Disposal and Dispersal of Radioactive Wastes

Experience in handling the waste-disposal problems to date is mostly limited to conditions as they exist in the areas of the national atomic energy establishments. The determination of hazards from the disposal of wastes in these areas, most of which are in remote and somewhat isolated regions, involving relatively short periods of time, has to date revealed no deleterious effect on the public or its environment.

This does not provide, however, a completely adequate basis for projecting the magnitude of the hazard into the vastly expanded realm of industrial atomic power production. Not only does the problem itself take on new significance with the projected amount of wastes, but environmental factors which may lie dormant under conditions existing in the remote areas take on full-blown importance when viewed under the more stringent requirements for highly populated areas.

Many such problems immediately come to the surface as a result of consideration of the long-term legal and insurance aspects. These problems reflect first of all a need for deeper understanding of the basic issues and for more refined measurements, and not merely for greater but still unknown factors of safety. Long-term responsibilities—moral, legal, and financial—stemming from the ownership of atomic wastes simply come into sharp focus when it is emphasized that the radioactive life of the wastes would probably exceed by several centuries the official life of the organization itself. Legal and insurance requirements, therefore, will undoubtedly have a great deal to do with the shaping of rigid administrative policies with respect to these long-range aspects of the atomic-waste disposal problem. It may be difficult to maintain an adequate balance between objectives which primarily must emphasize the legal requirements and those which in the broad biological sense must establish the foundations for a truly preventive approach to this problem.

Present Status of Problem

The following listing summarizes the conclusions regarding the status of waste dispersal and disposal operations.

1) The safe handling and ultimate disposal of radioactive wastes is an important technical, economic, and administrative aspect of the nuclear energy industry. Waste operations must be thoroughly integrated with all other phases of nuclear energy operation.

2) From a technologic standpoint, the highly radioactive wastes resulting from the processing of reactor fuels constitute the bulk of the problem. To date essentially none of those wastes has been disposed of—that is, returned to the environment. Tank storage is presently utilized as an interim answer to this problem.

3) Wastes resulting from normal reactor operations are an important consideration, but technically represent a problem for which solutions are generally available.

4) Research and development have indicated possible feasible systems for ultimate controlled disposal of highly radioactive wastes, but considerably more work is required to bring these systems to the point of economic operating reality.

5) Major technical and economic considerations underlying the waste problem are (i) characteristics of nuclear fuels and chemical (or other) processing associated with them; (ii) separation of specific isotopes from the wastes and use of these materials to economic advantages; (iii) the proper selection of the site for nuclear facilities—especially reactor and fuel-processing plants; (iv) the detailed quantitative evaluation of the environment in order to assess its capacity to receive radioactive materials without creating deleterious effects on the environment; [and] (v) systems for the physical handling and transportation of highly radioactive materials.

6) Major policy and administrative considerations relevant to the regulation of the waste problem are (i) the establishment, perhaps through private enterprise, of suitable waste disposal services; (ii) the regulation and control of waste-disposal practices through existing and traditional state, interstate, and local channels where feasible; [and] (iii) continuation and strengthening of established practices in relations with the public and its agencies.

Growth of Nuclear Industry

Based on the best estimates available (which vary over rather wide ranges) and, to a substantial extent on technical judgment, the indications are that the principal source of fission products from nuclear reactors in the next decade will arise from the generation of electricity at nuclear-powered central stations. On the basis of present developments, the second most important source probably will be reactors for naval service. Compared with these, other sources are comparatively small and amount to substantially less than the uncertainty in the estimates of the principal uses.

By 1965 the average rate of reactor heat release is estimated to be about 11 million kilowatts. Naval service will account probably for 20 percent of this output in 1965. This rate of heat release will result in the production of somewhat over 10 kilograms of fission products per day in 1965.

