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Disposal of Radioactive Wastes

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Summary. Scientists appointed by the International Council of Scientific Unions have concluded that nuclear wastes may be safely disposed of using current technology. Interim storage for 50 to 100 years greatly reduces the problem of thermal loading at the final disposal sites, but more research devoted to such interim storage is needed.

The president of the National Academy of Sciences, Washington, D.C., wrote to the president of the International Council of Scientific Unions (ICSU) on 29 August 1977 to suggest that ICSU enter the discussion of nuclear waste management. The letter stated that "the tentative scope of the proposed effort would be to obtain the considered opinions, and consensus where available, of an international body of scientists (which combines the prestige of the respective national academies and scientific unions and the knowledgeability of a wide range of experts from several relevant fields) on technical issues involved with the management of the back end of a nuclear fuel cycle, including reprocessing (whether and what), waste solidifications, and isolation (disposal)." The proposal was made jointly with the president of the National Academy of Engineering and with the encouragement of the International Atomic Energy Agency (IAEA).

A small preparatory committee, appointed by the president of ICSU, was asked to prepare a report on the issue for circulation at the 19th General Assembly of the ICSU in September 1978. The matter was discussed informally with senior officers of the IAEA and of the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development. All expressed interest and indicated they would provide information and data where available.

Members of the preparatory committee were J. M. Harrison, Canada, convenor, consultant; H. Lacombe, France, Laboratoire d'oceanographie physique; A. Preston, United Kingdom, Directorate of Fisheries Research; Gilbert White, United States, president of ICSU's Scientific Committee on Problems of the Environment; Y. Yamamoto, Japan, professor emeritus, Tokyo University; V. Yemelyanov, U.S.S.R., corresponding member, Academy of Sciences.

The committee's report suggested that ICSU might undertake to appraise existing research efforts on the safe disposal of high-level radioactive wastes (HLW), which are highly radioactive materials containing long-lived radioactive isotopes, generally resulting from spent nuclear reactor fuel. ICSU is responsible to no government, has no vested interest in nuclear power (or any other kind of power), has access to the world's scientific and technical community, and can come to conclusions purely on scientific grounds.

In 1978 the General Assembly of the ICSU authorized a review of the research being conducted on disposal of high-level radioactive wastes. The review was to be performed by three working groups whose chairmen would be nominated by the appropriate international scientific union or scientific committee. W. S. Fyfe was nominated by the International Union of Geological Sciences as chairman of Working Group No. 1, Terrestrial Disposal; C. D. Hollister, by the Scientific Committee on Ocean Research as chairman of Working Group No. 2, Marine Disposal; and F. Morley, by the Scientific Committee on Problems of the Environment as chairman of Working Group No. 3, Environmental Pathways. The general committee of ICSU appointed a steering committee to provide overall guidance to the working groups to assist in selecting their members and to review their reports. The steering committee was composed of J. M. Harrison, geologist, Canada (chairman); H. Lacombe, physical oceanographer, France; F. B. Staub, biochemist, Hungary; P. Watanabe, mineralogist, Japan; V. S. Yemelyanov, nuclear specialist, U.S.S.R., and the chairmen of the three working groups.

A preliminary report was presented to the 18th General Assembly in 1980 and the working groups were asked to continue their reviews and to prepare a final report for consideration by the General Assembly in 1982.

During the period of review, the steering committee was informed that the U.S.S.R. preferred to make its international presentation through the IAEA, and V. S. Yemelyanov attended only one early meeting of the committee. Also, after preparation of the preliminary report, F. Morley withdrew as chairman and member of Working Group No. 3; he was succeeded by R. H. Clarke, a colleague and member of Working Group No. 3.

Thousands of scientists in laboratories around the world are working on the problems of HLW disposal. The accessibility of their reports and publications varies widely, but the quantity of this material is enormous. Faced with the

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problem of what could be achieved with the means available, the committees sought aspects of the problems where there might have been insufficient research on subjects of significance. Provision of special funds from the Science Council of Japan and from the Japanese Nuclear Safety Research Association greatly helped the study.

