SAFETY SERIES

No. 24

Basic Factors for the Treatment and Disposal of Radioactive Wastes

INTERNATIONAL ATOMIC ENERGY AGENCY

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FOREWORD

A great deal of information on the treatment and disposal of radioactive wastes has been accumulated in recent years. At new establishments the problem is to compare the practical and economic advantages of the different methods available, and to select the safest and cheapest for the given circumstances.

This publication is the outcome of a panel meeting on Selection Factors for Waste Management Systems, which was held at the headquarters of the International Atomic Energy Agency in Vienna from 24 to 28 October, 1966. It presents a guide to the factors that should be evaluated in selecting a waste management system, and should be of particular assistance to new establishments and to those in developing countries.

A summary of the main points, in the form of a questionnaire, is given in an Annex, and references are made to the background literature.

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1. INTRODUCTION

Radioactive waste management began when an awareness of the problems connected with disposal of all types of waste had begun to develop, and the problem of radioactive wastes has been given more attention than all other forms of waste.

Radioactively contaminated waste can either be dispersed or contained. Both methods or combinations of them can be used safely with known techniques. There is a wide range of proven treatment methods available. Every site must be investigated thoroughly before deciding on the methods of treatment and disposal. What is satisfactory at one site may not be safe or economic at another. There is no general method of treatment or disposal which is the most satisfactory at all locations. However, the various methods of treatment or disposal are fairly well established and it is a relatively simple matter to evaluate the problem. Waste management has advanced more than is commonly believed and the problem nowadays is not so much concerned with the increasing quantities of waste as with the most economical methods of treatment and disposal.

The problem in establishing a waste management system is to decide whether all or part of the waste will be disposed of to the environment and whether it is necessary to treat all or part of the waste.

The waste management systems evolved in the early days of the nuclear age were generally developed under conditions in which the people involved were not entirely aware of the problems of management of radioactivity, and there were very few established guidelines for them to follow. Nevertheless, these problems were overcome and satisfactory systems for their specific requirements were developed. The experience gained in developing these systems should enable guidelines to be established which can be followed by other people faced with waste management problems.

There are several excellent text books on waste management and numerous references to waste management practices in the technical literature. The International Atomic Energy Agency has published and will publish various reports on waste treatment and disposal. There is ample technical information in all this literature but in general it is not reported why establishments chose various methods of treatment or disposal and what other methods or waste management schemes were considered and rejected. Faced with this vast amount of technical information revealing that establishments have chosen many different methods and combination of methods of treatment and disposal, all of which appear to be satisfactory, it is not surprising that countries with developing nuclear programmes find it difficult to decide what is the best approach to determine their own specific waste management system. In fact what often happens is that these countries follow the methods used at an existing establishment, only to realize later that, while it was extremely satisfactory at the establishment from which it was copied, it is not the most satisfactory or economic for their requirements.

The purpose of this manual is to set out the factors that should be evaluated in selecting a waste management system so that establishments, particularly in developing Member States, can select the most satisfactory and economical waste management system for their particular needs. The manual therefore discusses factors such as type of waste, legislation, climate, location and availability of materials, equipment and services, etc., which must be taken into account before the preliminary evaluation can be made to decide which treatment and disposal methods should be further investigated.

