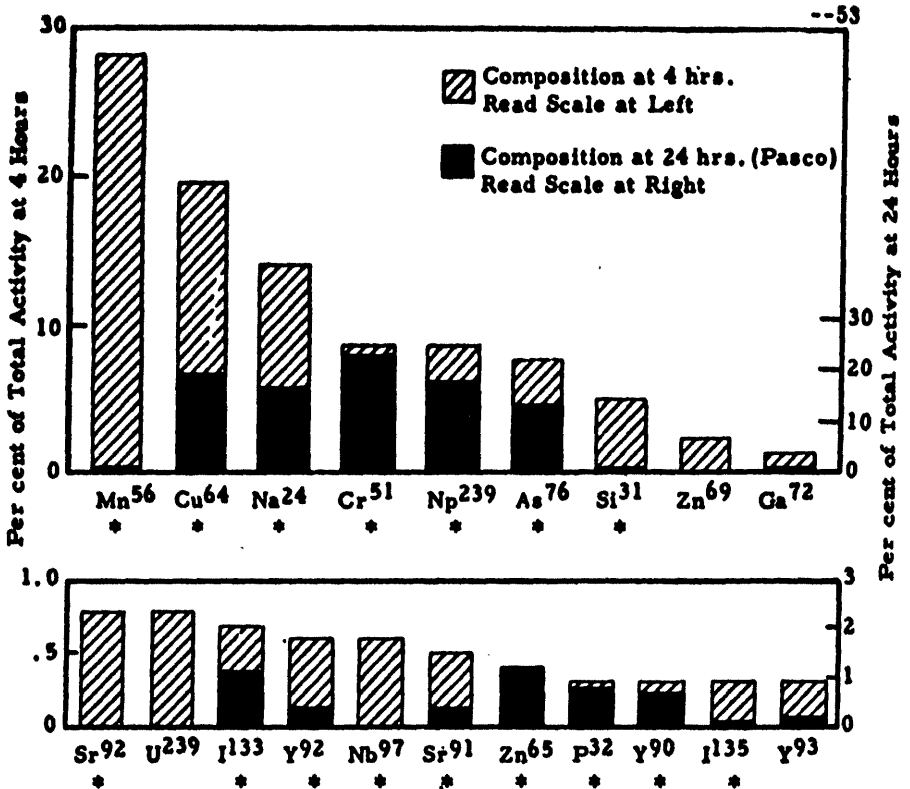
Shippingport.—The Shippingport reactor (PWR) uses recirculated pressurized water as reactor coolant. Activity builds up in the coolant due to activation of (1) corrosion products, (2) formation of tritium from lithium hydroxide used to raise the pH of the water for corrosion control, and (3) from fission products introduced by fuel ruptures. To limit the buildup of these contaminants the coolant is continuously purified by circulating a portion of it through a bypass demineralizer. When saturated, the resin is not regenerated but is transported to buried storage tanks on the site.

FIGURE 2. WATER FLOW THROUGH A TYPICAL REACTOR AREA *



* "Radioactive Waste Management Operations at the Hanford Works." Paper prepared for the record of JOAE hearings on "Waste Disposal," January 1969, by staff members of HAPO.

FIGURE 3. ISOTOPIC COMPOSITION OF REACTOR EFFLUENT 4 HOURS AND 24 HOURS AFTER IRRADIATION *



In addition to the isotopes shown above, which contribute about 98 per cent of the activity 4 hours after irradiation, trace amounts of the following have also been found.

Eu-152	Eu-157	I-131*	Y-91	Pr-145	Ca-137
Sm-153	Ba-140*	Ce-141	Fe-59*	Pm-151	Sr-85
W-187	Mo-99	Pr-142	Sr-89*	Co-60	U-238*
La-141	Sm-156	C-14	Mn-54	Pr-143	Pu-239*
Nd-149	Sc-46*	Nd-147	Zr-95	Ru-103	Ac-227
La-140	Cd-115	Ca-45*	Pm-149	Sc-47	Po-210*
I-132*	Ce-143	Ag-111	Eu-156	Sr-90*	

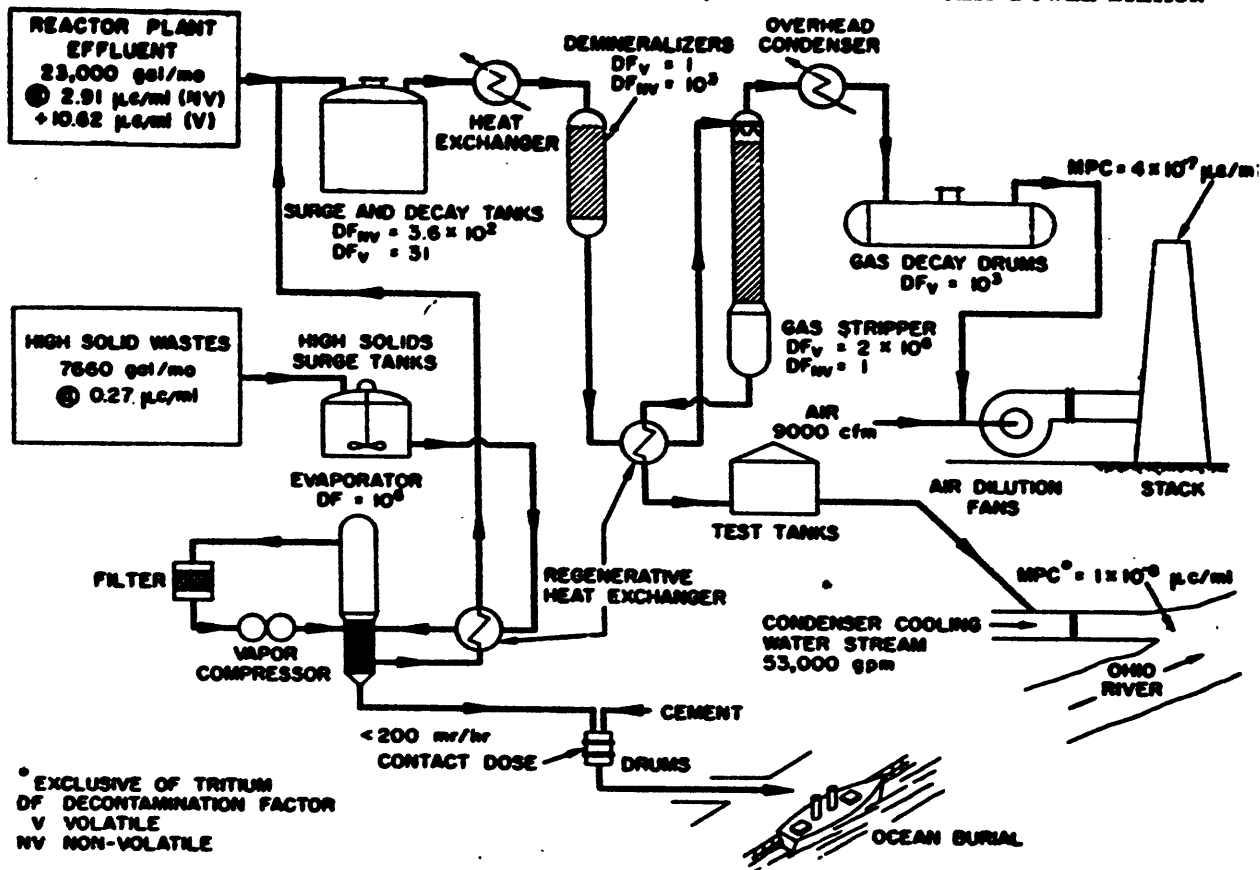
* Routine measurements are made on these isotopes.

* "Radioactive Waste Management Operations at the Hanford Works." Paper prepared for the record of JOAE hearings on "Waste Disposal," January 1959, by staff members of HAPO.

The radioactive-waste-disposal facilities at the PWR are shown in figure 4. The volume of reactor-waste effluent is about 23,000 gallons per month; it contains about $3\mu\text{c}/\text{ml}$ of nonvolatile activity and about $10\mu\text{c}/\text{ml}$ of gaseous activity. The treatment process reduces the activity to about $5 \times 10^{-6}\mu\text{c}/\text{ml}$ for the nonvolatile and $1 \times 10^{-5}\mu\text{c}/\text{ml}$ for the volatile activity.

Combustible solid wastes are burned in an incinerator, the flue gases of which are scrubbed and filtered before discharge. Noncombustible waste, consisting of resins, residue ash from the incinerator, solids from strainers in the pipelines, and contaminated items of plant equipment, are stored on site or imbedded in concrete and disposed of at sea.

FIGURE 4. RADIOACTIVE WASTE DISPOSAL FACILITIES, SHIPPINGPORT ATOMIC POWER STATION *



* EXCLUSIVE OF TRITIUM
DF DECONTAMINATION FACTOR
V VOLATILE
NV NON-VOLATILE

* "Shippingport Atomic Power Station Waste-Disposal Facilities," A. L. Bethel, J. E. La Pointe, and W. J. Hahn. Paper prepared for the record of the JOAE hearings on "Waste Disposal," January 1968.