In addition, the presence of radioactive wastes in quantity will have a profound effect on certain nonnuclear industries which may be damaged by air or water contaminated with radioactive wastes. Numerous wet-processing industries are likely to be detrimentally affected by radioactive wastes even in trace concentrations. Among this vulnerable group are those requiring water of the highest purity, such as for the manufacture of photographic film. Other industries which should be alerted to the problem are pharmaceutical manufacturers and food-processing companies. It is not possible, at this time, to enumerate with assurance the industrial processes which can be

This article, with slight shortening of the subheads, is the text of the summary report of the Committee on Disposal and Dispersal of Radioactive Wastes. The report is part of the Study on the Biological Effects of Atomic Radiation conducted by the National Academy of Sciences with the support of the Rockefeller Foundation. The full report will be published in monograph form by the NAS. Members of the committee were Abel Wolman, Johns Hopkins University, *chairman*; F. L. Culler, Oak Ridge National Laboratory; Arthur E. Gorman, U.S. Atomic Energy Commission; L. P. Hatch, Brookhaven National Laboratory; H. H. Hess, Princeton University; Clarence W. Klassen, Illinois State Department of Public Health; Sidney Krasik, Westinghouse Atomic Power Division; Joseph A. Lieberman, U.S. Atomic Energy Commission; H. M. Parker, General Electric Company; W. A. Patrick, Johns Hopkins University; Sheppard T. Powell, consulting engineer, Baltimore, Md.; Leslie Silverman, Harvard University; Philip Sporn, American Gas and Electric Company; Conrad P. Straub, Oak Ridge National Laboratory; Charles V. Theis, U.S. Geological Survey; and Forrest Western, U.S. Atomic Energy Commission.

completely eliminated as subjects of this potential hazard, without the assembly of extensive research and statistical data applicable to specific operations.

Fuel Processing and Types of Reactors

Neither the type of fuel nor the length of irradiation time greatly influences the accumulated total radioactivity of fission products. After approximately 3 years' decay, the residual radioactivity is essentially the same for various irradiation times, assuming constant heat generation during the irradiation period.

Essentially all of the radioactive material from fuel-separations processes must be kept from the environs to maintain human exposures within maximum permissible limits. An important problem which possibly limits storage volume is the rate of heat removal from the containers. After solvent extraction wastes are concentrated by supplied heat to about 2000 gallons per ton of irradiated uranium, the heat of radioactive decay will continue the concentration to 100 to 500 gallons per ton. Practical heat removal mechanisms may require that more concentrated waste produced by other separations processes be diluted to the same volume range. More concentrated fluid wastes also need stronger, less economical containers. The volumes of stored waste accumulated by 1980 are estimated at 20×10^7 gallons, by 1990 at 60×10^7 gallons and by 2000 at 240×10^7 gallons.

The future possibility of high burn-up of reactor fuels might ultimately result in a situation where processing may be unwarranted. This would not change accumulation of fission products, but would have a profound effect on waste storage and disposal considerations. Similarly, the development of nonaqueous chemical processing methods would be important in modifying the waste-management problem.

Isotopes Problems

The technical and administrative problems associated with the transport, use, and disposal of radioactive materials in medicine, biology, and industry will undoubtedly grow in complexity and quantity as the demand for the use of these radioactive materials increases. The expanding demand is already apparent in the rapidly increasing number of individual isotope users as evidenced by the expansion of the isotope-distribution program. The program for the distribution of reactor-produced radioisotopes is nearing 1 decade, having been initiated on 2 August 1946. During this period, more than 100,000 shipments of radioisotopes have been made from AEC facilities to some 3200 institutions throughout the United States. These materials are being applied in science, agriculture, medicine, and industry. The Oak Ridge National Laboratory, the principal radioisotope-production facility in the United States, has shipped approximately 130,000 curies to date.

All indices of radioisotope utilization reveal continued rapid growth. A look at the last 3 years of the program shows a growth in the number of using institutions from 1400 to 3200. This is an increase of approximately 125 percent. There has been a 100-percent increase in annual numbers of shipments made since 1 January 1953. The principal growth during the period has been in the industrial use of radioisotopes.

