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NUCLEAR POWER

Management of High-Level Radioactive Waste

WORLD HEALTH ORGANIZATION
REGIONAL OFFICE FOR EUROPE
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Report on a Working Group
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The World Health Organization is a specialized agency of the United Nations with primary responsibility for international health matters and public health. Through this Organization, which was created in 1948, the health professions of more than 150 countries exchange their knowledge and experience with the aim of making possible the attainment by all citizens of the world by the year 2000 of a level of health that will permit them to lead a socially and economically productive life.

The WHO Regional Office for Europe is one of six Regional Offices throughout the world, each with its own programme geared to the particular health problems of the countries it serves. The European Region has 33 active Member States,[a] and is unique in that a large proportion of them are industrialized countries with highly advanced medical services. The European programme therefore differs from those of other Regions in concentrating on the problems associated with industrial society. In its strategy for attaining the goal of "health for all by the year 2000" the Regional Office is arranging its activities in three main areas: promotion of lifestyles conducive to health; reduction of preventable conditions; and provision of care that is adequate, accessible and acceptable to all.

The Region is also characterized by the large number of languages spoken by its peoples, and the resulting difficulties in disseminating information to all who may need it. The Regional Office publishes in four languages — English, French, German and Russian — and applications for rights of translation into other languages are most welcome.

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[a] Albania, Algeria, Austria, Belgium, Bulgaria, Czechoslovakia, Denmark, Finland, France, German Democratic Republic, Federal Republic of Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Monaco, Morocco, Netherlands, Norway, Poland, Portugal, Romania, San Marino, Spain, Sweden, Switzerland, Turkey, USSR, United Kingdom and Yugoslavia.

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Cover design by M.J. Suess.
Detail of fuel assembly
by courtesy of Westinghouse, USA.

NOTE

WHO policy in respect of terminology is to follow the official recommendations of authoritative international bodies, and every effort has been made in this publication to comply with such recommendations.

Nearly all international scientific bodies have now recommended the use of the SI units (*Système international d'Unités*) developed by the Conférence générale des Poids et Mesures (CGPM),[a] and the use of these units was endorsed by the Thirtieth World Health Assembly in 1977. The following table shows two SI derived units used frequently in this report, together with their symbols, the corresponding non-SI units and the conversion factors.

SI unit and symbol	Non-SI unit	Conversion factor
becquerel, Bq	curie, Ci	1 Ci = 3.7×10^{10} Bq (37 GBq)
sievert, Sv	rem	1 rem = 0.01 Sv

[a] An authoritative account of the SI system entitled *The SI for the health professions* has been prepared by the World Health Organization and is available through booksellers, from WHO sales agents, or direct from Distribution and Sales, World Health Organization, 1211 Geneva 27, Switzerland.

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Introduction

The WHO Regional Office for Europe, in collaboration with the Government of Belgium, convened a Working Group on Health Implications of High-Level Radioactive Waste Disposal, from 2 to 6 June 1980. This was the third in a series of meetings arranged in Belgium on the health aspects of nuclear power production. The report on the first, a general review, was published in 1978 (*1*). The second and third were on health aspects of specific topics relevant to nuclear power production; the report of the former, on the transuranium elements, was published in 1982 (*2*).

The purpose of these meetings was to respond to the need for national health and environmental authorities in European countries to keep themselves and the general public well informed of the consequences for health of new developments in the peaceful uses of nuclear power. Although the development of nuclear power has declined in the past decade, despite the sharp rises in the cost of oil since about 1974, European countries are deriving an increasing proportion of their electricity supply from nuclear power reactors and the trend may be expected to continue (*3*). With this trend there is a natural and increasing concern about the possible exposure of workers and the general public to high-level radioactive waste and about the environmental consequences of its handling, treatment, transport, storage and disposal.

The report of the first meeting in this series describes the unit operations of the nuclear fuel cycle and the radiation doses that may be received during these operations, both by workers and by members of the general public. It also discusses the possible accidents that may occur and their predicted radiation effects, together with the possible consequences of the proliferation of nuclear weapons, sabotage and terrorism. There is a discussion of the implications for health in quantitative terms based on the studies of the International Commission on Radiological Protection (ICRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the US National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (BEIR).