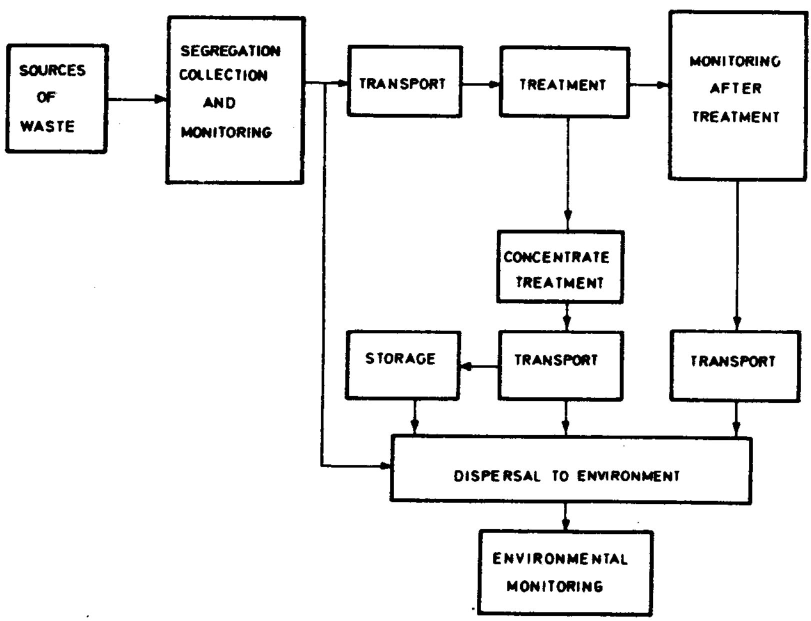


FIG. 1. Typical waste management flow sheet.

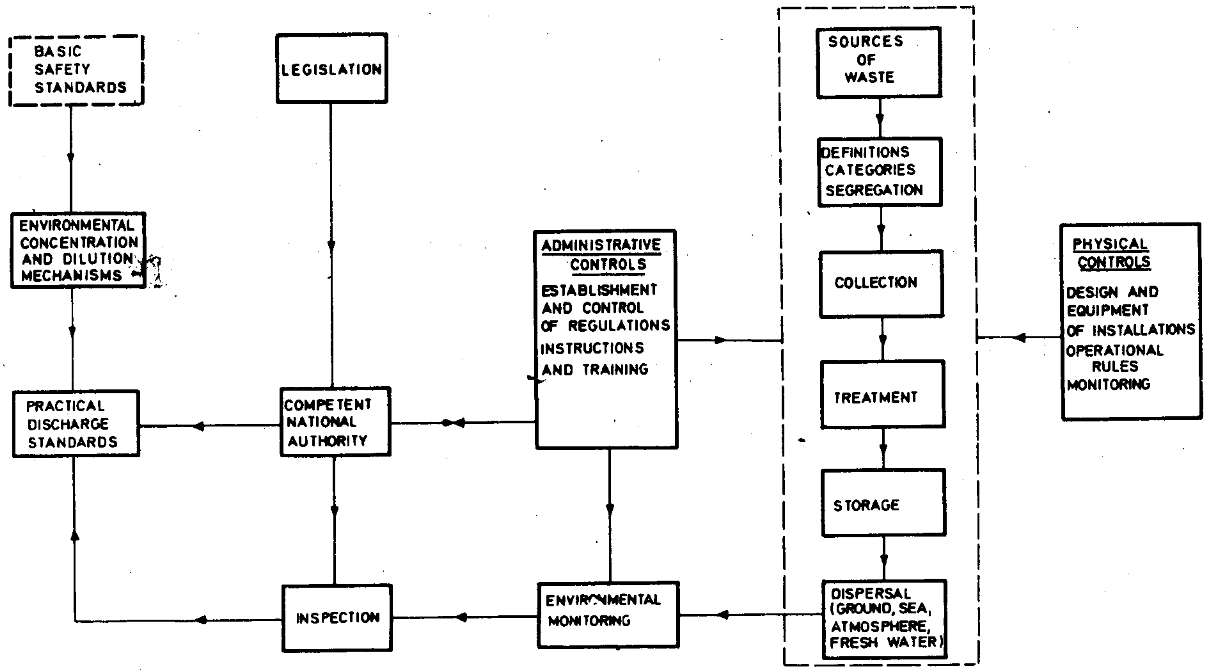
The manual should be applicable to the evaluation of waste management systems at research establishments, reactor centres, large users of radioisotopes, and central waste treatment facilities, i.e. facilities which treat and dispose of waste from a number of small users of radioisotopes. To a limited extent, it should also be applicable to fuel processing facilities although only limited consideration has been given to the problem of high level liquid wastes (i.e. 1st cycle processing wastes).

As an aid in selecting the most suitable type of waste management system, a simple questionnaire (see Annex) has been prepared drawing attention to those factors which should be taken into consideration.