Review of Ongoing Activities

Four international organizations are particularly involved in coordinating programs of research into disposal of HLW, and to these programs particular attention was paid. The four are the IAEA and NEA, which were referred to earlier, the Commission of the European Communities, and the Council for Mutual Economic Assistance (CMEA). The last organization named coordinates research in the U.S.S.R. and most of the Eastern European countries.

In general terms, these international agencies coordinate and promote technological developments, provide safety guidelines, initiate research programs, and coordinate specific activities concerning seabed disposal and terrestrial disposal. All have a large publications program, and they have supported numerous technical reports and conferences. Their publications are freely available.

In reviewing national programs of research on the disposal of HLW, recent publications were consulted, as well as papers given at international symposia and scientists from the various countries. Argentina, Brazil, China, Mexico, and Norway, all users of nuclear power, had not published details of research programs on disposal of HLW up to the time the review ended. Countries with broad programs on terrestrial or seabed disposal, or both, include Belgium, Canada, Federal Republic of Germany, France, Japan, the Netherlands, Sweden, Switzerland, the U.S.S.R. (and other CMEA member countries), the United Kingdom, and the United States, with the largest of all programs described. The total field of research on both geologic and subseabed disposal options is very extensive, covering the topics of interest in varying degrees of detail.

In addition to the foregoing, the following countries have comparatively small programs of research into HLW disposal: Australia, Austria, Denmark, Finland, Italy, and Spain. While small, however, their contributions can be important because they are directed toward specific aspects of HLW disposal.

ICSU Summary and Recommendations

Summary. This is a brief account of the review by the ICSU's steering committee and of the reports prepared by the working groups on terrestrial disposal, marine disposal, and environmental pathways. The conclusions and recommendations are based on several postulates that were agreed to by the steering committee and the working groups.

1) Disposal is taken to mean the sequestering of material with no intention to retrieve it (although it may be technically possible to do so), whereas storage is intended to be temporary.

2) Criteria for site selection should be determined by safety and science and not by economics and politics, although these factors will inevitably be involved for the actual selection.

3) Nuclear wastes are with us now, so safe means must be found for their disposal. Programs are already under way in different countries to investigate various methods of disposal.

4) High-level wastes are potentially hazardous for at least 10^5 years and the behavior of the nuclides contained therein must be considered over that period.

5) The system of dose limitations developed by the International Committee on Radiation Protection is rational, and the dose limits are set at a level so low that risk is comparable to other risks of everyday life.

6) Primary attention should be given to international agencies and the research they support, sponsor, or coordinate; but national programs should be reviewed where necessary.

7) The review should be limited to disposal using technology now available.

8) The working group on environmental pathways should consider migration of nuclides in the biosphere and the other two working groups should review data concerning the migration of nuclides from the repository to the biosphere. Some overlap would be inevitable and probably useful.

The steering committee and the working groups are confident that HLW can be safely disposed of provided that some specific lines of research are intensified (see Recommendations that follow). Since it is impossible to eliminate all risks from any activity, safe disposal means their reduction to an acceptable level.

Disposal on land or beneath the sea demands a systems approach and close cooperation, beginning with early planning, and must involve all concerned. This approach must include the design of waste containers, the planning and building of the repository, and the transportation, emplacement, and monitoring of the filled container. Care must be taken to ensure that procedures for encapsulating the HLW do not create more dangers to any part of the population than the procedures would avoid in disposal.

The steering committee and working groups agreed that the HLW would be more safely disposed of if solid wastes were retained in appropriate storage facilities for 50 years or more beforehand. Hence, more research is needed on temporary, long-term storage.

Although both the proposed research and research under way are directed to HLW, their successful conclusion will ensure safe disposal of all toxic materials, including mercury and arsenic.

Recommendations

What follows are the annotated recommendations made by the working groups. These are extremely condensed versions of extensive reports (*1*). The data from which this article was prepared were those available up to about the first third of 1982. Since then new programs have been initiated in several countries; and, as is usually the case, some of the recommendations have been acted upon.