Savannah River reactors.—The Savannah River reactors are heavy water moderated and cooled. A secondary light water heat exchange system is used. Since the discharged cooling water is not exposed directly to the neutron flux, it does not build up induced radioactivity. The moderator becomes radioactive due to the usual activation products and due to the formation of tritium by neutron bombardment of deuterium. Suspended solids and dissolved materials are removed by a filter and ion exchange system. Spent filters and resin beds are removed and transported to the burial ground.

Naval reactors.—All nuclear propelled U.S. naval ships now planned, in construction or in operation are powered by pressurized-water reactors. The reactor coolant passes through heat exchangers which transfer the heat to a steam system, which is used as a source of power for the propulsion plant as well as for auxiliary machinery. Since these are mobile reactors, waste problems, although similar to those of stationary pressurized-water reactors, have some special considerations. The principal source of radioactive waste is the reactor-coolant water which contains small quantities of activated impurities. Some of the reactor-coolant water is discharged during plant startup due to expansion as the reactor plant is brought up to operating temperature. This normally happens a few times a month on each ship and the quantity of cooling water discharged on each averages about 500 gallons per month. The nature of the radioactivity in the coolant water and the dumping tolerances established are shown in table 4. Fission products also occur in smaller concentrations in the reactor coolant because of uranium impurity in core structural materials.

TABLE 4.—Measured activities of coolant from U.S. Naval nuclear-powered ships^a

Nuclide	Half life	Maximum $\mu\text{c/ml}$	Average $\mu\text{c/ml}$	Dumping tolerance $\mu\text{c/ml}$
Mn ⁵⁴	2.5 hours	8.3×10^{-4}	2.2×10^{-4}	15.
Co ⁶⁰	5.3 years	2.5×10^{-4}	8.7×10^{-5}	2.
Fe ⁵⁹	45 days	2.3×10^{-4}	1.3×10^{-4}	1×10^{-4} .
Ni ⁶³	2.58 hours	1.3×10^{-4}	1.6×10^{-4}	1.9.
Cr ⁵¹	27 days	8.3×10^{-4}	1.0×10^{-4}	50.
Na ²⁴	15 hours	2.0×10^{-4}	8.0×10^{-4}	3×10^{-4} .
Cu ⁶⁴	12.8 hours	9.1×10^{-4}	1.5×10^{-4}	8.
Ta ¹⁸²	113 days	8.5×10^{-4}	7.3×10^{-4}	10.
Fa ¹⁸⁷	1.87 hours	8.9×10^{-4}	1.3×10^{-4}	50.
W ¹⁸⁷	24 hours	8.9×10^{-4}	3.3×10^{-4}	9×10^{-4} .
Gross activity measured 15 minutes after sampling.		1.5×10^{-4}	8.0×10^{-4}	3.
Gross activity measured 120 hours after sampling.		3.0×10^{-4}	2.1×10^{-4}	1×10^{-4} .

^a "Radioactive Waste Disposal from U.S. Naval Nuclear Powered Ships," by T. J. Ellis and M. E. Miles. Paper prepared for the record of JCAE hearings on "Waste Disposal," January 1959.

The basic criterion adopted for disposal of coolant is that disposal should not increase the average concentration of radionuclides in the surrounding environment by more than one-tenth of the maximum permissible concentrations for continuous exposure listed in the National Bureau of Standards Handbook 52. On this basis the Navy has adopted the instruction that for discharge in port, reactor coolant gross activity must be less than $3 \mu\text{c/ml}$ and the fission product iodine-131 must be below $10^{-3} \mu\text{c/ml}$. In determining these dumping tolerances it was assumed that discharged waste will almost im-

mediately be diluted in the harbor by a factor of at least 1,000. This would require mixing with a volume of water approximately equal to the displacement of the ship. Actual measurements indicate that the immediate dilution factor is about 100,000.

Fuel reprocessing

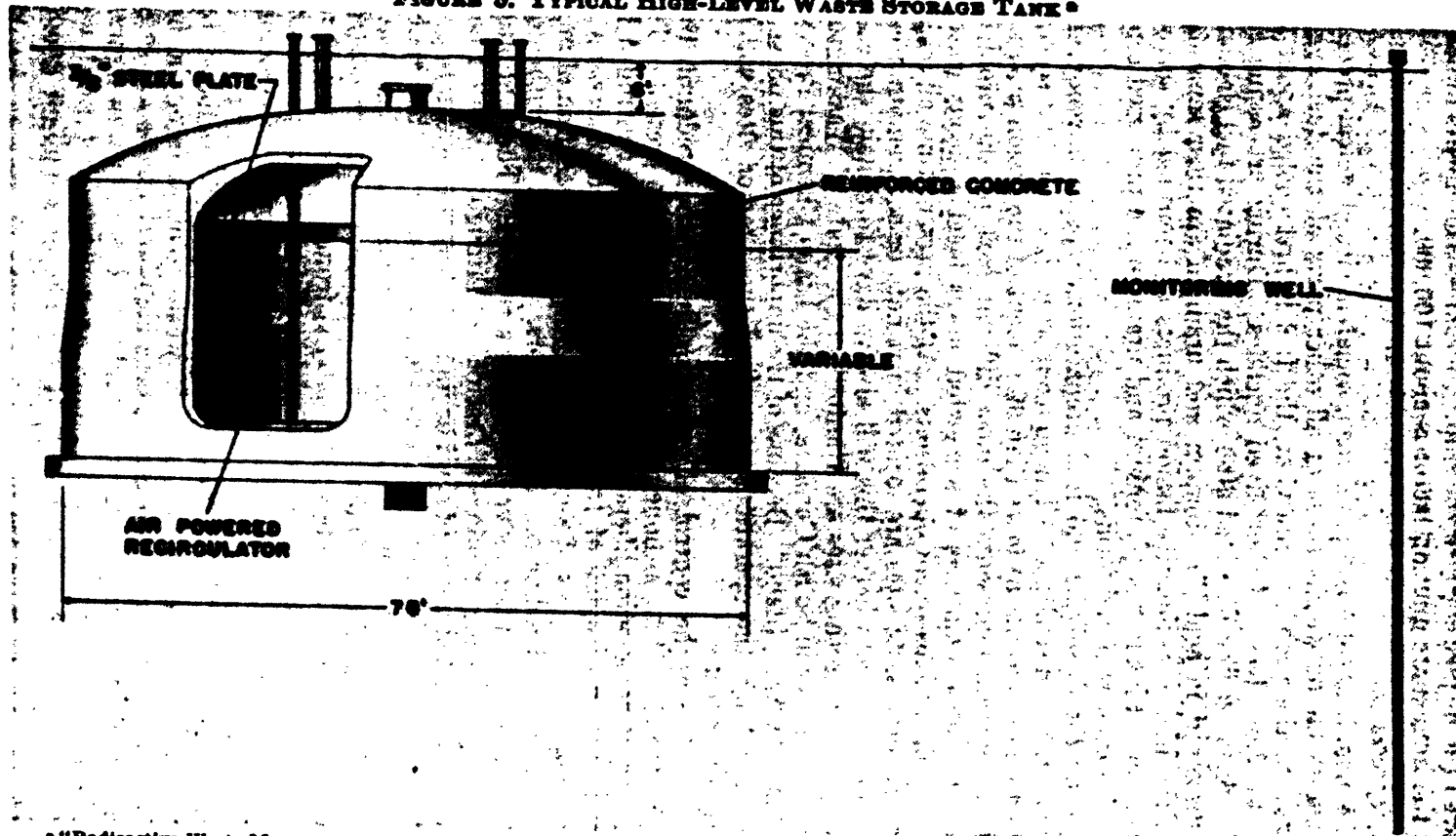
The magnitude of waste problems associated with chemical-processing plants far outweighs those of all other parts of the fuel cycle. To reduce the problem somewhat, the fuel is first cooled about 90 days to allow decay of short-lived nuclides. During processing the fuel jackets are first dissolved after which the irradiated fuel elements are dissolved in acid. Plutonium and uranium are then separated from the highly radioactive fission products and purified by solvent extraction. Finally the plutonium and uranium are processed separately to their required forms.

During the dissolving and feed preparation steps, radioxenon and radioiodine are discharged. The aqueous waste from the first solvent extraction cycle contains more than 99 percent of the fission products and this stream represents the most difficult part of the problem. There are also quantities of somewhat lower level aqueous wastes formed during subsequent operations. At the present time all major chemical processing sites are located in remote or semiremote areas. It is not yet clear whether this will always have to remain the case. The major processing sites are Hanford in the State of Washington, Savannah River in South Carolina, and the Idaho Chemical Processing Plant at Arco, Idaho. Because of the importance of this phase of waste handling, the operations at each of these major sites will be briefly described.

Hanford.—In the control of gaseous effluent, the predominating isotope is radioiodine, although radoruthenium is also present. The quantity of radioiodine liberated to the atmosphere is controlled by a combination of aging of the fuel elements prior to processing to allow radioactive decay of 8-day iodine 131 and the retention of most of the volatilized iodine on silver reactors. Most of the ruthenium which is volatilized is removed in caustic scrubbers. The ventilation air of the processing buildings is first passed through large filter beds made up of graded layers of sand or mats of glass fiber which remove virtually all of the entrained radioactive particles. It is then vented to high stacks. The amount of radioactive material which leaves the stacks is monitored continuously. Radiation exposure contributed by the release of radioactive material from the Hanford plants to the atmosphere have been well within the maximum permissible limits recommended by national authorities for people in the vicinity of such plants.