2. DEFINITION OF A WASTE MANAGEMENT SYSTEM

A typical waste management flow sheet is shown in Fig. 1. This flow sheet does not necessarily apply to all types of wastes and it is possible that not all or a slightly different arrangement of the elements may be applicable at any given site. It is also important to recognize that there are other factors and items than those shown in Fig. 1 which must be included in the waste management system and that these are outside the control of the waste management group. A general breakdown of a typical waste management system is shown in Fig. 2.

The items within the dotted lines will vary according to the type and location, etc., of the establishment, but essentially this area is what is generally considered as containing those items controlled by the waste management group. The waste management group may take part directly or indirectly in some of the other activities but usually it will not have any administrative control over these activities. It is important for waste management personnel to be aware of the breakdown of the waste management system as it applies to their establishment, in particular the items outside their control. This is especially important in evaluating the waste management system most suitable for a particular establishment for it can enable a much more systematic and logical approach to be made so that the most satisfactory system can be developed.



NOTE: (a) Items in dotted area will vary from establishment to establishment.
(b) Not all items will necessarily occur.
(c) Directional arrows may alter in some cases.

FIG. 2. General breakdown of waste management system.

3. GENERAL FACTORS IN THE SELECTION OF A WASTE MANAGEMENT SYSTEM

3.1. Dispersal to the environment of wastes containing radioactivity

In discussing dispersal it will be shown that wastes must be discarded at levels that will be harmless to the environment. This implies that something must be known about the toxicity of the waste. The determination of concentrations believed to be harmless is an extremely complex problem. It has involved much work by biologists, physicians, public health officials, chemists and radiological physicists [1].

Because of the diversity of characteristics between the different isotopes and their varying effects on man, the maximum permissible intakes vary considerably. When a mixture of isotopes is present, detailed analysis is difficult and is usually unnecessary since the most toxic of the elements known to be present decides the figure to be used for control purposes (Table III (1 to 3) in Ref. [2]).

The legislation and regulations applying to dispersal of radioactivity into the environment often state that aqueous effluents may be disposed into public waters or gaseous effluents may be dispersed into the atmosphere at maximum permissible concentrations (MPC) averaged over one year. This type of legislation is usually too restrictive since it does not take into account the capacity of the environment to accept radioactivity without hazard. At most locations dilution or dispersion factors of several thousands occur rapidly when aqueous or gaseous effluents are introduced into flowing water or the atmosphere respectively. Conversely, the other situation can apply, i.e. that a concentration or uptake mechanism occurs so that a particular isotope is concentrated many times and a hazard to man may be created if this mechanism occurs in the food chain. The use of MPCs for water and air as arbitrary discharge limits for radioactive effluents has been shown to be too restrictive in many cases and not sufficiently restrictive in others, and it is extremely important that the use of the environment is taken into account before deciding on discharge limits.

In paragraph 74 of the Recommendations of the International Commission on Radiological Protection [3], it is stated that:

"The basis for the limitation of exposures of members of the public is the dose to the various body organs and not the derived criteria by which the dose is controlled. The actual doses received by individuals will vary depending on factors such as differences in their age, size, metabolism and customs, as well as variations in their environment. The variation resulting from these sources makes it impossible to determine the maximum doses that might be received individually. In practice, it is feasible to take account of these sources of variability by the selection of appropriate critical groups within the population, provided the critical group is small enough to be homogeneous with respect to age, diet and those aspects of behaviour that affect the doses received. Such a group should be representative of those individuals in the population expected to receive the highest dose and the Commission believes that it will be reasonable to apply the appropriate Dose Limit for members of the public to the mean dose of this group. Because of the innate variability within any apparently homogeneous group, some members of the critical group will receive doses somewhat higher than the Dose Limit; however, at the very low level of risk implied, it is likely to be of minor consequence to their health if the Dose Limit is marginally or even substantially exceeded."

The ICRP (paragraph 75) further indicates that:

"In some situations, especially in the planning of proposed operations or installations, it may not be practicable to make the detailed studies necessary for the identification of the critical group. To allow for individual variability it will then be necessary to apply an operational safety factor to the derived concentration limits applicable to a member of the public."