1) More effort is needed to ensure secure storage of solidified HLW for periods of up to 100 years.

Comment. The heat content of the HLW decreases rapidly with time, reducing thermal effects in the disposal medium and making it possible to use less underground space for disposal. Present data are inadequate for optimum choice of disposal facilities. It follows that more attention should be given to studies on specific sites, so that optimum choices may be made in due time. The first disposal sites should be small so that any unexpected results can be better controlled.

2) Development of underground laboratories in all proposed host rocks should be accelerated.

Comment. Such laboratories could be used for interim storage. Materials could be tested there, and fluids monitored for the next 50 years or more. Some might even become small disposal sites.

3) Much more information is needed about fracture systematics and resultant permeability, not only for the immediate host rocks but for all those providing containment.

Comment. Techniques are needed to predict fracture systems and their relation to permeability on all scales. For example, large cracks in rocks such as granite are cause for concern, but a myriad of small fractures in rock such as shale might actually inhibit the movement of fluids. Methods are needed to locate fractures and estimate flow volumes through them over long periods.

4) Specialists in the study of the geological deposits that have formed during the last 5 million years or so should be more involved in research on HLW disposal.

Comment. Studies on these deposits can determine their tectonic stability and the effects of changes in climate, variations in water levels, and so forth. Seismic studies are also necessary, but they would not allow predictions over the periods of time under consideration.

5) Mining methods and technologies should be carefully studied to ensure the most favorable conditions for HLW emplacement.

Comment. Minimum disturbance to the rock during excavation is an important requirement for the repository. The employment of new giant machines for boring large underground passageways, for example, would greatly reduce the use of explosives, which would probably mean fewer fractures in the rock. The engineers for the repository, those who will construct the canister, and the scientists who will set the specifications for containment must work as a team to achieve the best procedures and methods for containment.

6) The disposal of HLW and other toxic wastes through the process of subduction should be carefully analyzed.

Comment. If further research shows that the sedimentary load is rafted under the crust in some areas of subduction, and if the speed of subduction can be predicted, ready-made disposal sites are available. All materials would be carried into the interior of the earth.

7) The effect of thermal perturbances on the containing medium and its resultant effects on fluid flow, fluid chemistry, rock and sediment alteration, and other physical properties should be studied so that they can be predicted with assurance.

Comment. This is important for all types of disposal. In the terrestrial environment, these studies would help determine the degree of fracturing of the rock, the subsequent permeability, and the hazard of lost containment. In the marine environment, the effects of pore-filled, fine-grained sediments must be better understood. For example, will the heat source cause a miniature eruption and eject the canister? Or will it cement the sediments to produce a "rock" that could be fractured?

8) A pilot survey should be conducted based on cores of deep-sea sediments, which are tens of meters long, from several locations.

Comment. It is essential for site selection that the cores be carefully studied, for they would relate the past history of the surveyed area, the rates of sedimentation, the composition of the sediment, the possibility of geological disruption, and other geologic information.

9) Much more information is needed about both the sorption and mechanical characteristics of deep-sea sediments.

Comment. Information needed about the sediments includes grain size, composition, ion-exchange capacity, ability to adsorb radionuclides, and contained biota and consequent bioturbation.

10) A more careful assessment of the adsorption of radionuclides by sediment systems is needed.

Comment. Radionuclides can occur in various oxidation states that may behave differently from related elements. They could move erratically, especially as the strata will be disturbed by emplacement of canisters. Moreover, the sorption characteristics of the containing media at elevated temperatures appear to be little known.

11) More research is needed on the processes that occur at the boundary between sediment and overlying sea water.

Comment. Results from the release of contained material into the water at the seabed surface will depend on such factors as mixing and advection at the boundary and exchange between the boundary layer and the overlying, stratified, deep water.

12) Physical and chemical models of diffusion processes in the seabed are needed.

Comment. Diffusion processes in undisturbed sediments are not well understood and much more verification is needed on disturbed sediments, such as what may happen as a result of emplacement of heat source, the effects of convection and adsorption, effects on the biota, and the potential escape of radionuclides.

