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No. 5

Radioactive Waste Disposal into the Sea

INTERNATIONAL ATOMIC ENERGY AGENCY

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RADIOACTIVE-WASTE DISPOSAL INTO THE SEA

REPORT OF THE *AD HOC* PANEL
CONVENED BY THE DIRECTOR GENERAL OF THE IAEA
UNDER THE CHAIRMANSHIP OF
MR. HENRY BRYNIELSSON
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FOREWORD

Preventing pollution of the seas from the discharge of radioactive wastes has been recognized as an international problem of considerable magnitude. In April 1958 the United Nations Conference on the Law of the Sea adopted a Convention on the High Seas, Article 25 of which provides that every State shall take measures to prevent pollution of the seas from the dumping of radioactive wastes, taking into account any standards and regulations which may be formulated by the competent international organizations. The Conference also adopted a resolution recommending that the IAEA pursue studies and take action to assist States in controlling the discharge of radioactive materials into the sea.

Later the same year, a Panel of experts was invited by me to meet in Vienna to study the technical and scientific problems connected with radioactive waste disposal into the sea, and Mr. H. Brynielsson of Sweden was designated Chairman of the Panel. Representatives of the United Nations, the Food and Agriculture Organization of the United Nations, the World Health Organization and the United Nations Educational, Scientific and Cultural Organization participated in the work of the Panel.

After a second series of meetings in 1959, the Panel completed its study, setting forth the result of its work in a report dated 6 April 1960, which has been submitted to the Agency's Scientific Advisory Committee and to Member States for their information.

The Panel's report is now published in the present volume of the Agency's Safety Series in the form in which it was submitted by the Chairman of the Panel.

I should like to add that the report represents the views of the experts participating in their individual capacity in the work of the Panel. It is offered as an information document and it should not be regarded as an official statement by the Agency of its views or policies in relation to the subject discussed.

Sterling Cole

September 1961 — Director General

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PREFACE

The views expressed in this Report represent the joint results of the Panel members acting in their capacity as individual scientists. Thus they are not necessarily an expression of the opinion of any body or authority with which the Panel members may normally be associated in the course of their employment.

The Appendices are largely the work of sub-committees or individual members of the Panel and do not necessarily represent the views of all members of the Panel with respect to matters of detail.

CHAPTER I

INTRODUCTION

United Nations Conference on the Law of the Sea

The possibility of undesirable contamination of the sea from disposal of radioactive wastes has become a matter of growing public concern. In November, 1956, the United Nations Scientific Committee on the Effects of Atomic Radiation initiated limited studies on the possibility of radioactive contamination of the sea from such disposal. As a result of this preliminary study it was able to report (Report of the United Nations Scientific Committee on the Effects of Atomic Radiation (1958) pp. 14, 38):

"Radioactive waste

... The Committee has not given any detailed consideration to the technical aspects of these problems, but from the information available it is clear that there is no general population hazard from this cause at the present time. The Committee realizes that these problems may become of importance in the future and considers that the release of radioactive wastes should be made a matter of international co-ordination and agreement." ... *(p. 14).*

"Radioactive waste

The discharge of radioactive waste in countries with nuclear reactors has not led to appreciable radiation exposure of populations, ... however, ... this subject (should) be kept under review. It is important that work should be actively continued on methods of minimizing environmental contamination from these causes." *(p. 38).*

At the United Nations Conference on the Law of the Sea (1958), concern with pollution of the sea, which had originated in connection with release of oil, was extended to include pollution by radioactive materials. As a result, it was decided to propose the inclusion of the following provision relating to the disposal of radioactive waste in the Convention on the High Seas (United Nations Conference on the Law of the Sea, Official Records, Vol. II (1958), pp. 22, 138):

"Article 25

1. Every State shall take measures to prevent pollution of the seas from dumping of radio-active waste, taking into account any standards and regulations which may be formulated by the competent international organizations.

2. All States shall co-operate 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 radio-active materials or other harmful agents."

The Conference, at its Tenth Plenary Meeting, adopted a Resolution on the pollution of the high seas by radioactive materials, which reads, in part (United Nations Conference on the Law of the Sea, Official Records, Vol. II (1958), pp. 24, 144):

"... the International Atomic Energy Agency, in consultation with existing groups and established organs having acknowledged competence 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 radio-active materials to the sea, in promulgating standards, and in drawing up internationally acceptable regulations to prevent pollution of the sea by radio-active materials in amounts which would adversely affect man and his marine resources."