There have been recent developments in these fields which, though they do not materially affect the fundamental conclusions, do change the emphasis and importance associated with the health and other implications of nuclear power, and they have been taken into account in this report. Publications of ICRP (*4, 5*) and BEIR (*6*) are of particular significance in this respect. Another important development since the first meeting in the series has been the publication of the working group reports and the Summary and overview of the International Nuclear Fuel Cycle Evaluation (INFCE) (*7*). The final plenary conference of INFCE, held in Vienna in 1980, concluded that nuclear energy production is expected to increase, that the specific needs of developing countries can and should be met, and that effective measures can and should be taken to minimize the danger of proliferation of nuclear weapons without jeopardizing nuclear energy supplies.

Several international organizations are concerned wholly or in part with the implications for health of radioactive substances and with their disposal. Of particular relevance to the topic of this report are ICRP and UNSCEAR, whose work is basic to an evaluation of radiation hazards; the International Atomic Energy Agency (IAEA), which has gathered and disseminated information, sponsored coordinated research programmes, and developed and formulated guidelines and codes of practice; and the Commission of the European Communities, which has organized and sponsored research on the disposal of high-level radioactive waste. A voluminous technical literature now exists.

In countries with active nuclear energy programmes there may be enough specialist advisers to be able to keep abreast of all this work and, indeed, to add to it by their own contributions, which extend and apply the fundamental conclusions of the international organizations. In other countries the same detailed knowledge and appreciation of the literature may not be available. In any case the knowledge may be confined to a narrow range of specialists often associated with the nuclear energy industry. In all countries there is a need for a balanced survey, independent of the nuclear energy industry, in which the literature is summarized and appraised in straightforward language. This report attempts to fulfil that need.

Radioactive aqueous waste, composed principally of fission products as well as some actinides, which is separated in the first solvent extraction cycle of the reprocessing of irradiated fuel, is universally classified as high-level radioactive waste. In some countries any other waste with levels of radioactivity intense enough to generate significant quantities of heat by decay is also so classified. Also, in some countries where reprocessing is not envisaged, the spent fuel from the reactor is classed as a waste, even though it contains fissile materials that could be removed and recycled; this spent fuel is then high-level radioactive waste. In this report the disposal of both the aqueous waste from the first extraction stage of reprocessing and spent fuel are considered. The other category of high-level waste is too vague for detailed consideration, but it is to be expected that the same general approach to its disposal would be applicable.

In any system for the management of high-level radioactive waste, storage will be provided for decay cooling and for use during the occasional plant shut-down. The final operation in the system will be long-term storage or disposal. In principle, there is a clear distinction between storage and disposal — disposal means that no further action (except environmental monitoring or restrictions on future use of the disposal site) is contemplated, whereas storage implies an intention to take further action at a later date in order to retrieve, treat, examine, or dispose of the waste. Although in practice the distinction may not be quite so clear, the difference in principle should be recognized.

As with most public health problems, an exact evaluation of the health aspects of the disposal of high-level radioactive waste is not possible, for much the same reasons that extrapolating from acute to chronic and from high to low doses is not. The justification for accepting the risks of exposure to ionizing radiation, despite the uncertainties of their evaluation, lies in balancing them against the health risks of not developing nuclear power; and the estimation of both sets of risk is subject to considerable uncertainty. Of course, this is not the whole story because in any attempt to assess the desirability of developing nuclear power, other factors such as social and economic effects have to be balanced too; these, however, lie outside the scope of this report.

Thus, while the report attempts to describe how the health risks may be estimated, it does not attempt to evaluate or even to describe fully the other factors that have to be taken into account in order to be able to justify the development of nuclear power. These other factors include the public's awareness or perception of the risks as distinct from the technical evaluation of the risk. Perhaps this report may help in bringing them together, though it is not deliberately concerned with this problem.