The bulk of the fission products present in the irradiated fuel elements are retained in the aqueous waste solution from the first stage of the separations process. These high-level wastes are stored as alkaline slurries in underground tanks, such as shown in figure 5. The tanks are constructed of reinforced concrete and lined with steelplate. Each has a capacity of 500,000 to 1 million gallons.

FIGURE 5. TYPICAL HIGH-LEVEL WASTE STORAGE TANK*



* "Radioactive Waste Management Operations at the Hanford Works." Paper prepared for the record of JOAE hearings on "Waste Disposal," January 1968, by staff members of HAFO.

The use of such tanks is considered waste storage rather than waste disposal and no environmental hazard exists as long as the tanks maintain their integrity. The life of the tank is not yet known since none has ever failed but it is estimated to be at least several decades. Laboratory data indicate that carbon steel exposed to simulated neutralized Purex waste media at 220° F. corrodes at a rate between 10⁻⁵ and 10⁻⁴ inches per month. Based on this the 1/2-inch steel side-liner of the Purex waste tank could be expected to last at least several decades. The bottom plate could be exposed to higher temperatures and might corrode somewhat more rapidly. Even so a life expectancy measured in decades appears to be conservative.

Separations plants at Hanford are located on a sandy plateau several miles from surface waterways or inhabited areas. The ground level is 200 feet or more above the water table. The underground waste-storage tanks were constructed in groups of 6 to 18 called farms. Surrounding each farm are 2 or 3 wells which penetrate to the ground water and 5 to 10 dry wells 100 to 150 feet deep. Table 5 presents data concerning the size, costs, and time of construction of the waste-tank farms at Hanford.

TABLE 5.—General information on waste-storage tanks at Hanford *

	Tanks per farm	Capacity per tank (gallons)	Capacity per farm (gallons)	Year constructed	Cost per farm ^b	Cost per gallon
Farm T.....	16					
	4	54,500	6,617,000	1943-44	\$3,087,000	.467
	12	530,000				
Farm U.....	16					
	4	54,500	6,578,000	1943-44	2,968,000	.451
	12	530,000				
Farm B.....	16					
	4	54,500	6,590,000	1943-44	3,019,000	.458
	12	530,000				
Farm C.....	16					
	4	54,500	6,578,000	1943-44	2,938,000	.447
	12	530,000				
Farm BX.....	12	530,000	6,360,000	1946-47	2,208,000	.347
Farm TX.....	18	758,000	13,644,000	1947-48	5,850,000	.429
Farm BY.....	12	758,000	9,096,000	1949-49	2,651,000	.291
Farm S.....	12	758,000	9,096,000	1950-51	3,951,000	.435
Farm TY.....	6	758,000	4,548,000	1951-52	1,845,000	.406
Farm SX.....	15	1,000,000	15,000,000	1953-54	3,983,000	.266
Farm A.....	6	1,000,000	6,000,000	1954-55	4,989,000	.831
Total.....	145		90,107,00		37,510,000	.416

* "Radioactive Waste Management Operations at the Hanford Works." Paper prepared for the record of JOAE hearings on "Waste Disposal," January 1959, by staff members of HAPO.

^b Includes original tank farm cost plus improvements, including instrumentation, agitation systems, and transfer lines from separation plants. A farm costs include the estimated cost of remotely maintained stainless-steel condensers and auxiliaries (\$800,000) currently being installed. Operating and maintenance costs of approximately \$200,000 per year for the entire complex are not included.

^c Average.

Approximately 52 million gallons of radioactive wastes are currently being stored at Hanford. The concentration of significant radioisotopes in the high-level wastes is shown in table 6.

TABLE 6.—Concentration of significant radioisotopes in the liquid waste from irradiated uranium ^a

Nuclide	Half-life years	Concentration ^b µg/ml	MPC ^c µg/ml of H ₂ O	Number of times above MPC
Sr ⁹⁰	0.148	1.6×10 ⁴	7×10 ⁻⁴	2×10 ⁴
Sr ⁹⁰	28	2.3×10 ⁴	8×10 ⁻⁴	3×10 ⁴
Y ⁹⁰	.150	2.3×10 ⁴	3×10 ⁻⁴	8×10 ⁴
Zr ⁹⁰	.178	2.7×10 ⁴	6×10 ⁻⁴	4×10 ⁴
Ru ¹⁰⁶	.110	3.8×10 ⁴	9×10 ⁻⁴	4×10 ⁴
Ru ¹⁰⁶	1	7.2×10 ⁴	1×10 ⁻⁴	7×10 ⁴
Tc ⁹⁹	.090	3.1×10 ⁴	2×10 ⁻⁴	2×10 ⁴
Ce ¹⁴⁴	30	2×10 ⁴	2×10 ⁻⁴	1×10 ⁴
Ba ¹⁴⁰	.035	5.2×10 ⁴	3×10 ⁻⁴	3×10 ⁴
Ce ¹⁴⁴	.068	9×10 ⁴	4×10 ⁻⁴	2×10 ⁴
Pr ¹⁴³	.038	5.5×10 ⁴	5×10 ⁻⁴	1×10 ⁴
Ce ¹⁴⁴	.78	6.9×10 ⁴	1×10 ⁻⁴	7×10 ⁴
Nd ¹⁴⁷	.032	1.6×10 ⁴	6×10 ⁻⁴	3×10 ⁴
Pm ¹⁴⁷	2.6	9×10 ⁴	2×10 ⁻⁴	4×10 ⁴
Sr ⁹⁰	80	5.6×10 ⁴	8×10 ⁻⁴	7×10 ⁴

^a "Radioactive Waste Management Operations at the Hanford Works." Paper prepared for the record of JOAE hearings on "Waste Disposal" January 1969, by staff members of HAPO.

^b Assumes the fission products from 1 ton of irradiated uranium (2,500 megawatt-days per ton at 5 megawatts per ton) are segregated in 100 gallons of water 90 days after reactor discharge.

^c The maximum permissible concentration (MPC) for each nuclide in potable water is given for each parent in equilibrium with its radioactive daughters. These values were taken from "HW-25457, Rev. 1, Manual of Radiation Protection Standards, Hanford Atomic Products Operation, May 1, 1967."

Liquids which have an intermediate concentration of radioactive materials include waste streams from the later decontamination steps, spent solutions used to absorb or scrub gases, condensed vapors from self-boiling tanks, various other condensates from processing equipment, and aged solutions from which the long-lived isotopes have been scavenged. Intermediate-level wastes are put into the ground by seepage from structures known as cribs.

Because of the favorable geological and hydrological conditions of the separations area and the capacity of the soil to adsorb the isotopes it is possible to retain the vast majority of the radioactive materials in a thick layer of sediment. Thus the wastes are essentially "stored" in the ground and the water percolating to the water table is substantially decontaminated. Besides cribs, swamps and trenches are also used for the disposal of essentially uncontaminated but suspect waters. Through 1958 there were about 35 billion gallons of water disposed to swamps. There were over 3.7 billion gallons of water with about 1.9 million curies of gross beta emitters disposed to the ground through a total of 71 crib structures and 28 million gallons containing 647,000 curies of gross beta emitters disposed to 18 trench sites.

Savannah River.—The process used at Savannah River is essentially the same as that used at Hanford and the methods of handling the highly radioactive wastes are also similar. Dissolver offgases are passed through a reactor containing silver nitrate to remove iodine. Particulate matter in the offgas is removed by a filter. After processing, the dissolver offgases along with exhaust air from the processing building are discharged to a 200-foot stack.

As at Hanford the bulk of the fission products appear in a first cycle aqueous waste stream. To minimize the volume of material to be stored, all waste streams are evaporated to the maximum solids concentration possible without the formation of precipitates. All liquid wastes are neutralized and stored in underground carbon-steel tanks.

Cooling water from various vessels and steam condensate from the evaporator coils is normally not contaminated and is discharged to surface streams. To avoid release of activity, however, the water is monitored and flows through a delaying basin which has sufficient capacity to permit shutting down the operation before activity actually reaches the streams.

High-level wastes are stored in tanks. The primary tank is constructed of carbon steel. The tank rests in a steel saucer designed to retain leakage from a faulty primary tank at least for a period. The tank and saucer are enclosed in a reinforced-concrete structure with annular space to permit inspection of the tank proper. Tank vents are provided with condensers and filters. Cooling coils are provided to avoid the possibility that the radioactive decay heat will lead to uncontrolled boiling. It has been found that the high-level wastes generate a precipitate during storage which carries an estimated 90 percent of the fission products to the bottom of the tank with the result that the bottoms of the tank have been heated to about 300° F. although the supernate was cool. The costs of the Savannah River tanks are shown in table 7.