The International Atomic Energy Agency *ad hoc* Panel on radioactive waste disposal into the sea

The programme of work recommended by the Preparatory Commission of the International Atomic Energy Agency in 1957 included the proposal that the Agency should undertake studies and consider the formulation of regulations governing waste disposal into the sea. To implement this programme, and in conformity with the recommendations of other United Nations bodies, an *ad hoc* Panel on Radioactive Waste Disposal into the Sea was set up in October 1958 under the chairmanship of Mr. H. BRYNIELSSON, of Sweden, to advise the Director General.

Members of the Panel were:

Dr. Bo ALER, Physicist	Sweden
Prof. Dr. F. BEHOUNEK, Physicist	Czechoslovakia
Mr. P. COHEN, Chemist	France
Dr. A. K. GANGULY, Chemist	India
Mr. H. HOWELLS, Physicist	United Kingdom
Dr. C. A. MAWSON, Biochemist	Canada
Prof. D. W. PRITCHARD, Oceanographer	United States of America
Prof. N. SAITO, Radiochemist	Japan
Mr. J. B. SCHIJF, Hydraulic Engineer	Netherlands
Mr. Ing. VESELY, Chemical Engineer	Czechoslovakia

In addition, the following representatives of United Nations Organizations took part in the work of the Panel:

Mr. A. DOLLINGER, Economist	United Nations
Mr. T. LAEVASTU, Fisheries Hydrographer	Food and Agriculture Organization of the United Nations
Dr. P. TAILLARD, Radiologist	World Health Organization of the United Nations
Mr. M. YOSHIDA, Engineer	United Nations Educational, Scientific and Cultural Organization

The Secretary of the Panel was Mr. G. W. C. TAIT of the International Atomic Energy Agency.

The results of the studies of this Panel are given in this Report.

Purpose and scope of the Report

The Report offers recommendations which could serve as a basis of international agreement to ensure that any disposal of radioactive waste into the sea involves no unacceptable degree of hazard to man. It is drafted for all who have responsibilities or interest in the problem of radioactive waste disposal at sea. The body of the Report is intended to ensure that such persons are adequately informed on the broad aspects of the problem. It is hoped that those more technically concerned with waste-disposal operations will find material in the Appendices which will guide them in a safe and efficient manner in their work. It should be noted that any special considerations of all eventualities which could arise from accidents is beyond the scope of the present Report. Finally, it is intended that the conclusions should be read on the understanding that they would be subject to modification and change in the light of the growth of knowledge in this field.

Basic scientific concepts

Radioactive nuclei

The atoms which form matter are conveniently visualized as being composed of a group of elementary particles (neutrons and protons) forming a compact core, or nucleus, held together by very strong forces, and an external diffuse region in which electrons are held by much weaker forces. Because of the relatively vast forces within the nucleus, the amounts of energy associated with possible nuclear changes, or disintegrations, are much greater — usually by a factor of 1 000 000 or more — than energies associated with changes in the outer areas of atoms. (Chemical reactions and temperatures normally at man's disposal only affect the outermost electrons).

Each nuclear grouping is characterized by a resultant electrical charge which is some integral multiple of the charge of a single proton. A specific nuclear charge is associated with each element. The number and arrangement of external electrons derive from the nuclear charge and, in turn, largely determine the chemical properties of each element. Of all possible arrangements of the elementary particles which, grouped together, form nuclei, only a limited number are stable groupings. These are the naturally-occurring stable nuclei. Other nuclei contain excess energy which can be released by a spontaneous rearrangement of the nucleus. These are unstable nuclei. Incidentally, such unstable nuclei form atoms chemically indistinguishable from corresponding stable atoms. Atoms with the same chemical properties, but differing nuclear composition, are called isotopes of the same element, and those with unstable nuclei, radioisotopes. Alternatively, when attention is directed to nuclear properties alone, the radioisotopes are often referred to as radionuclides.

The discovery of nuclear fission resulted in the production of artificially radioactive elements in two ways. The fission process itself gives rise to very radioactive matter, since the splitting of an only slightly unstable large nucleus into two, results in new nuclei which are highly unstable. These are the nuclei of the fission products. In addition, neutrons escape which, when captured by stable nuclei, cause the latter to become unstable. This resulting radioactivity is referred to as "induced radioactivity". These two processes have led to the production of very great quantities of radioactive matter compared to that previously available in the form of the naturally-radioactive elements, such as radium, of which only 1.5 kg was in use in 1953.

The nature of radioactive elements may, perhaps, be best understood if we consider that in all nuclei the constituents are in continuous motion. In the radioactive nuclei the arrangement is not absolutely stable and a more stable arrangement can be achieved by release of energy. However, such a transition is only possible during a certain fraction of the nucleus' pattern of internal motion, or we may say that the transition has a certain probability of occurring over a unit interval of time. An alternative way of looking at the same phenomenon is to say that we do not know when any particular nucleus will undergo a transition to a more stable state with release of energy, but that we can assign an "average life" to such a nucleus. An equivalent mathematical expression is to speak of the "half-life" of a group of radioactive atoms, that is, the time interval in which half the nuclei originally present have undergone transition, or "decayed". Radioactive isotopes are usually characterized by their half-life.