The close interaction of the technical and political arguments in this field requires a careful use of words and a clear appreciation of the limitations of the reasoning. In this report the basic recommendations of the ICRP, which are based on limited relevant data (though more extensive than for many, if not most, non-radioactive toxic materials) and extrapolation, are modified and reformulated in terms of the estimated risk to individuals and the collective risk to the general public. These estimates, which use projections of environmental and social factors far into the future, introduce other uncertainties. Inevitably the final conclusions are expressed as a probability or risk that a health effect or hazard will occur. There can be no assurance of absolute safety, only an estimate of the probability, however small, that the effect will occur.

This is the standard scientific approach. In some cases the probabilities can be fairly well calculated (the probability of being harmed in a traffic accident, for example) while in other cases (the very relevant probability of being harmed by the use of other energy sources may be cited) the estimate is more speculative. Essentially the approach of risk estimate in this report is no different from that in other aspects of government and public health control, though perhaps it is not always stated so explicitly.

The words "concern", "hazard", "probability" and "risk" have emotive connotations. In this report "concern" means "regard" or "interest" and is not used in the secondary and common meaning of "anxiety" or "solicitous regard". The disposal of radioactive waste is therefore a matter for concern but not for anxiety. "Hazard" is a potential deleterious effect but does not mean "peril" or "jeopardy" as it often does in ordinary usage; the deleterious effect may be quite minor. "Probability" is used in the mathematical sense, a measurable quantity of likelihood; it does not imply that the event may reasonably be expected to happen, as in the common use of the word "probable" and, indeed, an event having a probability of, say, one in a million is by no means likely to occur. "Risk" is also a measurable quantity: it is the product of the probability of the occurrence of an event and the probability of the harm if the event does occur. There is no implication of danger or peril when the word is used.

An insistence on the correct use and understanding of these words is not mere pedantry. This subject has important political undertones, and it is the normal practice in political debate to misrepresent the mis-statements of opponents. In the final decision-making when the technical, social, political and other factors, with all their uncertainties, are weighed up, it is important that there should be no ambiguity in the technical assessment. The considered view of the investigation into the Three Mile Island accident (*8*), that misplaced fear had greater implications for health than did the radiation, is a salutary reminder that the proper use of words and a clear understanding of health implications may be vitally important. In order to avoid any misunderstandings we have followed the definitions of IAEA (*9*) (see Annex 1).

The methods that have been suggested for the disposal of high-level radioactive waste are described briefly in this report with a fuller account of those that show most promise, and to which most effort is now being devoted. The way in which they may be evaluated for compliance with the ICRP recommendations as modified in the report is explained. Disposal in geological formations seems at present to be the most promising method, but disposal under the sea bed and possibly on the deep ocean bed deserves further research.

The Working Group considered 16 papers prepared by its members for the meeting and several shorter papers prepared during the meeting to clarify specific issues. The discussions took place in plenary session and in three subgroups formed to consider different aspects of the subject. Dr J. Schwibach was elected Chairman, Dr A. Lafontaine, Dr M. Kyrš and Dr F.L. Parker Vice-Chairmen, and Mr A.W. Kenny Rapporteur. Dr M.J. Suess acted as Scientific Secretary.

1

Conclusions and recommendations

The options for the disposal of high-level radioactive waste are part of the system of processing the waste for safe transport, storage and disposal, and for preventing the release of unacceptable amounts or concentrations of radionuclides into the human environment. They are based on the fundamental principles recommended by ICRP (*4*), i.e. that all radiation doses shall be kept as low as reasonably achievable, taking account of economic and social factors, and shall not exceed the appropriate dose limits now or in the future. This implies that the doses to future generations should be no greater than those acceptable at present.

The ICRP dose limits imply acceptance of a specific low level of risk to health, a level which, given what man voluntarily accepts from other beneficial but hazardous practices, is considered to be generally acceptable. The disposal methods will not isolate the radionuclides for ever, nor do they need to; the potential exposure of people, and therefore the potential overall risk, can be estimated by appropriate models. The risk inherent in the ICRP dose limits then becomes the standard against which these potential overall risks may be judged.