TABLE 7.—High-level-waste storage tanks at Savannah River plant ^a

	Number of tanks	Total gallons	Cost
Original plant.....	12	9,000,000	\$14,200,000
Added 1966.....	4	4,100,000	4,700,000
Under construction.....	4	5,200,000	2,300,000
Total.....	20	18,300,000	21,200,000

^a "Waste Management, Savannah River Plant," R. J. Christl, Paper prepared for the record of JOAE hearings on "Waste Disposal," January 1969, by staff members of HAPO.

Open seepage basins are used for disposal of very low level wastes since it would be economically unfeasible to evaporate the hundreds of thousands of gallons involved. Flow to these basins averages about 80,000 gallons per day and the total activity to the basin to date has been 2.5 curies of alpha emitters, 240 curies of nonvolatile beta emitters, and 2,300 curies of iodine 131.

All solid wastes are buried in a centrally located fenced area. Most burial is in slit trenches which are backfilled as waste accumulates.

Idaho Chemical Processing Plant.—The Idaho Chemical Processing Plant is devoted principally to the recovery of enriched uranium from spent reactor fuel elements. This recovery process also involves dissolution of the fuel elements in acid followed by solvent extraction. The wastes produced are analogous to those at Hanford and Savannah River. The high-level wastes are stored in underground stainless-steel tanks of 300,000-gallon capacity. These tanks are water-cooled to eliminate boiling and to reduce corrosion of tank materials. The later cycle wastes are stored together in uncooled tanks. The volume stored varies from 50 to 150 gallons per pound of uranium recovered.

The total investment in storage tanks is \$7,700,000, made up as follows: nine 300,000-gallon permanent storage tanks for aluminum wastes, of which six are cooled. The average cost is \$789,000, which is equivalent to a storage cost of \$2.63 per gallon, including a portion of piping. Four 30,000-gallon tanks are provided for storage of zir-

onium wastes. The total cost is \$580,000, which is equivalent to a per gallon cost of \$4.90.

Low-level wastes and intermediate-level wastes, such as cell floor drains, laboratory drains, and equipment decontamination solutions are collected in small underground tanks, sampled for radioactivity and then fed to an evaporator where most of the water is taken overhead at an activity level low enough to permit disposal after dilution directly to the area water table by means of a disposal well. The concentrate is added to the storage tanks.

Research activities

Papers were received from a number of sites whose business is primarily research. The amount of high-level waste handled at such sites is extremely small and the major problem is to arrive at a satisfactory working solution for large volume, lightly contaminated liquids, solids, and gases. The problem is complicated in most cases by the fact that the research sites tend to be more closely associated with urban populations than do the production sites. The practices at the Lawrence Radiation Laboratory, Oak Ridge National Laboratory, Knolls Atomic Power Laboratory, Brookhaven National Laboratory, Convair (Fort Worth), APPR (Fort Belvoir, Va.), Los Alamos Scientific Laboratory, and Argonne National Laboratory were described.

The basic operating philosophy at essentially all of these sites is to segregate at the source the very small volume of relatively high level material handled so that it does not contaminate the large bulk of material, thus permitting it to be returned to the environment with as little treatment as possible. Gases are in general filtered through AEC (CWS) filters at the point of production. This treatment is sufficient in almost all cases to permit discharge through short stacks. Solids are collected in convenient containers, accumulated in larger shipping containers and either shipped to a more remote site for burial (usually Oak Ridge National Laboratory, sometimes Idaho), or, in the case of installations located on the coasts, dumped at sea.

The problems of liquid disposal and the systems used to handle them are the most complex and they tend to vary more from site to site. In general they consist of segregation into two or more activity levels, monitoring and discarding without treatment as much of the waste as possible and collecting and routine treatment by evaporation, ion exchange, or flocculation of only the low volume, higher activity level fractions.

RESEARCH AND DEVELOPMENT PROGRAM

A comprehensive program of research and development on waste disposal has been underway since the late 1940's. This program has included work at all of the AEC National Laboratories, various universities, and other governmental agencies such as the U.S. Weather Bureau, U.S. Geological Survey, U.S. Public Health Service, U.S. Bureau of Mines, U.S. Coast and Geodetic Survey and others. The early phase of this program was primarily concerned with the handling and disposal of large volumes of low-level liquid effluents, gaseous and particulate wastes, and assessment of the effect of relatively low levels of radioactive materials discharged to the environment. By 1952 or

1953 adequate systems were developed at essentially every site for handling the low-level wastes.

In the last few years there has been an increased emphasis on high-level waste, as the feeling that tank storage is not an ultimate solution to the problem has become more firmly established. There has been considerable effort on the reduction of waste volumes and the conversion of liquid wastes to solids, on the fixation of radioactive material in chemically inert media, and on the physical or chemical incorporation of radioactive material into clays, glasses, or synthesized crystal minerals. The possibility of direct disposal of high-level waste into selected geologic formations is also being investigated. This includes disposal in salt structures, in permeable shales, and certain deep porous formations. Ocean disposal of high-level wastes also has been given some consideration. All witnesses agreed that this method of disposing of high-level wastes is not a promising one. In this section a short summary of the current status of each of these projects is presented.

Low-level wastes

Discharge to surface waterways.—Studies at Harvard to determine the degree of self-purification from radioactivity available in streams were described. The degree of self-purification varies considerably with the particular location and at any particular location from season to season. But under favorable circumstances it is substantial and considerable amounts of low-level wastes may be discharged to inland waterways. Clearly this mechanism must be used for the large volume of very low level wastes unless prohibitive waste-disposal costs are to be encountered. Storage of long-lived radioisotopes deposited on a streambed must be regarded as precarious and unreliable, however. Sudden release from bottom storage of hazardous isotopes, such as strontium, can occur during unusual stream conditions such as floods or droughts.

The effect of discharge to streams upon aquatic life is particularly important. This subject has been studied extensively at Hanford. Reactor effluent contains many different radioisotopes and the contribution which each makes to the overall exposure differs with water use, i.e., drinking, swimming, boating, industry, irrigation, or production of fish and wildlife. Some radioisotopes may be picked up by aquatic forms and become concentrated in certain tissues. The amount to which radiophosphorus and some other isotopes of biological importance are concentrated by Columbia River fish is shown in table 8. Over 90 percent of the activity in fish is radiophosphorus which deposits principally in the hard tissues, such as the bone and scales. No effect on fish population attributable to reactor operation has been discerned. Extensive tests have demonstrated that the concentration of radioactivity in the Columbia River is well below the toxic level. The limiting factor of toxicity of the reactor effluent is not due to radioelements at all but rather is due to dichromate which is added to inhibit corrosion. There also appears to be no problem associated with the use of reactor effluent water for irrigation. Crops of barley have been grown on experimental plots at Hanford and irrigated with the undiluted effluent for 7 years without any significant effect being noticed.

TABLE 9.—Hydrological and geological factors of ground disposal at various AEC sites *

	Hanford	Reactor Testing Station, Idaho	Oak Ridge	Savannah River
Main formations involved in waste disposal.	(a) Gravel and sand (glaciofluvial formation) (b) Gravel, sand and silt (Ringold formation.)	Basalt	Shale (Conasauga formation)	{(a) Fine sand and silt (formations of Tertiary Age). (b) Gravel and sand (Tuscaloosa formation).
Depth to water table (feet)	About 200	About 200 to 600	About 20	About 20.
Permeable sediments above water table (feet).	do	About 100 (alluvial sediment overlying basalt).	do	Do.
Permeability (gallons per day per square foot).	(a) 10,000 to 60,000 (b) About 400	Erratic; about 10,000 to 20,000 (?)	} Low; 1 to 10	{(a) 1 to 100 in various beds. (b) About 1,000.
Average rate of travel (feet per day)	{(a) 15 (b) About 1	} 20 (?)	About 1	About 1.
Place of emergence at surface	Columbia River	Snake River	{ Small creeks, thence to Clinch River.	{(a) Small creeks, thence to Savannah River. (b) Savannah River.
Distance to point of emergence	About 10 miles	About 100 miles	About 400 feet	{(a) About 500 feet. (b) A few miles.

* "The Disposal of Low- and Intermediate-Level Radioactive Wastes to the Ground," C. V. Thies. Oral testimony at JCAE hearings on "Waste Disposal," January 1960.

The ion exchange reactions of Hanford soils were studied intensively for some of the long-lived isotopes (strontium, cesium, and plutonium). The pH of the soil-waste system was found to be one of the most significant factors controlling isotope retention. Strontium and cesium were found to exchange best in alkaline solution while plutonium was readily removed over a wide pH range, including rather acidic solutions. The fission product ions are removed in a more or less definite sequence by the soil. Those held closest to the disposal point are the ones with the greatest affinity for the soil under the conditions which exist at that point. Ions less strongly held move farther through the soil before they may exchange.

At Oak Ridge National Laboratory three disposal pits are in operation. Each is roughly 200 feet long, 100 feet wide, and 15 feet deep, and has a nominal capacity of 1 million gallons. Through 1957, 8 million gallons of waste, containing 100,000 curies of activity, have been pumped into these pits. Two small streams flow past the low ridge on which the three pits are located. Seepage from the pits travels underground for distances of 150 to 600 feet before joining the flow of these streams which drain into the former basin of White Oak Lake, now dry, and thence to the Clinch River.