However, of even greater significance in connection with environmental and hazard-control problems is the ever-increasing desire for larger and larger individual sources of radioactivity. Requirements for intense radiation sources are obviously at their earliest stages. Such uses as food and pharmaceutical sterilization, promotion of chemical reaction, and other yet unknown applications will undoubtedly result in a much more extensive use of mobile and more widespread sources of intense radiation.

Increased use, especially of highly active materials, and the increase in the production of by-product materials at widely scattered geographic locations will result in ever-increasing new technical and especially administrative problems in both the transport of the material and the disposal of the wastes, in order to protect the environment against normal and potential emergency hazards.

Compliance with existing transportation regulations presents few significant problems in the shipment of by-product material even though certain specific limitations exist. However, consideration should be given to a complete critical review of existing ICC, Civil Air, Coast Guard, and Postal regulations to bring them in line with current requirements and radiation safety knowledge.

The radiological health and safety record in the nationwide use of radioisotopes is excellent. Incidents which have come to the attention of the Atomic Energy Commission involving significant overexposure of personnel are exceedingly small: fewer than ten. In large measure, this may be attributed to active educational efforts in radiological protection through a field advisory service to isotope users and through effective and practical licensing practices.

At present activity levels of use of radioisotopes and with the wide dispersal of users, substantial environmental health problems do not exist due to waste disposal or other practices resulting in the introduction of radioisotopes into the environment.

The following listing summarizes [our] conclusions [concerning items that require further study]: (i) geophysical and geochemical aspects of ultimate disposal of highly radioactive wastes; (ii) site selection for various nuclear facilities, particularly chemical processing plants and their location with respect to suitable waste disposal areas; (iii) transportation of highly radioactive materials; (iv) relationship of introduction and development of nuclear facilities to basic public health, social, and economic situations extant or resulting from such development.

Accidental Hazards

The following conclusions in respect to the consequences of accidents involving radioactive materials appear warranted.

1) The problems of waste disposal could be international in character and must be solved technically so that the total environment is maintained at a low level of radioactivity in order that accidents that are bound to occur will not be disastrous.

2) The type of accident that could result in a catastrophic spread of radioactive materials is the complete vaporization of the core of a reactor and its release to the surroundings. The probability of a catastrophic accident with a properly designed nuclear reactor is extremely small.

3) Reactor waste processing plants or storage facilities offer a greater hazard on a long-term basis than any single reactor.

4) Accidents in handling, transport, and chemical separation of radioactive materials, while locally severe, should not affect a wide public area and, in all cases, the contaminated areas can be cleaned up.

5) The probability of accidents in handling radioactive isotopes and low-level radioactive materials is similar to that in handling other types of lethal substances.

6) Use of nuclear reactors to drive ships appears feasible from a consideration of the consequences of possible accidents provided that uranium-233 and plutonium are kept to a minimum. The technology of the use of nuclear reactors to drive locomotives and commercial airplanes has not developed to the point where the committee can form a judgment as to the consequences of possible accidents.

7) Development of improved methods to limit the volumes of wastes produced in nuclear power reactors is justified from the viewpoint of the hazards due to possible accidents.

8) Continuous and vigorous appraisal of reactor and fuel-processing plants design and operation and waste storage will

be required in all nations using atomic energy in order to keep the radioactivity level of the world environment at tolerable levels.

9) Improved safety devices for control of transients in nuclear reactors should continue to be vigorously developed.

10) Further tests are required of reactors to evaluate their ability safely to withstand power excursions which may occur as a result of unusual operating circumstances.

11) Until such time as advances in the technology of reactors lessen potential hazards substantially, sealed buildings properly designed, constructed, and tested should be required for all nuclear reactors to be built in or near populated areas.

12) All operations involving radioactive materials in sufficient amounts to create possible health hazards should be supervised by trained and responsible people.