There has always been a greater emphasis on the safe handling and disposal of radioactive waste than of most if not all other toxic wastes. Despite the misgivings of some sections of the public, who doubt man's ability to solve the problem and perhaps misinterpret the emphasis on safety as a reason for fear, most knowledgeable workers in this field believe that the technology required for the safe disposal of radioactive waste is already available. What remains is to decide which of several approaches should be selected, and when to implement them.

There are two characteristics of radioactivity that help in the safe management, storage and disposal of radioactive waste. First, decay of the radionuclides greatly reduces toxicity and heat generation with time; second, the ease of adequate monitoring, detection and measurement allows the correction of abnormal conditions before an unacceptable situation develops. This has important implications for the concept of disposal of high-level radioactive waste, which implies that the waste is abandoned with no intention to retrieve or to provide for more than routine surveillance for a limited period. The repository site is not necessarily abandoned and may be subject to administrative control after disposal. On the other hand storage, which is generally a step in the process of waste management, implies retrievability and an intention to carry out further operations.

Methods for the management and interim storage of high-level radioactive waste are in use and are well proven. Disposal methods have not yet been selected, still less demonstrated, but extensive research and development are being carried out in many countries to ensure that the necessary technical experience will be available when the time for decision arrives. The technical problem is to ensure adequate isolation over the required period of time, so that the acceptable risk to health is maintained throughout that period.

Of the options for the disposal of this waste, placement in vitrified form in suitable geological formations has received most attention. The placement would be in suitably engineered facilities to avoid local overheating. The multibarrier approach — the disposal of immobilized waste in canisters, with or without additional absorbent material, in geological formations — appears to offer good assurance of long-term isolation from the human environment.

Two of the options for disposal would probably require amendments, one to the London Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter and the other to the Antarctic Treaty of 1959. While recognizing the political difficulties that might attend proposals for amendment, we consider that they should not hinder the proper technical assessment of the options and (if the assessment were to demonstrate their feasibility) their development. International organizations and agreements should not limit the options for waste disposal.

Two systems for the complete elimination of the waste, or at any rate of the actinides, have been proposed, but the outlook for these options is not promising.

No single characteristic alone will determine the behaviour of the waste in its repository; the method of treating the canister, the absorbent or migration retardant, the geological and other environmental barriers should all be analysed and the whole system evaluated in relation to other systems and to health standards. A suitable disposal system is one that provides the assurance that the waste will be safely isolated from the biosphere for a long time. Conservative engineering practices and multiple barriers are expected to be able to compensate for the lack of knowledge and degree of uncertainty involved in predicting what may actually be required of a repository. Thus the waste can be isolated so that it will not entail unacceptable health risks from radiation at present or in the future.

Transportation will be included in the overall evaluation of the system. Wherever practicable, it is desirable to locate the fuel reprocessing and waste processing facilities together, including the repository facility itself. It can all then be managed on one site with minimum handling and transportation (which in principle should reduce radiation doses to workers and the general public) and with appropriate security precautions against malicious acts.

Proper site investigation and selection are of paramount importance for establishing sufficiently favourable geological and hydrogeological conditions. Waste repositories may not isolate the waste from the biosphere for ever and, indeed, it is not necessary that they should do so; the multiple engineered and natural barriers in the repository system are expected to restrict the release of radionuclides to the human environment to acceptable amounts and concentrations so that the implications for health of the disposal of high-level radioactive waste will be so low as to be acceptable. Some conservatism in selecting the parameters used in the assessment of high-level radioactive waste disposal is desirable because of the uncertainty of predicting the behaviour of the geosphere and biosphere in both the near and distant future. The dynamics of the environmental transfer of long-lived natural radionuclides and of stable elements deserve to be studied carefully, both in the geosphere and in the biosphere, as analogues of some of the man-made radionuclides. In particular, careful attention should be paid to establishing the physicochemical forms of radionuclides in the relevant environmental phases; not only are appropriate analytical methods lacking in many cases, but those available have rarely been applied at the low atomic concentrations that are appropriate in this case.