Ocean and estuarial disposal.—The use of the ocean for the disposal of radioactive wastes has been considered from time to time. At the present there is little agitation for the use of even the ocean deeps for the disposal of large quantities of high-level wastes although some oceanographers are interested in doing additional research work to determine whether or not this would be feasible. The use of the coastal waters and tidal estuaries for the disposal of low-level wastes is of considerable interest, however.

The fate of the radioactive material introduced into the marine environment depends upon the following considerations: (1) the physical and chemical form in which the material occurs, (2) initial mechanical dilution of the waste by the receiving water, (3) advection of the wastes away from the source region by currents and simultaneous turbulent diffusion, (4) uptake of the activity by suspended silt and bottom sediments which removes some of the material from the water and restricts further dispersion, (5) concentration of activity by various parts of the biota, including shellfish and finfish important to man as a source of food. Some important fission and corrosion products are concentrated by certain marine organisms by factors of 100 to 10,000. Research is now in progress on each of these basic phenomena in restricted waterways and coastal waters.

There are three separate areas of the sea to be considered in waste disposal: estuaries, coastal waters, and deep sea. In the United States the estuaries are the kind of which the bottom water moves inshore so there would be a tendency for radioactive-waste materials to remain in the estuary and not be dispersed. These harbors and inshore waters in general also contain many bottom living animals which concentrate radioactive materials so the dispersal of radioactive materials from the estuaries takes place more slowly than the dispersal of the water itself.

In coastal waters, i.e., waters within 200 miles of the coast, there are two different situations—the shallow coastal waters of the gulf and Atlantic coasts and the relatively deep waters which exist quite close

to shore off the Pacific coast. Here there are possibilities for dispersal of low-level wastes only.

Finally, there is the deep sea, which lies below a virtual screen or curtain called the *thermocline*. It is isolated from the rest of the ocean and very few of man's food organisms come directly or indirectly from it. Although there is no clear theory on this it is generally believed, and there is quite a bit of evidence for believing, that the deep waters are isolated from the surface layer for periods of the order of hundreds to thousands of years. If this is true then the use of ocean deeps for disposal of some high-level waste may be possible but other methods of disposal of such wastes appear more promising.

The National Academy of Sciences has several working committees established preparing recommendations on specific disposal problems of concern to the AEC. The reports of two of these groups have been completed and are included in the record of the hearings: The report on "Disposal of Low-Level Wastes Into the Atlantic and Gulf Coastal Waters" at pages 1428-1488, and the report on "Radioactive Waste Disposal From Nuclear Powered Ships" at pages 1489-1526, both in volume 2. The report of the third working panel on "Disposal of Radioactive Wastes Into the Pacific Waters" is expected to be transmitted to the NAS within the next several months.

Meteorological studies.—The dispersal of radioactivity into the atmosphere has prompted considerable meteorological research at the U.S. Weather Bureau, Brookhaven, Argonne, Oak Ridge, and Hanford. Meteorology has been important to the nuclear-energy industry in three ways:

1. Site selection.
2. Determination of favorable weather conditions for specific operations.
3. Analysis of dispersal following accidental releases of activity.

Existing theories in engineering application of meteorology to nuclear science are useful, but there are many areas in which the knowledge is insufficient. Some of the specific meteorological problems being studied are atmospheric transport and diffusion, acute exposure (i.e., the study of peak concentrations which are to be expected within 1 to 2 miles of a tall stack), chronic exposure for specific sites, and deposition and wind erosion.

The useful application of meteorology to power reactor facilities is exemplified in the operation of the PWR at Shippingport, Pa. Data collected to date on all standard meteorological parameters, as well as temperature gradient measurements, have provided a basis for quantitatively assessing the limitations of the site because of the high frequency of inversion conditions. In this connection, a three-dimensional windflow study, using meteorological balloons and smoke as tracers, was conducted to measure vertical velocities and trajectories of the air currents in the area. This project, which was carried out during stable atmospheric conditions, furnished vertical motion data that was unattainable by other methods.

Air cleaning.—Since 1950 the AEC has sponsored at Harvard a program on air-cleaning research and development. The functions of this work have been to (1) perform research and development on new procedures or modification of existing approaches to solve nuclear energy gaseous waste problems, (2) provide consultation and evaluation of air-cleaning devices, (3) develop suitable test methods and

evaluation procedures, (4) provide training and education for contractor personnel.

Current air-cleaning investigations center around several major studies. An inexpensive method for iodine removal is being developed. The system consists of a low flow resistance, silver-plated copper gauze, which can be incorporated into existing systems with small additional fan load. These simple iodine reductors are now under consideration for standby use in reactor-containment vessels and in chemical-processing plants.

Another development project involves testing of a refractory slag wool filter made from inexpensive byproduct blast furnace slag which will operate at filtration temperatures in the range of 1,100° F. This filter has achieved gas-cleaning efficiencies exceeding 99 percent. The effects of blast or shock waves on air filters has also been studied. Laboratory investigations, substantiated by field tests during operation Plumbob in Nevada during September 1957, indicated that if a filter did not fail from a blast shock wave, over 90 percent of the deposited dust would be released from the filter. It has been concluded from this study that attenuating devices are required to protect these filters, by dissipating the shock wave and thereby preventing dispersion of the collected dust.

High-level wastes

High-level wastes come almost completely from the chemical-separation plants. At the present time these wastes are stored in underground tanks and the inventory of some 65 million gallons has already been mentioned. While the cost of tank storage probably could be borne by a nuclear-power economy, there is considerable doubt that tank storage represents disposal in the ultimate sense. This is particularly true since our experience is limited to 15 years and it is difficult to extrapolate this experience to give a realistic tank lifetime. Consequently, there is considerable interest in developing other methods of ultimate disposal. This program takes three directions: (1) the conversion of the liquid wastes to solids and the development of ultimate storage methods for the produced solids, (2) the direct disposal of high-level liquid wastes into the earth at great depth, (3) the removal of specific isotopes from the wastes in the hope that this might reduce the overall waste problem. At the present time there is considerable interest in the conversion of wastes to solids and their storage in some geological formation, probably salt. Research and development on direct disposal into deep wells is just getting underway. Finally, essentially all the witnesses agreed that the removal of specific fission products from the wastes would not significantly change the waste disposal picture.

Conversion to solids.—One method under investigation at Brookhaven, for fixing liquid wastes in solids is to adsorb the radioactivity from the liquid onto natural clay minerals. The waste solution is passed through a column containing extruded clay and the radioactive ions are adsorbed on the clay by an ion exchange process. In laboratory tests decontamination factors for simulated waste solution using strontium 90 as a tracer were shown to be about 10^3 . The actual fixation of fission products in the clay mineral is accomplished by heating the clay to about 1,700° F. After such treatment sea water leaches very little of the activity from the clay.

Another fixation method is to mix the clay and certain common fluxes with liquid wastes to form a paste which is then allowed to heat itself due to its radioactive decay heat to form a brick or sinter. This is under experimental investigation at Oak Ridge using Conasauga shale. Materials formed by this process have been more leachable than those formed by adsorption on clay.