The ICRP does not specify, however, any particular safety factor as this will be liable to a very wide range of variation. The IAEA's Basic Safety Standards [1] in its revised form (which is about to be published) will give, instead of derived concentration limits, derived total intakes by ingestion or inhalation applicable to members of the public. It will always be the responsibility of the competent authorities, taking into account all environmental effects such as dispersion and concentration mechanisms and the use of the environment, to ensure that the discharge from a particular location will not lead to intakes by the critical group of individuals which would give a dose greater than the limits set for the population.

Control of waste disposal is usually undertaken at a national level through the enactment of a statute specifically dealing with such disposal, or by inclusion of provisions relating to disposal in a statute dealing with the utilization of nuclear power generally or prohibition of pollution of the environment. Such a statute would incorporate by reference detailed technical regulations regarding dispersal of radioactivity into fresh water, into the atmosphere, the soil or the sea. Such regulations would also contain one or more annexes with scientific data relevant to the text. While a statute would refer normally to radioactive waste in general terms, regulations formulated under it would specify the particular prohibitions relating to the disposal of solid, liquid or gaseous wastes.

Regulatory devices aimed at securing the safe dispersal of radioactivity into the environment generally may, for the most part, be said to fall into three main categories:

(i) The requirement that all waste disposal operations must be carried out only after prior authorization by the competent authority and strictly in accordance with such conditions as may be stipulated.

(ii) The promulgation of special rules designed to ensure that the health and safety of radiation workers and the public shall not be endangered as a result of the disposal, such as the establishment of a maximum permissible dose for human beings, and maximum permissible concentrations of radionuclides in the environment.

(iii) The requirement for appropriate periodical measurements, the keeping of records, inspection of premises and other means of administration of the regulatory norms established.

As the scale of radioactivity released to the environment increases, it will become more and more difficult for governments to be certain they are safeguarding all possible interests in neighbouring countries, unless there is some form of agreement among them on permissible disposal limits. Any such agreement will undoubtedly be in the nature of an integration of existing national practices which have been based on sound scientific principles. Moreover, the objective of any international agreement will be to obligate governments to meet agreed standards, derived in large measure from existing national practices.

3.2. Public relations

One important factor in waste management operations that is sometimes overlooked is public relations. Radioactive waste management started at a time when a growing realization of the effects of pollution of the environment by all types of waste had begun. In addition, since the first use of atomic energy was as a wartime explosive the general public is somewhat scared of the effects that could result from the peaceful uses of atomic energy. Mankind is prepared to accept hazards resulting from non-radioactive industrial activities and to a limited extent mankind will accept hazards resulting from some uses of radiation, e.g. from X-ray machines. However, the public will generally object if it knows of any radioactivity that is introduced to the environment as a result of the operations of nuclear industry. Most of these objections are based on ignorance but it is a real problem in radioactive waste management, and it must be given serious attention. It is a positive fact that the operations of nuclear industry have proved to be much safer than many other industrial operations. It is also a fact that the radiation hazard to mankind resulting from disposal of radioactively contaminated waste to date is but a very small fraction of the total radiation to which mankind is exposed; the major fraction of such radiation is from diagnostic and therapeutic medical usage. Because of the conservative approach adopted in radioactive waste management it is certain that this situation will continue. It is essential to realize that it is the over-all pollution potential of the waste discharged which is of prime importance and that the radioactive materials present are only one factor, albeit often an important one.

The population is sometimes wary of accepting statements concerning the significance of radioactivity in the environment from atomic energy authorities, and it is generally a wise practice for such statements to be issued by other authorities such as public health services or conservation boards. It is essential that all governmental, semi-governmental and local authorities that have dealings with the public not only in public health but in the use of the environment be kept informed of all waste management disposal operations that occur in locations over which these authorities have some control. Sometimes these authorities, e.g. the public health service, have some control over waste disposal and this is set out in legislation or by governmental regulations. However, all the other authorities, even if they have no such control, should be kept informed of waste disposal operations. If this were done it would be these authorities who would advise the public that there is no hazard resulting from the disposal operations and their advice would be accepted by the public much more easily than if the advice came from the atomic energy authority. As the unwarranted fears of the public would be removed they would then realize the inherent safety of waste disposal and the nuclear industry as a whole, and the public relations aspect of waste management would be placed in proper perspective.