Fallout Considerations

It is apparent that as of the present time the dispersal of radioactive material resulting from weapons testing has not been an environmental contaminant of substantial public health significance. However, because of various unknown factors regarding the distribution and ultimate fate of this material, plus the potentials of possible wider spread and more frequent weapons testing, it is also apparent that the subject in all of its aspects merits meticulous and continuing attention. The problem of fallout is one of international significance and should be studied and evaluated on that basis, perhaps looking forward to international cooperation in control.

Louis C. Karpinski, Historian of Mathematics

Although he was best known and probably will be longest remembered as a historian of mathematics, Louis Charles Karpinski was remarkable for his breadth of interests and his vigorous pursuit of them. These included cartography, American history, bibliography and book collecting, chess, and public utility rates.

After graduating from Cornell University in 1901 where he was the ranking player on its championship chess team, he journeyed to the University of Strassbourg in France. There he completed in 1903 a doctorate in mathematics with a thesis in number theory. Upon his return to this country, he taught for a year at Oswego State Normal School, before being appointed to an instructorship at the University of Michigan where he remained, except for leaves, until his retirement in 1948.

His activities while on leaves from the university were typical of his interests and greatly influenced them. The first of these was a year (1909–1910) spent as a fellow at Teachers College, Columbia University. There, with David Eugene Smith, he developed his interest in the history and pedagogy of mathematics, the fields wherein lie his greatest contributions, both in research and in teaching. Out of this period came his first of more than ten articles in *Science, The International Commission* [on the Teaching of Mathematics], and his first book, *The Hindu-Arabic Numerals,* (1911) written jointly with David Eugene Smith. This work is still the most complete and accurate study of this topic available.

His *History of Arithmetic* (1925) and monumental *Bibliography of Mathematical Works Printed in America Through 1850* (1940) show the continuity and vigor of his interest in the history of elementary mathematics and in bibliography. Also of a bibliographic nature are his two books on the early maps of the Great Lakes and Michigan. These volumes published by the Michigan Historical Commission represent an even broader interest in maps and historical source materials.

It was typical of him that he not only enjoyed these interests but made them serve him both financially and in the pursuit of his research. He helped finance one trip abroad by the sale of his map collection to Yale University and another by photographing manuscripts related to America in libraries and archives in France, Spain, and Portugal. Shopping in bookstores on his trips abroad and avidly scanning catalogs from dealers all over the world were the means of constructing what is probably the most lasting monument to Professor Karpinski, the outstanding collection of source materials in the history of science that he built up in the University of Michigan Library.

The internationalism of his interests (he was proud of his father's Polish birth) is further attested by the range of foreign journals in which his more than 100 publications appeared (for instance, *Biblioteca Mathematica, Isis, Archeion*), his publications of studies of Spanish, Italian, Provencal, English, and Arabic algebraists and arithmeticians, and the fact of which he was most proud—namely, that he was elected an effective member (No. 14) of the Comité Internationale d'Histoire des Sciences at the time of its establishment. He also served a term as chairman of Section L of the AAAS, and later (1941) was elected president of the History of Science Society.

He was frequently involved in controversies, because he was sensitive to what he thought to be wrongs to himself or to society and responded fearlessly and vigorously when a wrong was perceived. It was in this spirit that he attacked utility rates and studied this problem to the extent that he was once listed as an "expert" on them. His colleagues and friends often secretly admired his forcefulness and fearlessness in rushing to an attack where others awaited more data or a better opportunity. His students recall him affectionately as one whose friendliness as a counselor belied his occasional classroom "bark" and as one who was always ready to help, even beyond the regular duty of an instructor, with suggestions and materials from his own resources and with references from his astonishing reserve of information about the literature of his fields.

He died in his sleep early in the morning of 25 January 1956 at his home in Winter Haven, Florida, from which since his retirement he had continued as a book dealer to exercise his bibliophilistic urge.

PHILLIP S. JONES
Department of Mathematics, University of Michigan, Ann Arbor