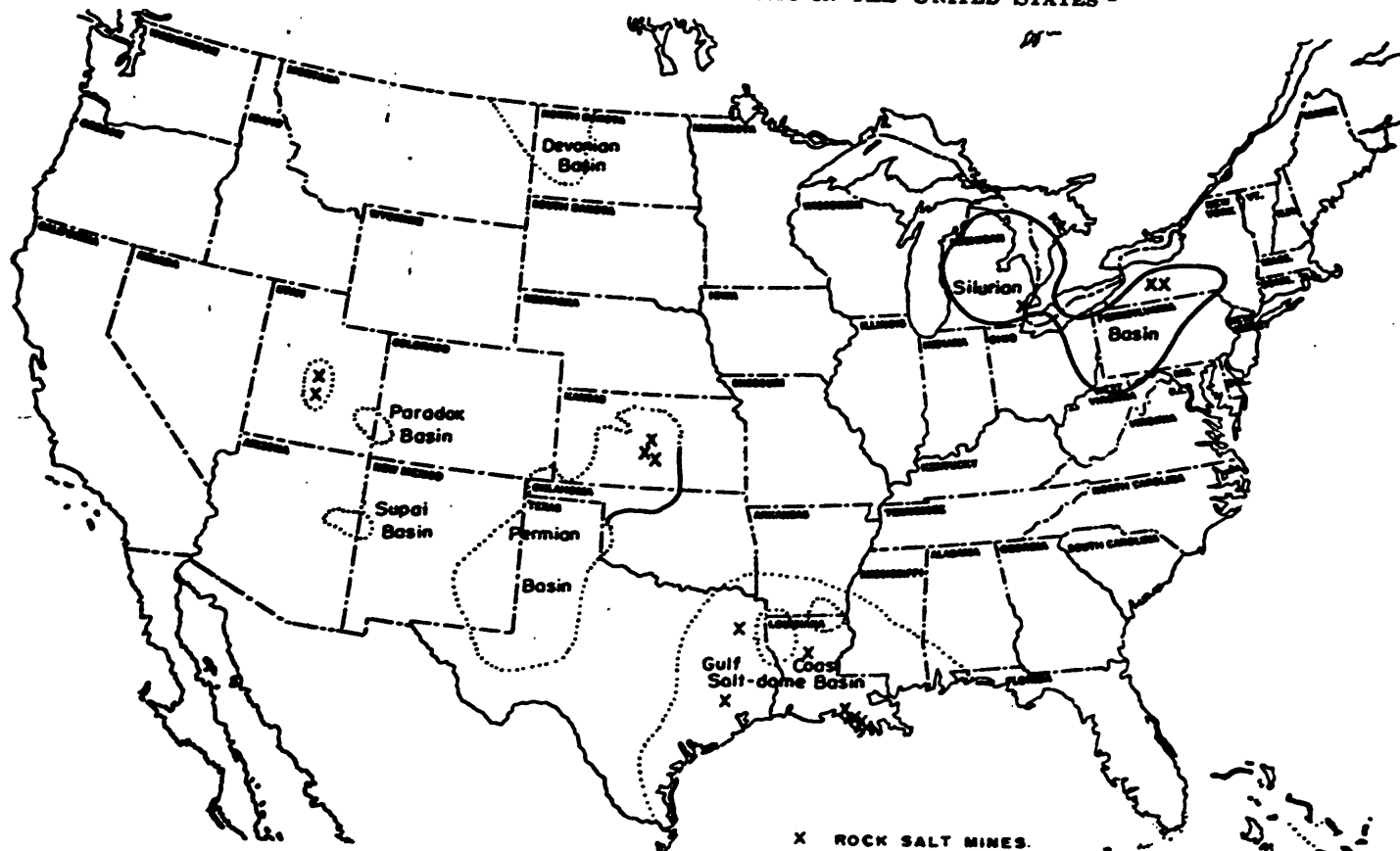
A method for conveniently converting liquid wastes to solids is fluid-bed calcination. This process consists of spraying a radioactive waste solution into the side of a heated fluidized bed of inert oxide. The calciner acts to drive off the water and to decompose the contained salts to their oxides. This process has been carried out on a pilot-plant scale at Argonne, using radioactive solutions, and on a somewhat larger scale using nonradioactive solutions at the Idaho Chemical Processing Plant. There is also being installed at the Idaho Chemical Processing Plant, a \$4 million pilot plant to test this process on a large scale using Redox wastes. The offgases from the calciner must be filtered. It has been found possible to retain essentially all of the radioactivity in the calcined oxide with the possible exception of ruthenium. Decontamination factors of 10^5 for ruthenium and 10^7 for nonvolatile species have been demonstrated.

Direct disposal.—The first comprehensive discussion of the possibilities of underground waste disposal resulted from a conference on "The Disposal of Radioactive Wastes in Land," held at Princeton University in September 1955 under the auspices of the National Academy of Sciences. At this meeting two approaches to underground storage were discussed: (1) storage in deep porous beds and sedimentary rocks by means of deep wells and (2) storage in underground openings, either natural or artificial, at comparatively shallow depths. Concerning the latter, several alternative possibilities were developed. Storage in surface excavations such as quarries was considered to be unreliable because such openings are rarely watertight. Underground caverns and shallow mines pose similar problems of leakage. The possibility of storage in deep mines below the shallow fresh water table was then studied. The consensus was that openings in salt domes or salt beds or space in abandoned salt mines were the most promising environments.

Salt has considerable compressive strength. At normal temperatures its movement is controlled by plastic flow and deformation occurs only slowly when salt is under pressure below the yield point. These unique characteristics give salt remarkable geological features. Excavations in salt are practically always dry. Because of its plasticity any fractures in salt close rapidly. Large spaces may be mined out; even at depths of 1,000 feet, two-thirds of the salt area may be removed without perceptible deformation of the pillars.

The location of salt deposits is widespread in the United States. (See fig. 6.) Deposits of rock salt underlie 400,000 square miles of the United States and they represent some of the few naturally occurring dry environments in the eastern part of the country. The volume of high activity wastes that will probably be produced in the year 2000 is computed to be about 168 acre-feet or less than 10 percent of the salt space now being mined out annually.

FIGURE 6. LOCATION OF SALT DEPOSITS IN THE UNITED STATES *



* "Disposal of High-Level Waste in Natural Salt Formations." Oral testimony of W. B. Heroy at JOAE hearings on "Waste Disposal," January 1968.

Although extensive laboratory experiments have been conducted on the behavior of salt in relation to nuclear wastes, it is realized that all of the principal factors cannot be conclusively determined in laboratories but must be established by means of field experiments. Such an experiment is now in the planning stage. Consideration is being given to the storage of both solids and liquids in salt mines and this appears to offer one of the best current possibilities for a solution to the ultimate storage problem.

The petroleum industry has developed an extensive technology of injecting fluids into deep wells. The American Petroleum Institute was requested to appoint a small committee to consider the feasibility of disposing of radioactive liquids in this way. The following major problems are associated with the development of a system for disposing of radioactive wastes in deep wells: (1) a suitable disposal reservoir must be clearly defined and must be capable of confining radioactive waste solutions for indefinite periods; (2) the heat generated by the radioactive material must be safely dissipated; (3) the disposal reservoir must be protected against damage such as fracturing, premature plugging or other causes; (4) the failure of equipment as a result of corrosion or other causes must be prevented; (5) an economical disposal plant must be designed and safe operating procedures must be developed. Many of the problems associated with deep-well disposal should be clarified through a program of laboratory work and theoretical study. The site suitable for the disposal of radioactive waste in this method should be selected through geological and geophysical exploration. The disposal of radioactive waste in association with secondary recovery or any other oil-producing operation is not recommended.

Separation of specific fission products for industrial utilization.—The time necessary for the process of decay to reduce various nuclides to tolerance varies considerably with the radioactive half life and the biological tolerance of the nuclide. (See table 10.) The twin facts that a few of the long-lived nuclides account for the long-range hazard of wastes and that the same nuclides may have industrial applications have led to the repeated suggestion that perhaps the waste-processing problem could best be solved by separating out these isotopes and making use of them industrially. While the industrial use of these isotopes certainly should be and is being encouraged, it is a fallacy to assume that such utilization would materially change the waste picture. In the first place, even if it were possible to separate each of the hazardous isotopes out by degrees sufficient to permit the remainder to be discarded, the separated product would still have to be stored and would become useless from an industrial utilization standpoint long before it had decayed to innocuousness. Secondly, the recovery of specific isotopes for beneficial use is quite a different problem from that of removing them to facilitate waste disposal. For a recovery process, a yield of 90 percent might be quite satisfactory. If the goal were to permit the residue to be treated as a conventional industrial waste, however, essentially complete removal would be required for all of the elements of concern. For these purposes any plutonium or other transuranic elements must also be removed with comparable efficiency. Microscopic losses ranging to as low as 1 part per 20 billion would have to be simultaneously achieved for the many elements of widely different chemical characteristics. Achieving this

simultaneous high recovery of such chemically diverse products is without precedent in the chemical industry.

TABLE 10.—Comparative amount of fission products in waste from the reprocessing of irradiated fuels ^a

Nuclide	Concentration ^b $\mu\text{C}/\text{ml}$	Half-life years	MPC ^c $\mu\text{C}/\text{ml}$ of H ₂ O	Years' decay to reach MPC	Ratio of concentration to MPC after 6-year decay
Sr ⁹⁰	2.3×10^4	28	8×10^{-7}	1,000.0	2×10^6 .
Ru ¹⁰⁶	7.2×10^4	1.0	1×10^{-6}	30.0	1×10^7 .
Cs ¹³⁷	2×10^4	30	2×10^{-6}	700.0	8×10^6 .
Ce ¹⁴⁴	6.9×10^4.....	.780	1×10^{-6}	26.0	3×10^7 .
Pm ¹⁴⁷	9×10^4	2.6	2×10^{-6}	66.0	9×10^6 .
Sm ¹⁵⁴	5.6×10^4	80	8×10^{-6}	1,300.0	7×10^4 .
Sr ⁹⁰	1.6×10^4.....	.148	7×10^{-6}	4.1	
Y ⁹¹	2.3×10^4.....	.159	3×10^{-6}	4.7	
Zr ⁹⁵	2.7×10^4.....	.178	6×10^{-6}	5.1	
Ru ¹⁰⁶	8.5×10^4.....	.110	9×10^{-6}	2.9	
Te ¹³⁰	3.1×10^4.....	.090	2×10^{-6}	2.2	
Ba ¹⁴⁰	5.2×10^4.....	.035	3×10^{-6}.....	.8	
Ce ¹⁴⁴	9×10^4.....	.068	4×10^{-6}	1.6	
Pr ¹⁴⁵	5.5×10^4.....	.038	8×10^{-6}.....	.9	
Nd ¹⁴⁷	1.6×10^4.....	.032	6×10^{-6}.....	.7	

^a "Removal of Specific Isotopes from High-Level Waste." Oral testimony of R. E. Tomlinson at JOAE hearings on "Waste Disposal," January 1959.