3.3. Economics

In waste management the health and safety factors demand first attention but the economic factor is so basic that it must be considered a close second in importance.

To try to achieve a discharge level approaching zero would be extremely expensive and is seldom required. In the past unnecessary restrictions have often been placed on discharge levels, which have resulted in high costs for waste management. On the other hand, attempted saving in such costs can result in excessive and needless expenditure in other directions. For example, it could result in the necessity for extensive environmental surveys or, ultimately, for restoration of the environment which, even if possible, would be prohibitive in costs. A balance must always be sought between using the capacity of the environment to receive wastes without detriment and the treatment necessary to ensure that the discharge levels are such that no hazard arises.

From information available it appears that the capital costs[1] that should be allocated to waste management as a percentage of the total capital cost of the establishment are of the following order:

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[1] These figures should only be used as a rough guide as there are so many factors affecting the costs that the figures may not necessarily be applied to a new establishment. They do however give an order of magnitude.

On the subject of long-term waste management costs in a nuclear power economy Belter has stated [4] that the total fuel cycle cost for a 15 000-MW(e) economy is estimated to be about 2.5 mill/kWh(e). (It is noted that with the operation of US power reactors in the 1000 MW(e) size range by 1970, fuel cycle costs are estimated at about 1.9 mill/kWh(e). Included in these costs are fuel fabrication, chemical processing, transportation, ^{235}U burn-up, inventory for use charges and a 0.3-mill/kWh(e) credit for the plutonium produced. The estimated cost of chemical processing includes the cost of gaseous and low-level waste management and interim tank storage of high-activity waste but no ultimate disposal of the high-activity waste. Ultimate waste treatment and storage costs have been estimated at 0.03 mill/kWh(e). This represents about 1% of the total fuel cycle cost and substantially less than 1% of the cost of nuclear power in a 4-mill/kWh economy. It is believed therefore that waste management costs will not deter the development of economical nuclear power.

(i) For general research establishments – 1% to 6% with a mean of about 2.5%;
(ii) For power reactor sites – 1.5% to 6% dependent on the power output and decreasing as the reactor size or the number of reactors at a site is increased.

In addition, annual operating and maintenance costs[2] for waste management expressed as a percentage of the establishment's annual operating and maintenance costs are of the following order:

(i) For general research establishments – 1% to 6% with a mean of about 2%;
(ii) For power reactor sites – 5% to 10%.

Much of the published cost data is fragmentary, incomplete and does not always contain the same items. It was for this reason that the IAEA convened a Panel on the Economics of Waste Management and its report will be published.

The objectives of the study were:

(i) To examine the elements of waste management; to establish all the factors that determine their costs and to determine the effect of various combinations of these elements on the costs of waste management, and
(ii) To suggest a system of costing which, if used, would permit comparisons of costs and enable a close approximation of the true costs of various processes to be obtained.

It was agreed that the items presented in Fig. 1 are all straightforward operational elements of waste management. In addition to these there are indirect elements that must be considered. For example, applied research has been found necessary at many sites and pre-operational site surveys may be required to establish waste management philosophy and disposal limits. It is these so-called "hidden" costs that can be easily overlooked and that can contribute significantly to the total costs.

In the report a simple but adequate costing system is recommended together with details of how the various cost figures may be obtained. Attempts have been made also to give orders of costs for various elements of waste management even though it is appreciated that such costs must vary from establishment to establish-

[2] See Footnote 1.

ment. The reasons for the variations are numerous but the main factors may be summarized as follows:

(i) The activity level and volume of the waste handled.
(ii) The size of the plant installed. For example, should the initially installed capacity be based on the need predicted for some future year or should a more economical plant be built initially with provision for connecting to additional equipment in the future.
(iii) The decontamination factor required which will be dependent not only on the activity level of the waste but also on the permissible discharge to the environment.
(iv) The chemical composition of the raw waste.
(v) Manpower costs, the availability of power, climate, etc.
(vi) The amount of "overheads" charged against waste management.
(vii) The variation in capital costs from country to country and the manner in which such costs are amortized.
(viii) The question of "interest on investment", which is the charge some sites assign to all operations to compensate for interest that must be paid on capital borrowed to invest in the land, buildings and equipment required for waste management.