13) Physical oceanographers need to determine how those radionuclides that reach the water would be distributed.

Comment. What aspects of dispersion and dilution are most significant? The local, transient effects of radionuclides in the large discrete plumes or blobs of deep water that have recently been recognized might lead to higher doses to the biota. The probabilities of occurrence and the effects of such events, such as upwelling, need to be evaluated.

14) Major research is needed on all aspects of engineering related to emplacement.

Comment. Scientists must ensure that engineers are involved in all aspects of planning the disposal of HLW. Only by so doing can optimum designs and techniques be assured. This collaboration should begin with techniques for coring and drilling of holes and continue through the design, construction, and emplacement of canisters to the plugging of boreholes, both on land and in the seabed.

15) More data are needed on rates of removal of radionuclides from the ocean by sedimentation and their return to the ocean from the seabed.

Comment. When fine-grained sediment descends through water containing radionuclides, it will certainly adsorb some of them and carry them to the bottom. Conceivably, the seabed sediments will lose some radionuclides to the water. Predictions on relative rates of those processes are needed.

16) Better understanding of how radionuclides concentrate in marine organisms is essential.

Comment. Different radioactive elements may be concentrated in different parts of an organism, so it is especially important to distinguish the factors that lead to concentrations of radionuclides in the edible parts.

17) The factors that determine dose per unit of intake for radionuclides need much more study.

Comment. Rates of metabolism of radionuclides, and hence dose per unit intake, depends on the chemical form of the radionuclides that is ingested or inhaled. Further work on this topic is needed.

18) More effort should be given to investigating the chemical speciation of radionuclides in ground water and to research on the methods for retarding radionuclide migration.

Comment. Radionuclides are adsorbed at different rates by different media. Little is known about the kinetics of sorption reactions, so the transport may not be as slow, relative to ground water, as is thought.

19) Research should be intensified on the mechanisms involved in movement of radionuclides in the terrestrial environment, including freshwater, over long time periods.

Comment. Considerable work has been done on transfer rates over relatively short term (decades), but the time scale of HLW is very long and, in general, there is insufficient knowledge to make adequate long-term predictions.

Appendix

Terms of reference for the working groups. The working groups will:

1) Review relevant research completed, under way, or planned for the purpose of: (i) ensuring that the proposed methods of disposal of high-level radioactive wastes, whether into geological formations on land, below the seabed, or on the seabed, provide the degree of containment necessary to protect the biosphere from undue risks of radiation originating from the wastes; (ii) estimating with sufficient accuracy any radiation exposure to man that may result from such disposal; and (iii) assessing any harm to ecosystems from such disposal.

2) Conduct the reviews so that account is taken of the relevant behavior of nuclides following loss of any man-made containment of the wastes.

3) Principally base their reviews on the relevant activities of the IAEA, NEA, the Commission of the European Communities, and the Council for Mutual Economic Assistance, but extend these to national agencies where necessary to complete the reviews.

Membership of the working groups. The membership of Working Group No. 1, Terrestrial Disposal, included Dr. V. Babuska, Czechoslovak Academy of Sciences; Dr. W. S. Fyfe (chairman), University of Western Ontario; Dr. D. I. Norton, University of Arizona; Dr. N. J. Price, Imperial College of Science and Technology, United Kingdom; Dr. E. Schmid, Anglo-American Corporation of South Africa Ltd.; Dr. S. Uyeda, University of Tokyo, Bunkyo-ku; and Dr. B. Velde, Université Pierre et Marie Curie.

Working Group No. 2, Marine Disposal, included Dr. Kurt Bostrom, University of Lules; Dr. Egon T. Degens, Universität Hamburg; Dr. E. K. Duuersma, Delta Institute for Hydrobiological Research, Netherlands; Dr. Charles D. Hollister (chairman), Wood's Hole Oceanographic Institution; Dr. Ronald Pusch, University of Lulea; Dr. John C. Swallow, National Environmental Research Council, United Kingdom; and Dr. Gleb Udintsev, U.S.S.R. Academy of Sciences.