^b Assumes the fission products from 1 ton of irradiated (2,500 megawatt-days per ton at 5 megawatts per ton) uranium (1.3 percent U²³⁵ before irradiation) are segregated in 100 gallons of waste 90 days after reactor discharge.

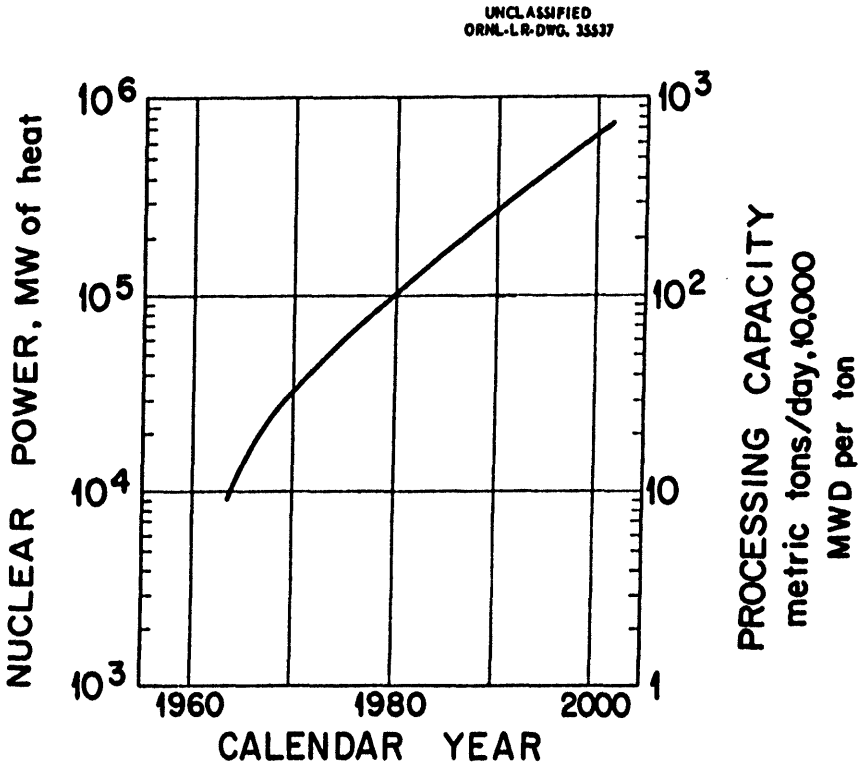
^c The maximum permissible concentration (MPC) for each nuclide in potable water is given for each parent in equilibrium with its radioactive daughters. These values were taken from "HW-26457, Rev. 1, Manual of Radiation Protection Standards, Hanford Atomic Products Operation, May 1, 1957."

The isolation of specific fission products with good recovery and fair decontamination has been demonstrated by the operation of the fission-product pilot plant at Oak Ridge, where cesium 137 sources are being made from Purex waste with an annual output of 200,000 curies of cesium 137.

ESTIMATES OF THE FUTURE PROBLEM

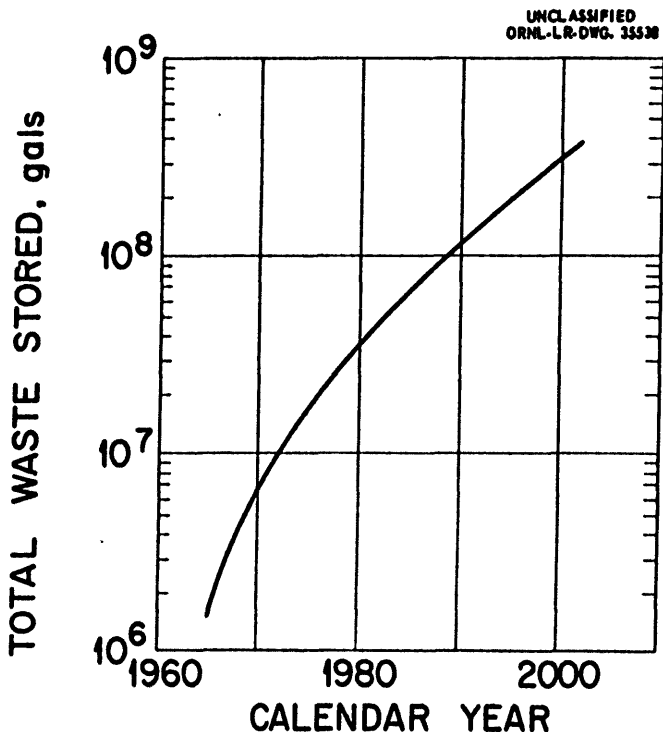
The magnitude of the waste-disposal problem of the future depends upon the size of the nuclear-power economy. An estimate of installed nuclear power is shown in figure 7. It is expected that natural or slightly enriched power-reactor fuels on the average will be irradiated to a level of about 10,000 megawatt-days per ton, at which time they will be reprocessed for recovery. The quantities of fuel that must be reprocessed are also shown in figure 7 since this determines the volume of waste produced.

FIGURE 7. PREDICTED POWER GROWTH AND FUEL REPROCESSING CAPACITY *



* "Waste Treatment and Disposal Problems of the Future Nuclear Power Industry," ORNL-CF-60-1-38. Oral testimony of F. R. Bruce at the JCAE hearings on "Waste Disposal," January 1959.

Figure 8 shows the waste volumes that will be accumulated under these assumptions. By 1980, 36 million gallons of waste will be accumulated from the civilian power program. By way of comparison it has been reported that at the Hanford site 52 million gallons of waste is stored in underground tanks. Thus, it appears that even by 1980 the waste accumulated from the nuclear-power industry will be less than the volume now stored at Hanford. Prospects for markedly decreasing the volume of waste resulting from power reactor fuels lies in three areas: (1) mechanical-processing methods for separating cladding agents from the fuel core may help reduce the volume of cladding waste; (2) methods for converting power-reactor wastes to solid form prior to storage are being studied; (3) new processes may be developed which will produce much smaller waste volumes initially.

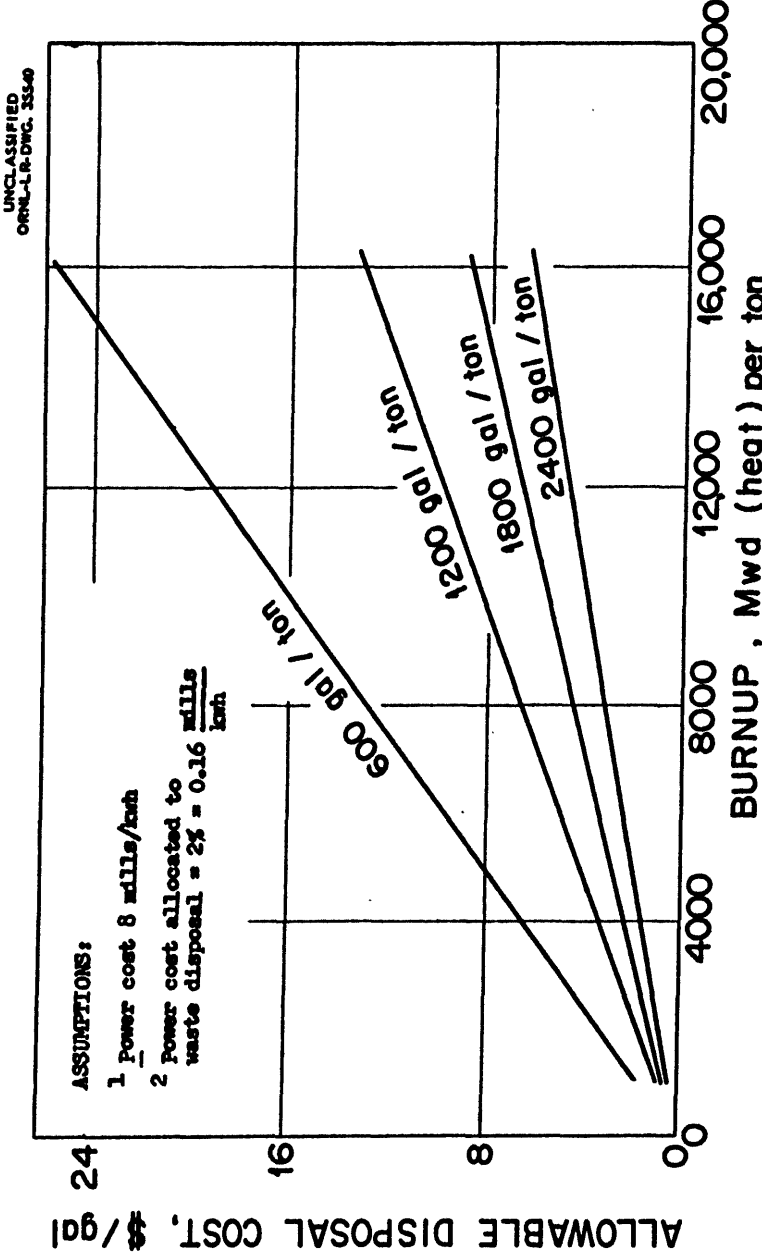
FIGURE 8. ACCUMULATED VOLUME OF HIGH AND INTERMEDIATE LEVEL WASTE STORED ^a

^a "Waste Treatment and Disposal Problems of the Future Nuclear Power Industry," ORNL-OF-59-1-38. Oral testimony of F. R. Bruce at the JCAE Hearings on "Waste Disposal," January 1959.