Nuclear radiation and biological effects

The energy released during the nuclear "transition", or radioactive "decay", appears in the form of radiation. The energy carrier may take a number of forms, for instance, alpha, beta or gamma rays. From the point of view of biological effects these rays, or carriers of energy, only differ materially in the ease with which they will pass through matter. The final effect in tissue, or the individual cell, is the same. The absorption of radiation results in ionization and excitation, with the breakdown of the water contained in the cells into chemically-unstable components, i. e. the "free radicals", which, in achieving chemical stability, in turn damage important constituents of the living cells. The significance of this final chemical action results from the large ratio that the nuclear energy carried by the radiation bears to normal chemical energy. As a result, about 100 000 of these chemically-active "free radicals" are produced by each individual particle of nuclear radiation, in coming to rest in the cells of living tissues.

Radioactive material can be dangerous to man for the following reasons:

(1) The release of energy, since it arises from rearrangement of the nuclei of atoms involving very great internal forces, is not subject to regulation by means at man's disposal.

(2) The released energy is often in the form of radiation which can penetrate readily available protective devices.

(3) The energy, being in highly concentrated form, can arise in dangerous amounts from quantities of matter so small that they will evade control measures normally applied to dangerous substances.

(4) The energy, on being released in living tissue, acts in an indiscriminate fashion, and deleteriously, on the fundamental constituents of all cells in such a way as to make protective measures generally ineffective.

Significance of radiation

Such dangers must be considered as matters of degree rather than kind, since all living tissue is normally exposed to some amount of high-energy radiation coming from naturally-radioactive material present everywhere (including the human body) in small quantities, and to cosmic radiation.

This latter consideration is particularly important, since devices for detecting nuclear radiation are extremely sensitive. With many other forms of hazardous exposure which affect man it is possible to recommend that there be no exposure, since available detecting devices usually fail to respond below a certain level. The problem has been to develop a detecting device which is sufficiently sensitive to respond to the minimum degree of hazard which is notably dangerous. When this degree of sensitivity is reached, instrument development often ceases. Any degree of hazard less than the accepted minimum permissible is indicated as "zero hazard". With nuclear radiation this is not the case. In general, even a simple detecting device, such as a Geiger-Müller counter, will respond to amounts of radiation commonly present in nature so that the instrument always shows some "background". For this reason control of radioactivity must always be on a quantitative basis and the term "no activity" is meaningless. This illustrates a point frequently overlooked, that measurement has meaning only in terms of the instrument which is used.

The activity of a radioisotope is often characterized by the disintegration rate, which is expressed in the unit "curie". A "curie" is defined as 37 thousand million disintegrations per second and is approximately the rate of disintegration for one gram of radium. This unit does not take into account the nature and energy of the radiation emitted by the radionuclide in question. For measuring radioactivity a useful range of physical instruments exists which respond to the physical phenomena produced by such radiation. Fortunately, the biological effects and damage produced can usually be related in a simple fashion to such physical measurements. The biological effects are dependent on the amount and nature of radiation energy absorbed in the tissue. The biologically-effective dose, which is the product of the total energy absorbed in the tissue and a factor representing the relative biological effectiveness of the particular type of radiation, is designated in "rem" and dose-rates in units, such as "rems per year".

CHAPTER II

EXISTENCE AND EXTENT OF RADIOACTIVE-WASTE PROBLEMS

Nature of wastes

CLASSES OF WASTES

The discovery and use of nuclear fission has led to the production of large quantities of radioactive substances. In general, the bulk of these are merely a by-product of the fission process and constitute a waste product from the moment of their formation. Other radioactive material which has useful application eventually becomes waste when the purpose for which it was made has been fulfilled.

The nuclear-energy industry produces high-activity, intermediate-activity, low-activity and so-called non-active wastes. The different categories are not sharply delineated. "High-level wastes" have been defined elsewhere [1] as those with "concentrations of hundreds or thousands of curies per gallon" whereas "low-level wastes" have "concentrations in the range of one microcurie per gallon". It is evident that between these classes of waste must lie a wide range of wastes of intermediate activity. The waste can be solid, liquid or gaseous; combustible or non-combustible; aqueous or non-aqueous.