Working Group No. 3, Environmental Pathways, included Dr. B. G. Bennett, Environment Measurements Laboratory, New York; Dr. Y. Inoue, Kyoto University; Dr. R. H. Clarke (chairman), National Radiological Protection Board, United Kingdom; Dr. P. Jumans, University of Washington; Dr. J. P. Massue, Council of Europe; Dr. F. Morley, National Radiological Protection Board, United Kingdom; Dr. I. Nerethnicks, Royal Institute of Technology, Sweden; and Dr. J. B. Robertson, U.S. Geological Survey.

References and Notes

1. The full reports can be obtained from the International Council of Scientific Unions, 51 Boulevard de Montmorency, 75016 Paris, France.
2. A list of the references consulted by the working groups and steering committee would fill several pages. Moreover, this article provides only the conclusions of a study that directly involved about 30 individuals. It is suggested, therefore, that readers interested in specific details refer to the ICSU report with its 174 citations. The most comprehensive coverage is contained in the various reports and proceedings of the International Atomic Energy Agency in Vienna and of the Nuclear Energy Agency. Probably the best place to begin is *Underground Disposal of Radioactive Wastes* (International Atomic Energy Agency, Vienna, 1980). The Council for Mutual Economic Assistance also publishes material of relevance to the countries of Eastern Europe, but mainly in the Slavic languages. Many papers from the region, however, are included in several of the publications from The International Atomic Energy Agency. In addition, various regional groups have sponsored studies, seminars, and workshops on different aspects of waste disposal. From all of these it is relatively easy to investigate the literature of any aspect of radioactive wastes.

Heroin-Related Deaths: New Epidemiologic Insights

A. James Ruttenber and James L. Luke

The epidemiology of heroin use and associated mortality has been well described in a number of cities (*1–7*). Frequency of heroin use and overdose fluctuates widely over time and depends on geographical and cultural factors as well as drug availability. Heroin overdose also appears to be related to the concentration of heroin in street preparations and the loss of tolerance to heroin (*2, 7*). Over the past 30 years, the types of individuals using heroin and their patterns of heroin use have also changed. However, relatively little is known about why epidemics of heroin-related deaths (HRD's) develop, whether particular groups are at high risk for fatal overdose during these times, or how demographic and toxicologic variables during epidemics differ from those that precede and follow such periods.

The changes in heroin usage require continuous surveillance by medical and social support communities to provide appropriate emergency intervention, treatment, and rehabilitation. We describe an epidemic of HRD's in Washington, D.C., from 1979 through December 1982. We have identified risk factors for HRD's and suggest possible causes of such epidemics.

The Office of the Chief Medical Examiner investigates all deaths in the District of Columbia not demonstrated to have resulted from natural causes. When circumstances of death or postmortem findings suggest drug involvement, subjects receive autopsy examination and complete toxicologic screening. Since 1971, medical-legal investigations have been performed there with uniform methods and interpretive criteria (*2, 7, 8*).

We reviewed records of all drug-associated deaths reported to the Medical Examiner's Office from 1 January 1976 through 31 December 1982. A death was considered heroin-related either (i) when postmortem toxicology was positive for morphine (a metabolite of heroin) but no trauma or natural disease contributed to death or (ii) when death occurred during hospitalization for effects of documented heroin administration. We excluded any overdose deaths with toxicologic evidence of other narcotics alone or in combination with morphine. Heroin-related deaths are the cases in the case-control analyses.

Two control groups were used for comparisons with HRD's. The general control (GC) group consists of all deaths due to natural or traumatic causes with either cutaneous stigmata of intravenous narcotic use or positive blood morphine levels. The morphine-positive control (MPC) group is composed of members of the GC group that had positive blood morphine levels and no measurable level of any other narcotic drug. Comparison to the MPC group adjusts for the possibility that some controls were not active heroin users at the time of death. We excluded autopsy toxicologic data for cases and controls if an individual was admitted to a hospital, survived longer than 12 hours after injection, or if medical treatment after drug overdose was not specified.

From the autopsy protocols of cases and controls, we abstracted the number

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