To assess the significance of waste-disposal costs in the production of economic nuclear power, assume that power is to be produced for 8 mills per kilowatt-hour and that 2 percent of this cost or 0.16 mill may be allocated to waste disposal. Figure 9 shows the allowable waste-disposal cost as a function of fuel burnup and waste volume per ton of fuel.

Assuming a burnup of about 10,000 megawatt-days per ton and a volume of high level waste produced of 1,200 to 1,300 gallons per ton, we can afford to spend about \$8 per gallon for waste disposal. Tank storage of high-level neutralized waste from aluminum-clad uranium fuel costs from 40 cents to \$1 per gallon. Therefore power costs allocated to initial high-level waste storage may be about 0.02 mill per kilowatt-hour. It seems apparent that the difference between this value and the allowable 0.16 mill is more than sufficient to treat and dispose of the low-level wastes. The initial cost of the waste storage in tanks does not have to contribute greatly to the cost of nuclear power. However, since steel tanks have a finite life and will have to be replaced many times it is not now possible to assign a realistic cost to tank storage as a method of ultimate waste disposal.

FIGURE 9. ALLOWABLE WASTE DISPOSAL COST AS A FUNCTION OF BURNUP AND PROCESS WASTE VOLUME.



* "Waste Treatment and Disposal Problems of the Future Nuclear Power Industry," ORNL-CF-69-1-38. Oral testimony of F. R. Bruce at the JCAE Hearings on "Waste Disposal," January 1969.

INDUSTRIAL POINT OF VIEW

One oral presentation and half a dozen papers for the record were submitted to indicate the ideas of industry in this problem. The oral testimony took the following position: (1) the responsibility for disposal of waste products created by the power industry should lie with the industry itself under regulation; (2) the nuclear energy industry will be better off the sooner industrial organizations take over the chemical-reprocessing operations; (3) in the field of government regulations, the ultimate responsibility should best lie with the State governments.

Some of the committee members pointed out during questioning of the industrial witness, that, notwithstanding guarantees from industrial organizations, the Federal Government could not be relieved of its ultimate responsibility for the handling of wastes. For despite guarantees there is no assurance that a private organization might not go out of business and should it do so the ultimate responsibility would necessarily revert back to the Federal Government.

A paper for the record, discussing the Commonwealth Edison plant under construction at Dresden, Ill., contrasted the wastes from the present conventional power industry with those from nuclear power. It pointed out that in 1956 the power industry produced 4,000 trainloads of solid wastes. Had this entire electrical output been obtained from nuclear plants with a burnup of 10,000 megawatt-days per ton of uranium, the total amount of nuclear wastes would have been less than one-half a trainload, assuming it were reduced to solids. It maintained that although radioactive wastes have a higher degree of hazard than fossil fuel wastes, the volume is so small that it should be perfectly practical to store the residue indefinitely in leakproof vaults. Using Dresden as an example, a fraction of the site area would store the solid waste for 100 years of operation.

In discussing gaseous wastes the paper indicated that 1 ton of coal will produce about 3 tons of carbon-dioxide gas. The stacks of the powerplants in this country in the year 1956 released over 600 million tons of carbon dioxide into the atmosphere. A nuclear powerplant by contrast would produce an extremely small amount of gaseous waste, most of which would be confined within the cladding. The paper concludes that—

the long-term waste disposal from Dresden will present fewer problems of waste disposal than would a coal-fired plant the same size.

It should be noted that, in all of the foregoing, this paper discusses only the waste disposal at the reactor site. Since it assumes that spent fuel elements from Dresden will be sent elsewhere for processing, it does not take into account by far the most hazardous and the most costly portions of the fuel cycle waste disposal problem.

ACTIVITIES OF FEDERAL, STATE, AND INTERNATIONAL AGENCIES

U.S. Public Health Service

The legal responsibility for regulation and control of many pollution problems lies with the States. The Public Health Service, however, is charged with the responsibility to stimulate and strengthen the States to use their powers for the promotion of effective administrative and sound technical programs. There are a number of functions for

the Public Health Service to perform which are generally beyond the power of competence or resources of individual States. The Public Health Service renders assistance to States through consultation, technical assistance, demonstrations, etc. They also deal with interstate air and water pollution problems, collaborate with other Government agencies or scientific groups to resolve problems which have a health component, conduct research, development and research training in Public Health Service installations, provide a source of public information, and have a substantial role to play in the establishment of adequate and reasonable radiation standards.

U.S. Atomic Energy Commission

The AEC Division of Licensing and Regulation regulates the use of radioactive materials by its licensees. The Atomic Energy Act provides that no person within the United States shall transfer, receive in interstate commerce, manufacture, produce, acquire possession, use any production facility or any source or special nuclear or byproduct material except as authorized by license issued by the Commission. The Commission's regulations do not attempt to spell out detailed standards for waste disposal. Rather they establish permissible concentrations in effluents to unrestricted areas and provide for the disposal of only minimal quantities of wastes by release into sanitary sewer systems and by burial in soil on a routine basis. The regulation provides that the Commission will consider alternative methods of higher levels of waste disposal on an individual case basis.

The AEC has issued licenses to eight commercial firms to collect, package, transport, and dispose of radioactive waste generated by licensees. Six of these companies propose to ultimately dispose of the waste at sea and one commercial concern collects and packages the waste and ships it to the Oak Ridge National Laboratory. One license has been issued for storage of low-level radioactive waste.

All licensees are subject to periodic inspection by the AEC to insure that the regulations, terms, and conditions of licenses are being complied with.

State health departments

Statements were received from several State departments of health. The State of Illinois representative testified as follows:

From our Illinois experiences with the Atomic Energy Commission and its contractors, particularly in regard to radioactive-waste disposal, it has been apparent that they have made every effort to prevent hazardous conditions from developing in the environment.

While a large measure of the satisfactory relationship that Illinois has mutually enjoyed with the AEC has been due to the administrative and technical attitude of the Commission and its contractors, I feel that of equal importance has been the attitudes and policies of the State of Illinois. The following are some of the reasons for this successful relationship:

1. The State administration has not avoided assuming a direct responsibility in this field. There has been no reluctance on the part of the State department of public health or the sanitary water board to accept its administrative and technical responsibilities for the protection of the environment.

2. We have followed a policy calling for early establishment and the maintaining of contact with the AEC and its contractors. There have been free exchange of information regarding local environmental requirements in addition to information concerning the problems of the facilities.

3. All concerned have accepted the mutual realization that there must be a practical and realistic approach to these problems of waste disposal in order to prevent the atomic energy industry from reaching the brink of being economically purified out of business.

International activities

A representative of the International Commission on Radiological Protection summarized the activities of that organization in developing international standards for maximum permissible concentrations of specific radioisotopes in man and his environment. He also noted the work of a subcommittee of that group concerned with the subject of disposal of radioactive waste. The activities of the International Atomic Energy Agency were also summarized.

Disposal of radioactive wastes to the sea was the subject of sharp and revealing debate at the United Nations Conference on the Law of the Sea held at Geneva, Switzerland, February through April 1958. Eighty-six nations were represented at this Conference. Two of the articles debated, "Freedom of the High Seas" and "Pollution of the High Seas," dealt with uses of atomic energy. Delegates were quite willing to refer strictly technical matters to an international atomic energy agency for investigation. But it was clear that this Conference was unwilling to release from its jurisdiction judgments as to effects of atomic energy operations on the sea and the uses of the sea by various nations.

Delegates from many nations took the stand that under existing national law, testing of nuclear weapons was a violation of the freedom of the seas. The matter, however, was referred to the General Assembly for appropriate action. In regard to pollution of the high seas, the International Law Commission's report read in part:

every state shall draw up regulations to prevent pollution of the seas from the dumping of radioactive wastes. All states shall cooperate in drawing up regulations with view to preventing pollution of the seas or air space above resulting from experiments or activities with radioactive materials or harmful agents.

The debate which took place on these paragraphs was far from moderate. Delegates from Afro-Asian, Latin, and even Western European nations in NATO were adamant in their insistence that the Conference adopt regulations forbidding pollution of the high seas. In a very close vote a resolution was adopted which recommended that—

The IAEA, in consultation with the existing groups, having acknowledged confidence in the field of radiological protection, should pursue whatever studies and take whatever action is necessary to assist states in controlling the discharge or release of radioactive materials to the sea, and to set standards and draw up internationally acceptable regulations to prevent pollution of the sea by radioactive materials in amounts which adversely affect man and its marine resources.

The resolution finally adopted unanimously was—

(1) every state shall take measures to prevent the pollution of the seas from the dumping of radioactive wastes taking into account the standards and regulations which may be formulated by the competent international organizations; (2) all states shall cooperate with the competent international organizations in taking measures for the prevention of pollution of the seas or air space above resulting from any activities with radioactive materials or other harmful agents.

It is obvious that a real task lies ahead of the IAEA under the terms of this resolution even though the Conference on the Law of the Sea adjourned without international agreement.