The protection of the public against exposure to ionizing radiation is the overriding health concern in the disposal of high-level radioactive waste. It is recommended that the acceptability of waste disposal methods be determined on the basis of the effects of predicted doses on individuals and populations, while also taking into consideration the probability of their occurrence. In performing the calculations of predicted doses, it is necessary to take into account the uncertainties of many parameters, which will lead to ranges of results rather than precise answers. The probability of occurrence will be determined mainly by the probability of occurrence of the initiating event. The selection of a waste disposal option should follow a sequential procedure incorporating the following steps.

1. Apply appropriate predictive models to estimate the potential doses to individuals in critical groups and the collective doses to populations at all future times. These models should incorporate estimates of the probability of their occurrence.

2. The probability (risk) of the effects on health of the estimated doses and their probability may then be assessed by appropriate standards.

3. If more than one disposal option meets the standards, selection should be based on a comparison of the collective dose commitments calculated to cut off at a selected time in the future (10^4 years, for instance) and the probabilities of their occurrence.

4. In the selected option, predicted collective dose commitments should be reduced as low as reasonably achievable, taking economic and social factors into account.

In view of the importance of this subject, national and international bodies should give high priority to their programmes of work on the development of such standards of acceptability. Health effects predicted as a result of the disposal of high-level radioactive waste should be compared with those predicted as a result of other activities, such as alternative methods of generating power, the use and disposal of other toxic substances, or natural radiation doses.

Guidelines for the licensing, operation and final closure of repositories are being prepared in parallel with the development of waste disposal methods. Records and inventories for these sites should be maintained by national authorities and should contain all the information necessary for the future. Governments and international organizations should encourage the exchange of information and the latter should establish an international register of high-level radioactive waste repositories.

The disposal of radioactive waste into international waters, territories and space should be subject to international agreement and supervision, with the participation of international organizations and the national authorities concerned.

National and international organizations should be encouraged to support and coordinate research and development in order to improve the assessment of the parameters required for evaluating the impact on health of all sources of energy, so that proper comparisons of the various energy options may be made.

Advisory services and expertise should be made available by international organizations at the request of governments for the planning and implementation of national waste disposal programmes.

2

High-level radioactive waste

Nuclear reactors derive their energy from the fission of nuclear fuel, the splitting of the fuel atoms into two or more smaller atoms. The fuel (which may be normal or enriched uranium, or a mixture of uranium and plutonium, either as elements or as oxides) is contained in metal cans or cladding in the reactor. In the reactor, some of the fuel (uranium and plutonium) is fissioned, generating the fission products, some is converted by neutron absorption into heavier (transuranium) elements and some remains unaffected.

Although the cans are usually made of stainless steel, zirconium alloy or magnesium alloy, which are materials chosen for their low neutron absorption capacity, they nevertheless become very radioactive in the intense neutron field of the reactor owing to the formation of activation products, radionuclides generated from the elements of the canning material by neutrons. For the most part these are of relatively short half-life compared with many fission products and do not contribute appreciably to the fuel element (i.e. fuel and can) activity in the long term.

A fuel element often includes a number of fuel pins held in a bundle by a structure. This may be metallic, with spacers for holding the fuel pins apart in the reactor, and the pins may be shaped externally to produce appropriate coolant flows and aid heat transfer. The assembly with its spacers and structural parts is an additional source of activation products.

Whatever the type of nuclear reactor, a method for the treatment of the spent fuel has to be chosen when the fuel assembly is withdrawn from the reactor. The simplest option is to store it, either indefinitely or until substantial decay has occurred; storage can be in water-cooled or air-cooled facilities. Some cooling provision is essential during the first few decades because the irradiated fuel elements are significant sources of heat while the fission products undergo radioactive decay. This option has been explored in Canada and more recently in the United States, during the moratorium on fuel reprocessing pending a decision on the nuclear fuel proliferation risks of the various fuel cycles.

This storing of irradiated fuel without reprocessing is called the "stowaway fuel cycle". At first sight it would seem to avoid the problem of