However, if all the factors that influence costs are examined systematically it is possible to determine the most economical methods of treatment and disposal.

One other factor that must be taken into account in the less industrialized countries is the availability of equipment and particularly of spare parts for that equipment. If this has to be purchased from another country and especially if hard currency has to be used it may be advisable to choose equipment which can either be purchased locally or manufactured in the country. Sometimes this may appear to be uneconomic but may well prove more satisfactory and result in savings in the over-all period.

4. SELECTION FACTORS FOR WASTE MANAGEMENT SYSTEMS

The problem in establishing a waste management system is to decide whether all or part of the waste will be disposed of to the environment and whether there is any necessity to treat all or part of the waste. It is important to realize that treatment does not destroy the radioactivity, but only creates another waste that may require further treatment.

The various factors that will affect the selection of the most satisfactory system are interwoven and one cannot proceed in a straight line fashion from one factor to another. A certain amount of back tracking is required but nevertheless it is possible to proceed in a somewhat logical fashion.

The two starting points in evaluating any waste management system are the amount of radioactivity that may be dispersed to the environment and the types of waste that occur. These two factors will effectively decide the collection method, the amount of segregation of wastes that is required, the type and amount of treatment that is needed and the amount of environmental monitoring necessary.

4.1. Establishment of permissible discharge limits

The permissible discharge limits may be set directly by legislation. This legislation may bear direct reference to the Agency's publication, Basic Safety Standards for Radiation Protection, or the ICRP recommendations for maximum permissible concentrations of radioactivity or radionuclides in air and water. Conversely the legislation may permit discharge limits set indirectly by the MPCs but take into account the usage of the environment and its capacity to receive radioactivity. The radioactivity in the waste may be only a small portion of the potential hazard of the industrial waste and as such it is important to determine whether there is legislation setting discharge limits for non-radioactive contamination.

Annex II in Ref. [5] gives extracts from three sets of national regulations concerning the dispersal limits of radioactivity. These show two different approaches, the regulations of the USSR and the United States of America specifying disposal limits of wide applicability and those of the United Kingdom specifying disposal limits on a case-by-case basis.

The first factor which must be considered is the legislation and regulations applying to disposal into the environment not only with respect to radioactive contamination, but also with respect to non-radioactive contamination. In this connection the following should be closely studied.

(i) National and local laws and ordinances regulating radioisotope handling, radiation protection associated with waste disposal, especially the maximum permissible discharges into the environment and whether disposal to public sewers is permitted.

(ii) National and local laws and ordinances regulating environmental pollution by contaminants other than radioactivity, particularly the permitted discharge concentrations for such materials.

(iii) If there are no national or local laws or ordinances it must be determined what regulations and guides should be used before they are prepared.

If the national legislation specifies dispersal limits that are to be applied for all discharges regardless of the particular environment then this limit must be accepted and the only environmental study required is to ensure that there is no hazardous build-up of radioactivity in that environment. If, however, the national legislation specifies dispersal limits which are set on a case-by-case basis, a pre-operational study will be necessary to determine the amount of radioactivity that can be released to the environment. Even in the first instance, a pre-operational study should be done as this will often mean that a more economical operational environmental monitoring programme is required later. It is important to determine any possible biological indicators as part of the pre-operational study. The scope of any environmental surveys should be related to the margin between specified disposal limits and foreseen discharges.

For small releases of waste it may be possible to demonstrate safety without much detailed information. This can often be achieved by making conservative assumptions.

For information on environmental monitoring see Refs [6, 7].

For small quantities of soluble wastes containing radioisotopes of short half-lives, the most convenient and generally the most practicable procedure is disposal into the sanitary sewerage system. This implies, of course, that a sewerage system is available which is capable of having industrial wastes discharged into it.

Chapter 3 in Ref. [8] deals very fully with direct disposal of radioactivity to sewers. Further reference may also be made to Ref. [9]. The factors that should be considered if disposal to a sewerage system is being considered are:

(i) The size of the sewerage system, and the over-all flow, daily flow and hourly variations of flow that occur within the system.