The range of properties of radioactive wastes is so great that two different approaches to waste treatment exist. In general, the more radioactive and dangerous wastes are subject to concentration and containment while the less dangerous wastes are often diluted and dispersed. By its nature waste disposal into the sea is predominantly an example of the latter approach and would therefore be considered chiefly in terms of low-level wastes. However, to the extent that containment may be achieved, either by non-destructible packaging or placement in sites possibly offering isolation over long periods of time, it could be considered to be based on aspects of both approaches. To some degree it might therefore be possible eventually to extend sea disposals to wastes other than those of strictly low activity.

The present practice of waste management is to contain the high- and intermediate-activity wastes in storage tanks on land. Low-activity wastes are discharged into the ground or, in some centres, released through pipes to the sea, either directly or after treatment, or they are fixed in concrete or in packaged containers, some of which are disposed of in the sea. Although radioactive wastes occur in many different forms, some order can be achieved by considering them in relation to the operations from which the arise.

Wastes from ore treatment and refining

Initial refining and beneficiation processes are an important source of low-level wastes. At the processing stage, the steps include crushing, grinding, washing and chemical operations. Wastes from ore processing include wash waters, waste solids and process liquids. After recovery of uranium by chemical processes, the waste liquids contain daughter products of uranium. The refining processes also contribute non-active wastes which may prove to be a greater hazard to the environment than the radioactive matter.

Wastes from reactor operations on land

Radioactive wastes can arise from land-based reactors in several ways. In early reactors the primary coolant was simply passed through and returned to the environment. If air was the coolant no problem of sea disposal could occur, except possibly in connection with any coolant filters used. With water as a coolant, impurities originally present in the water supply, or arising from corrosion, acquire induced activity in passing through the reactor and could appear as radioactive waste. Under normal operating conditions such radioactivity is usually relatively short-lived. Radiophosphorus (P^{32}) is probably one of the most important contaminants because of the biological significance of phosphorus.

In more modern reactors the primary coolant is in a closed system linked by heat exchangers to the secondary coolant. The latter will only carry radioactive wastes if the heat exchangers develop defects. However, radioactive wastes in the form of fission products can enter the closed circuits through failure of fuel cladding, or other mechanical failures. In such closed-circuit systems the coolant is purified, using such devices as ion exchangers and associated filters on side streams. The exhausted filters and exchangers must be disposed of as radioactive waste.

The great majority of the radioactive-waste products are present in the spent fuel from the reactor. Customarily, the radioactive material is transferred to the fuel-treatment plants, where it appears as highly-active waste. However, in certain reactor systems it might not be considered economic to recover the spent fuel. Such highly-radioactive fuel elements would provide a high-activity waste-disposal problem.

Wastes from reactors operated at sea

The primary wastes from ship reactors will arise in connection with a shore fuel-treatment plant and are similar to those produced by land-based reactors. Wastes peculiar to nuclear shipping include those radioactive materials contained in the excess volume of coolant which is displaced at warm-up. This may contain both radioactive corrosion products and fission products in low concentrations. In addition, there will be operational wastes from leakage of various reactor systems, laboratory effluents and decontamination wastes. In general, contaminated solutions are purified by passage through ion exchange columns so that the ion exchangers contain the bulk of such actual radioactive waste material.

Waste from irradiated fuel treatment installations

The vast majority of radioactive materials and resultant wastes come from the nuclear fuel used in reactors. On a comparative basis the radioactivity from all other sources is small. There is an important difference between the high-activity wastes, originating from the first stages of chemical processing of irradiated nuclear fuel as currently practised, which are concentrated and represent more than 99.99% of the total activity of the fission-product wastes, and the other types of wastes which are much less active and occur in much larger volumes.

The activities associated with present-day primary wastes, formed by dissolving irradiated fuel in chemical processing plants, are of the order of 1000 c/l. The use of longer irradiation times, or treatment by new processes, could raise this figure by an order of magnitude. The primary waste solutions differ considerably in chemical composition, depending on the process used. They are all highly corrosive. From the chemical point of view the non-radioactive reagents used in the treatment process completely dominate their behaviour. However, their high radioactivity will generate heat, especially when the material is held in large bulk. The radiation itself may have deleterious effects in degrading organic substances, and possibly even leading to dangerous gas formation or other phenomena. These wastes are contained but their existence should always be borne in mind.

In addition to these high-level wastes, low and intermediate wastes result from certain operations in the processing of irradiated fuel. The intermediate wastes are either placed directly into storage or are pretreated to produce further low-level wastes and separated wastes of higher actiyity suitable for storage.

Waste from uses of radioisotopes

The radioactive wastes which arise from the industrial, agricultural, scientific and medical uses of radioisotopes also occur in many different forms. However, in practically all circumstances they will be of intermediate- or low-level activity.

A major nuclear-research centre may produce a wide variety of radio-